

Management of Manufacturing Facility for Nylon 6 6

Enclosed is the report for the proposed manufacturing facility of Nylon 6 6 in Calvert City, Kentucky. As per the project statement, the task was to perform a preliminary design and conduct an economic analysis for a grass roots plant producing 85 MM lbs/yr of Nylon 6 6.

Nylon 6 6 is a polymer formed through polycondensation of Adipic Acid (ADA) and Hexamethylene diamine (HMDA) and step-growth polymerization.

In this report, four different production methods were analyzed. The Nylon 6 6 was produced in a batch or continuous process and then was extruded and sold as either granulated solid pellets or spun fibers through a spinneret. Additionally, a byproduct stream of diamine was produced and sold. The processes were designed for 100% capacity as well as a turndown case of 67% capacity.

Of the cases analyzed, it was concluded that the most economically viable option is a continuous process producing spun fiber Nylon 6 6. Subsequently, the most inherently safe and economically attractive design will be presented in the report.

Sincerely,

AIChE 2017 Student Design Competition

MANUFACTURING FACILITY FOR NYLON 6 6

9 March 2017

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Abstract

A preliminary design and economic analysis was performed for the development of a grass roots manufacturing facility of Nylon 6 6 in Calvert City, Kentucky. Nylon 6 6 is a polymer that is synthesized from Adipic Acid (ADA) and Hexamethylene diamine (HMDA) through polycondensation and step-growth polymerization reactions. The two reactions pursued were batch and continuous processes, in which Nylon 6 6 was sold either in solid pellet or spun fiber form. Additionally, the process yields a byproduct of 1,6 hexanediamine (diamine). The objective of the project was to determine which of the four production methods served as the most economically viable option. The optimum Nylon 6 6 production design is an intricate balance between capital and operating expenses that maximizes revenue and minimizes costs.

Given the opportunity to invest in the generation of a grass roots facility, it is our recommendation to proceed with the production of spun Nylon 6 6 fibers using a continuous production process. The economic analysis determined which option was the most economically viable for the company to invest in. From this point, a series of optimization procedures took place to reduce utility and capital costs in an effort to maximize annual profits and reduce the payback period of the project. Through changes in the maximum temperature of the evaporation unit within an acceptable range, capital costs and utility costs were reduced resulting in the lowest PWC. The evaporation unit temperature of 280°C was determined to be the most economical case for this production process, with a capital investment of \$13,015,000, a DCFROR of 211%, breakeven processing cost of \$2.40, and an NPV of \$17,874,000. It was determined advantageous to continue with project development; therefore, the project is scheduled to be completed and fully operational in June of 2018 and will have a payback period of 1.57 years.

The fundamental safety concept for this process was to make the operation inherently safer and to mitigate hazards. The hazardous components present in the process consist of ADA, HMDA, and diamine. The risks associated with these components include possible combustion, irritation to respiratory system and skin, and hazardous release to the environment. To mitigate these risks, it is recommended that the equipment is designed to operate within specified design temperatures and pressures and to implement a Distributed Control System (DCS).

Introduction

A preliminary design and economic analysis of the proposed manufacturing facility for Nylon 6 6 is presented in this report. Nylon 6 6 is a versatile co-polymer that is used for a variety of applications pertaining to textile, plastic, automotive, and consumer goods industries [1]. Due to its physical properties, such as high tensile strength and hardness, resilience, dimensional stability, resistance to wear and abrasion, excellent machinability, and high melting point, Nylon 6 6 may be used for heavy-duty applications [2]. Furthermore, Nylon 6 6 may be reinforced with fibers and internal lubricants, fillers, and impact modifiers to further enhance its properties and performance [3]. Its resistance to abrasion makes it an ideal candidate for use in carpets, conveyor belts, and upholstery. In addition, its light-weight properties and flexibility make it a favorable alternative for use in aircrafts, automobiles, and electronic devices, as well as materials for clothing, airbags, and parachutes. Nylon 6 6 is also resistant to fuels, most organic solvents, and alkaline solutions at moderate temperatures, making it suitable for use in industrial manufacturing applications, such as pipes, ball bearing cages, electro-insulating elements, and various machine parts. It may also be used as a substitute for low strength materials in structural applications and high-impact machines. Due to its wide range of applications and advancements in technology and functionality, the global demand for Nylon 6 6 continues to progress.

The primary objective of this study was to design and perform an economic analysis for building a grass roots manufacturing facility in Calvert City, Kentucky, for the production of Nylon 6 6. Nylon 6 6 is produced via polycondensation of Adipic Acid (ADA) and Hexamethylene diamine(HMDA), as shown in the chemical process below.

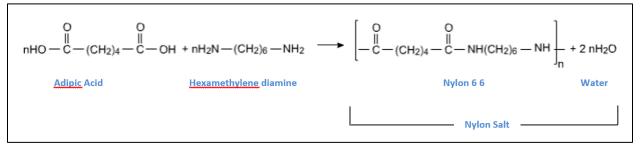


Figure 1: Synthesis of Nylon 6 6

Equimolar amounts of ADA and HMDA react in the presence of water to form high molecular weight Nylon 6 6. When the carboxyl group of the ADA monomer and the amino group of the HMDA monomer react, a water molecule is released and a polypeptide bond is formed. If an excess of reactants are used, the formation of an acid or an amino end group will terminate the polymer chain, resulting in a low molecular weight polymer. Therefore, Nylon salt is formed as a result of the polycondensation reaction. To drive the reaction towards polymerization, water is removed from the Nylon salt to form molten Nylon 6 6. 1,6 Hexanediamine, or diamine, an intermediate component, is also removed with the water to be sold as a byproduct stream. Then, the product is either extruded and granulated to solid pellet form, or extruded and spun into fibers. The specified production rate of Nylon 6 6 is 85 MM lbs/yr. Four preliminary design cases for the production of Nylon 6 6 were optimized in order to determine the most economically feasible option:

- 1. Batch, solid pellet
- 2. Batch, spun fiber
- 3. Continuous, solid pellet
- 4. Continuous, spun fiber
- 5.

The primary unit operations utilized in the processes were batch reactors, continuous-stirred tank reactors (CSTR), evaporators, pumps, flash drums, storage tanks, twin screw extruders, and spinnerets.

All economic evaluations were performed using a 10-year project evaluation life, a hurdle rate of 15%, and an effective tax rate of 40%. Equipment was depreciated using MACRS depreciation. Table 1 details the component prices that were considered when determining which case would be most profitable. The following prices were obtained from external sources and Invista [4][5].

Component	Purchase / Sell Cost	Unit				
ADA (ADA)	\$1.50	\$/kg				
HMDA(HMDA)	\$2.50	\$/kg				
Diamine	\$1.19	\$/kg				
Nylon 6 6, pellets	\$2.50	\$/kg				
Nylon 6 6, spun	\$4.15	\$/kg				
Water	\$0.08	\$/kg				

Table 1: Component Prices

These comparisons, weighed the operating costs against the capital costs to construct the most profitable simulation with the lowest Present Worth Cost (PWC) and the highest Net Present Value (NPV). Economic comparisons of the four production designs are presented in this report. The primary polymerization reaction vessel, the evaporator, was optimized by a present worth cost (PWC) analysis. Once capital costs, revenues, and operating expenses were determined, the profitability of each case was evaluated by analyzing the net present value (NPV), discounted cash flow rate of return (DCFROR), and payback period. Health, safety, and environmental hazards were also taken into design considerations. Lastly, a HAZOP evaluation of the proposed design was performed to reduce the probability of a hazard.

II. Process Flow Diagram and Material Balances

A material balance was performed to determine the component flowrates in the Nylon 6 6 manufacturing process. The general block flow diagram is presented in Figure 2 below.

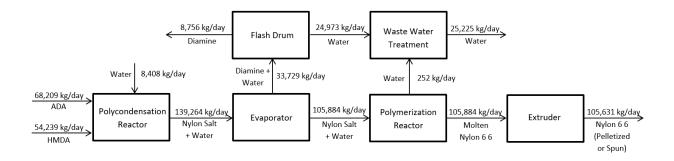


Figure 2: Block Flow Diagram

To determine the feed flow rates of ADA and HMDA, the specified production rate of Nylon 6 6 was divided by the molecular weight repeat of one mole and then multiplied by a one to one molar ratio of Nylon 6 6 to the reactant. The feed flow rate of the reactant was then determined by multiplying the number of moles of the reactant by its molecular weight, shown below in Equation (1) and Equation (2).

$$F_{ADA} = \left(\frac{105,631 \, kg \, Nylon \, 6 \, 6}{1 \, day}\right) \times \left(\frac{1 \, mol \, Nylon \, 6 \, 6}{0.266 \, kg \, Nylon \, 6 \, 6}\right) \times \left(\frac{1 \, mol \, ADA}{1 \, mol \, Nylon \, 6 \, 6}\right) \times \left(\frac{0.146 \, kg \, ADA}{1 \, mol \, ADA}\right) \tag{1}$$

$$F_{HMDA} = \left(\frac{105,631 \, kg \, Nylon \, 6 \, 6}{1 \, day}\right) \times \left(\frac{1 \, mol \, Nylon \, 6 \, 6}{0.266 \, kg \, Nylon \, 6 \, 6}\right) \times \left(\frac{1 \, mol \, HMDA}{1 \, mol \, Nylon \, 6 \, 6}\right) \times \left(\frac{0.116 \, kg \, HMDA}{1 \, mol \, HMDA}\right) \tag{2}$$

The feed flow rates of ADA and HMDA were determined to be 68,209 kg/day and 54,239 kg/day, respectively. Additionally, the flow rate of Nylon salt produced was determined to be 122,448 kg/day with the assumption that there was conversion greater than 99% [6]:

$$F_{NY\,SALT} = \left(\frac{105,631\,kg\,Nylon\,6\,6}{1\,day}\right) \times \left(\frac{1\,mol\,Nylon\,6\,6}{0.266\,kg\,Nylon\,6\,6}\right) \times \left(\frac{1\,mol\,NY\,SALT}{1\,mol\,Nylon\,6\,6}\right) \times \left(\frac{0.262\,kg\,NY\,SALT}{1\,mol\,NY\,SALT}\right)$$
(3)

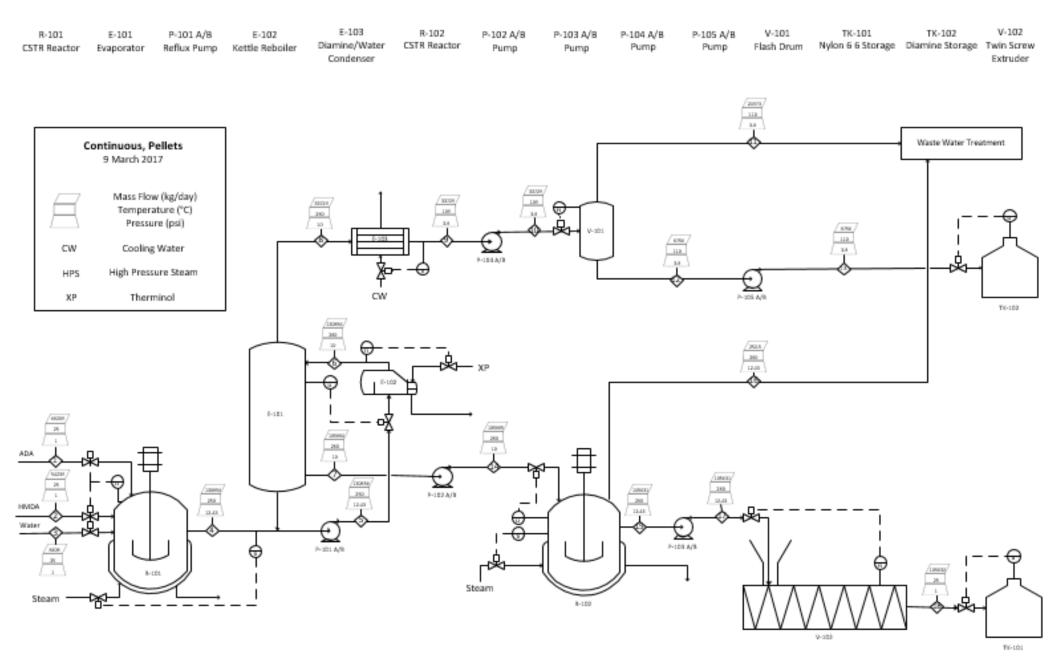
According to the reaction mechanism displayed in Figure 1, two moles of water are released for every mole of Nylon salt produced. However, water must be added to the polycondensation reactor initially to aid the formation of Nylon salt; therefore, it was assumed that an equimolar amount of water was added to the ADA and HMDA. Since the solubility of ADA and HMDA in water increase exponentially as temperature increases, the addition of equimolar water will dissolve the reactants [7]. Therefore, the total water produced for one mole of Nylon salt exiting the polycondensation reactor was determined to be 25,225 kg/day.

$$F_{H2O} = \left(\frac{105,631 \, kg \, Nylon \, 6 \, 6}{1 \, day}\right) \times \left(\frac{1 \, mol \, Nylon \, 6 \, 6}{0.266 \, kg \, Nylon \, 6 \, 6}\right) \times \left(\frac{3 \, mol \, H2O}{1 \, mol \, Nylon \, 6 \, 6}\right) \times \left(\frac{0.018 \, kg \, H2O}{1 \, mol \, H2O}\right) \tag{4}$$

As a result, 8,408 kg/day of feed water is entering the polycondensation reactor, which is one-third of the total water produced in the system. The removal of water shifts the equilibrium of the Nylon 6 6 reaction towards completion; therefore, the majority of the water is removed from the Nylon salt in the evaporator. The flow rate of water leaving the evaporator was determined by multiplying the total outlet flow rate of water by 99%, resulting in a flow rate of 24,973 kg/day. Approximately 7.2% of diamine is removed from Nylon salt with the water [8]. Therefore, the Nylon 6 6 flowing from the evaporator only reaches a conversion of 92.8%. Applying the conservation of mass principles, *inlet flow*

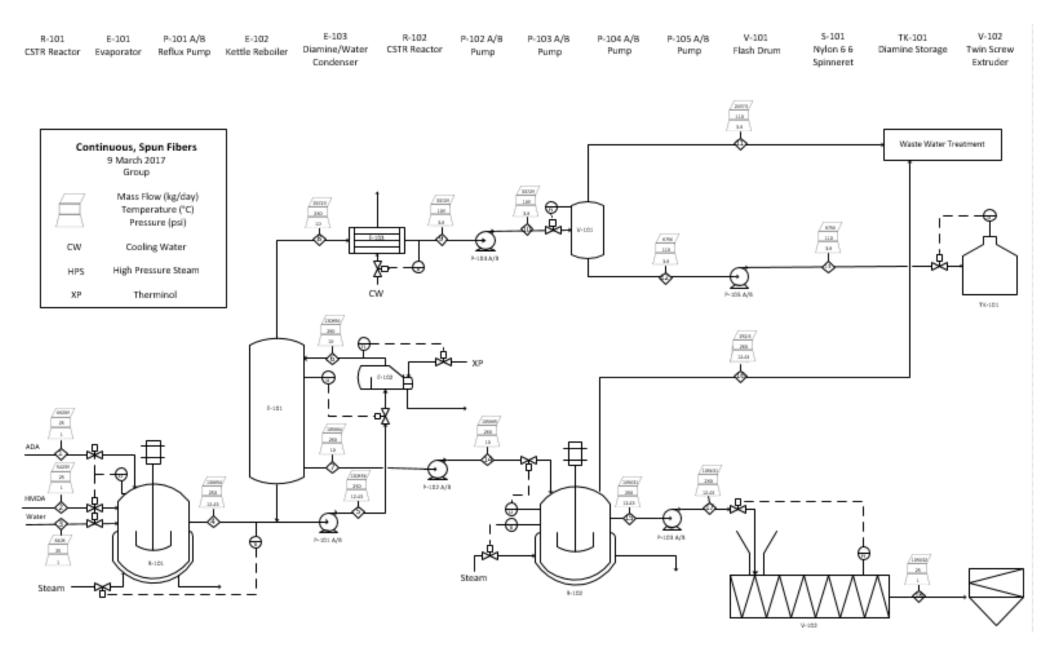
rate – *outlet flow rate* + *generation* = *accumulation*, the flow rate of Nylon 6 6 leaving the evaporator is 105,884 kg/day. In addition, 8,756 kg/day of diamine is evaporated with the water. Once the stream is separated in a flash drum, the water is sent to wastewater treatment and the diamine is sent to storage to be sold as a byproduct. Then, the flow rate of Nylon salt leaving the evaporator was determined by subtracting the outlet flow rate of water from the total flow rate of Nylon salt and water entering the evaporator. The final polymerization reaction removes the remaining water, which was determined to be 252 kg/day by subtracting the specified production rate of Nylon 6 6 from the entering flow rate of Nylon salt. All calculations and equations for the material balance are presented in Appendix A.

Shown in the proceeding pages are the Process Flow Diagrams and the respective stream summary tables.



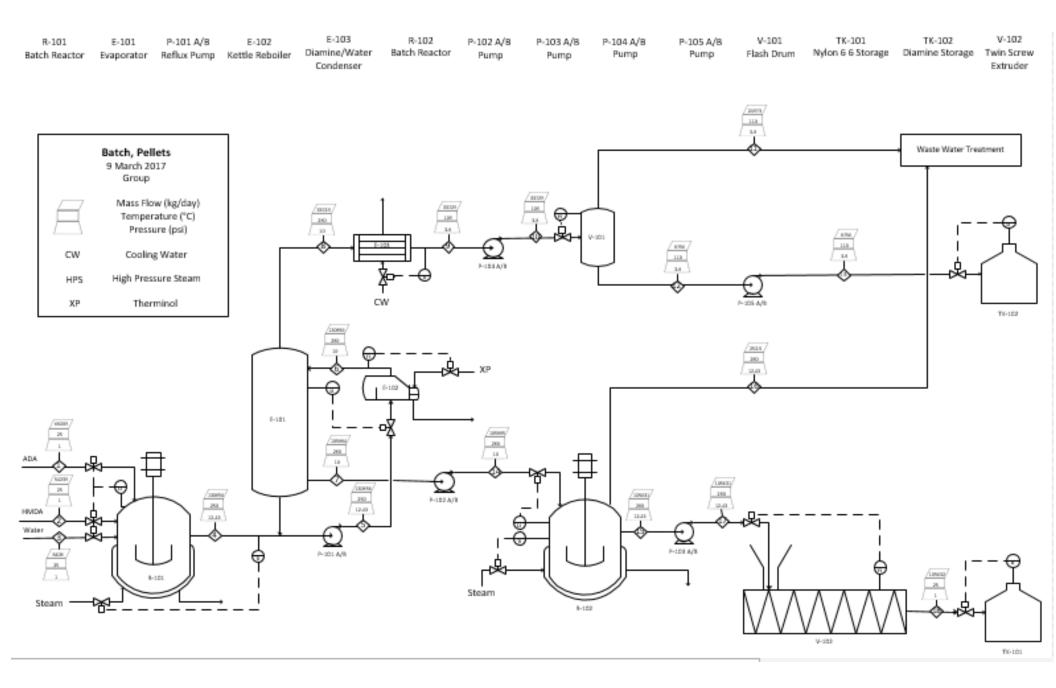
Stream Number	1	2	3	4	5	6
Stream Description	ADA Feed	HMDA Feed	Water Feed	Reactor 1 outlet	Pump to Heater	Heater to Evap
Temperature (°C)	25	25	25	250	250	280
Pressure (barg)	1	1	1	12.43	12.43	10
Vapor Fraction	0	0	0	0	0	0
Mass Flow (kg/day)	68,208.9	54,239.2	8,408.2	130,855.8	130,855.8	130,855.8
Mole Flow (kgmol/day)	466.74	466.72	466.85	583.39	583.39	583.39
Std Ideal Vol Flow (m ³ /d)	5015	64.57	8.41	117.67	117.67	117.67
Mass Density (kg/m ³)	1,359.99	840	999.99	1,112	1,112	1,112
Stream Number	7	8	9	10	11	12
Stream Description	, Evap. Liquid	Evap. to Cond.	Condenser Outlet	Flash Inlet	Flash Vapor	Flash Liquid
Temperature (°C)	280	280	109	109	110	110
Pressure (barg)	10	10	3.8	3.8	3.8	3.8
(8,						
Vapor Fraction	0	1	0	0	1	0
Mass Flow (kg/day)	105,884.2	33,728.7	33,728.7	33,728.7	24,972.5	8,756.2
Mole Flow (kgmol/day)	472.06	775.37	775.37	775.37	1386.59	75.35
Std Ideal Vol Flow (m ³ /d)	95.20	35.02	35.02	35.02	24.97	10.42
Mass Density (kg/m ³)	1,112	963.2	963.2	963.2	999.99	840
Stream Number	13	14	15	16	17	18
Stream Description	Diamine Storage	Reactor 2 Inlet	Reactor 2 Outlet	Reactor 2 Vapor	Extruder Inlet	Extruder To Tank
•	_					
Temperature (°C)	110	280	280	280	280	25
Pressure (barg)	3.8	10	12.43	12.43	12.43	1
Vapor Fraction	0	0	0	1	0	0
Mass Flow (kg/day)	8,756.2	105,884.2	105,631.1	252.25	105,631.5	105,631.5
Mole Flow (kgmol/day)	75.35	472.06	470.93	14.01	470.93	470.93
Std Ideal Vol Flow (m ³ /d)	10.81	92.881	92.66	0.252	92.66	92.66
Mass Density (kg/m ³)	840	1,140	1,139.99	999.99	1,139.99	1,139.99
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Stream Summary Table for Pelletized Continuous Process



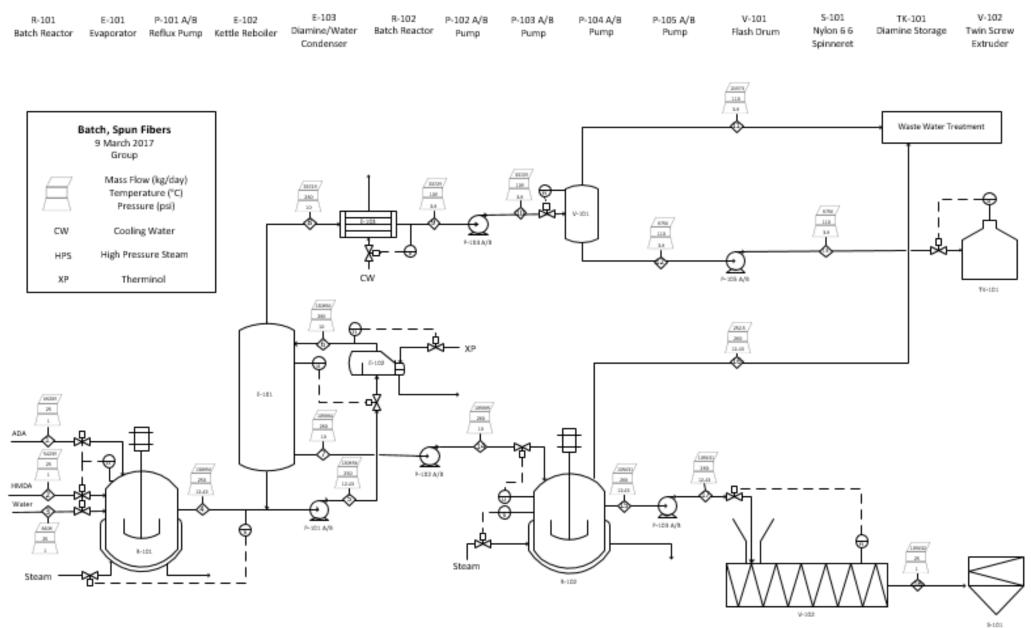
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Stream Number	1	2	3	4	5	6
Stream Description	ADA Feed	HMDA Feed	Water Feed	Reactor 1 outlet	Pump to Heater	Heater to Evap
Temperature (°C)	25	25	25	250	250	280
Pressure (barg)	1	1	1	12.43	12.43	10
Vapor Fraction	0	0	0	0	0	0
Mass Flow (kg/day)	68,208.9	54,239.2	8,408.2	130,855.8	130,855.8	130,855.8
Mole Flow (kgmol/day)	466.74	466.72	466.85	583.39	583.39	583.39
Std Ideal Vol Flow (m ³ /d)	5015	64.57	8.41	117.67	117.67	117.67
Mass Density (kg/m ³)	1,359.99	840	999.99	1,112	1,112	1,112
Stream Number	7	8	9	10	11	12
Stream Description	Evap. Liquid	Evap. to Cond.	Condenser Outlet	Flash Inlet	Flash Vapor	Flash Liquid
Temperature (°C)	280	280	109	109	110	110
Pressure (barg)	10	10	3.8	3.8	3.8	3.8
Vapor Fraction	0	1	0	0	1	0
Mass Flow (kg/day)	105,884.2	33,728.7	33,728.7	33,728.7	24,972.5	8,756.2
Mole Flow (kgmol/day)	472.06	775.37	775.37	775.37	1386.59	75.35
Std Ideal Vol Flow (m ³ /d)	95.20	35.02	35.02	35.02	24.97	10.42
Mass Density (kg/m ³)	1,112	963.2	963.2	963.2	999.99	840
Stream Number	13	14	15	16	17	18
Stream Description	Diamine Storage	Reactor 2 Inlet	Reactor 2 Outlet	Reactor 2 Vapor	Extruder Inlet	Extruder To Spin.
Temperature (°C)	110	280	280	280	280	25
Pressure (barg)	3.8	10	12.43	12.43	12.43	1
Vapor Fraction	0	0	0	1	0	0
Mass Flow (kg/day)	8,756.2	105,884.2	105,631.1	252.25	105,631.5	105,631.5
Mole Flow (kgmol/day)	75.35	472.06	470.93	14.01	470.93	470.93
Std Ideal Vol Flow (m ³ /d)	10.81	92.881	92.66	0.252	92.66	92.66
Mass Density (kg/m^3)	840	1,140	1,139.99	999.99	1,139.99	1,139.99
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Stream Summary Table for Spun Continuous Process



Stream Number	1	2	3	4	5	6
			-		_	
Stream Description	ADA Feed	HMDA Feed	Water Feed	Reactor 1 outlet	Pump to Heater	Heater to Evap
Temperature (°C)	25	25	25	250	250	280
Pressure (barg)	1	1	1	12.43	12.43	10
Vapor Fraction	0	0	0	0	0	0
Mass Flow (kg/day)	68,208.9	54,239.2	8,408.2	130,855.8	130,855.8	130,855.8
Mole Flow (kgmol/day)	466.74	466.72	466.85	583.39	583.39	583.39
Std Ideal Vol Flow (m ³ /d)	5015	64.57	8.41	117.67	117.67	117.67
Mass Density (kg/m ³)	1,359.99	840	999.99	1,112	1,112	1,112
Stream Number	7	8	9	10	11	12
Stream Description	Evap. Liquid	Evap. to Cond.	Condenser Outlet	Flash Inlet	Flash Vapor	Flash Liquid
Temperature (°C)	280	280	109	109	110	110
Pressure (barg)	10	10	3.8	3.8	3.8	3.8
Vapor Fraction	0	1	0	0	1	0
Mass Flow (kg/day)	105,884.2	33,728.7	33,728.7	33,728.7	24,972.5	8,756.2
Mole Flow (kgmol/day)	472.06	775.37	775.37	775.37	1386.59	75.35
Std Ideal Vol Flow (m ³ /d)	95.20	35.02	35.02	35.02	24.97	10.42
Mass Density (kg/m ³)	1,112	963.2	963.2	963.2	999.99	840
Stream Number	13	14	15	16	17	18
Stream Description	Diamine Storage	Reactor 2 Inlet	Reactor 2 Outlet	Reactor 2 Vapor	Extruder Inlet	Extruder To Tank
Temperature (°C)	110	280	280	280	280	25
Pressure (barg)	3.8	10	12.43	12.43	12.43	1
Vapor Fraction	0	0	0	1	0	0
Mass Flow (kg/day)	8,756.2	105,884.2	105,631.1	252.25	105,631.5	105,631.5
Mole Flow (kgmol/day)	75.35	472.06	470.93	14.01	470.93	470.93
Std Ideal Vol Flow (m ³ /d)	10.81	92.881	92.66	0.252	92.66	92.66
Mass Density (kg/m ³)	840	1,140	1,139.99	999.99	1,139.99	1,139.99
			1	1		1

Stream Summary Table for Pelletized Batch Process



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Stream Number	1	2	3	4	5	6
Stream Description	ADA Feed	HMDA Feed	Water Feed	Reactor 1 outlet	Pump to Heater	Heater to Evap
Temperature (°C)	25	25	25	250	250	280
Pressure (barg)	1	1	1	12.43	12.43	10
Vapor Fraction	0	0	0	0	0	0
Mass Flow (kg/day)	68,208.9	54,239.2	8,408.2	130,855.8	130,855.8	130,855.8
Mole Flow (kgmol/day)	466.74	466.72	466.85	583.39	583.39	583.39
Std Ideal Vol Flow (m ³ /d)	5015	64.57	8.41	117.67	117.67	117.67
Mass Density (kg/m ³)	1,359.99	840	999.99	1,112	1,112	1,112
Stream Number	7	8	9	10	11	12
Stream Description	Evap. Liquid	Evap. to Cond.	Condenser Outlet	Flash Inlet	Flash Vapor	Flash Liquid
Temperature (°C)	280	280	109	109	110	110
Pressure (barg)	10	10	3.8	3.8	3.8	3.8
Vapor Fraction	0	1	0	0	1	0
Mass Flow (kg/day)	105,884.2	33,728.7	33,728.7	33,728.7	24,972.5	8,756.2
Mole Flow (kgmol/day)	472.06	775.37	775.37	775.37	1386.59	75.35
Std Ideal Vol Flow (m ³ /d)	95.20	35.02	35.02	35.02	24.97	10.42
Mass Density (kg/m ³)	1,112	963.2	963.2	963.2	999.99	840
Stream Number	13	14	15	16	17	18
Stream Description	Diamine Storage	Reactor 2 Inlet	Reactor 2 Outlet	Reactor 2 Vapor	Extruder Inlet	Extruder To Spin.
Temperature (°C)	110	280	280	280	280	25
Pressure (barg)	3.8	10	12.43	12.43	12.43	1
Vapor Fraction	0	0	0	1	0	0
Mass Flow (kg/day)	8,756.2	105,884.2	105,631.1	252.25	105,631.5	105,631.5
Mole Flow (kgmol/day)	75.35	472.06	470.93	14.01	470.93	470.93
Std Ideal Vol Flow (m ³ /d)	10.81	92.881	92.66	0.252	92.66	92.66
Mass Density (kg/m ³)	840	1,140	1,139.99	999.99	1,139.99	1,139.99

Stream Summary Table for Spun Batch Process

III. Process Description

The purpose of this project was to produce a grass roots facility in Calvert City, KY, which has a production capacity of 85 MM lb/yr of Nylon 6 6. To accomplish this, four methods of production were generated. These methods consisted of a continuous or batch process having the final product spun or pelletized.

In both batch and continuous simulations, the process began by introducing HMDA, ADA, and water into a reaction vessel. All components entered from a storage tank that contained a week's capacity of raw materials. In this scenario, the feed streams were fed into the first reaction vessel at atmospheric pressure with a mass flow rate of 54,239 kg/day HMDA, 68,209 kg/day ADA, and 8,408 kg/day water. Upon entering the reaction vessel, the temperature was maintained at steady state after the initial startup of the process. A temperature of 250°C was maintained using a steam-fed heating jacket surrounding the reactor. Upon entering the reactor, the three feed streams were completely mixed using an agitated stirrer to ensure equal composition throughout the batch reactor. The mixing of raw materials to form Nylon salt acted as the polycondensation phase of the production process. The mixture was held in the reactor until ample mixing and reaction time had passed, such that the stream exiting the reactor maintained a conversion of 99%. The Nylon salt was then pumped into an evaporator that was used to remove 99% of the water from the salt solution. Through an increase in temperature from 250°C to 280°C, using high pressure steam at a temperature and pressure of 254°C and 41 barg, the water within the salt mixture vaporized. In addition to water vapor, the diamine monomer also vaporized and exited the evaporation unit, while the molten Nylon salt was pumped to the second batch reactor where polymerization occurred.

In both scenarios, as the water and monomer vapor left the evaporator, they were fed to a condenser where they underwent both a temperature and pressure change to reach 109°C and 3.8 bar. Upon leaving the condenser, the stream was pumped to a flash drum to separate the two components. The diamine was then sent to a storage tank to be sold on a weekly basis, while water vapor was sent to wastewater treatment to be reused within the plant. Additionally, as the polymerization reaction occurred within the second reactor under adiabatic conditions, at a pressure of 12.43 barg, any additional water was removed. The molten Nylon then proceeded to an extrusion unit to be processed as either a pelletized or spun fiber. In the instance that Nylon 6 6 in the spun fiber form is desired over pellets, the material leaving the extruder would be introduced to a spinneret in which the molten Nylon would be stretched and cooled into flexible fibers and spun onto spools for sale and distribution. However, if the pelletized form of Nylon 6 6 is the preferred method of production, the products from the extruder would be heat dried and cut into small pellets based on design specifications. Any further specifications on equipment and their purpose within the process are further explained in Section V below.

IV. Energy Balance and Utility Requirements

For this process, there were several pieces of equipment that required external energy or that produced energy through the internal reactions taking place. Within the first reactor, an endothermic reaction took place and required external input of energy into the reactor to reach the desired reaction temperature of 250°C. To calculate the duty or heat flow of this reaction, Equation (5) was used.

$$Q = \dot{m}C_p\Delta T \tag{5}$$

Where:

Q= heat flow (kJ/day) \dot{m} = mass flow rate (kg/day) ΔT = temperature difference of the process stream (°C)

Additionally, the heat flows within the evaporation unit and the condenser were calculated utilizing the same process, with the additional use of the log mean temperature calculation, which analyzes the variations in temperatures between hot and cold streams in the heat exchanger.

The heat flow needed for each piece of equipment that produced a temperature change was calculated using a heat transfer medium. As a result, the area, volume, and diameters could be calculated accordingly. This was due to the heat flow being the independent variable for much of the sizing and costing of each process vessel.

The utility costs consist of cooling water, hot oil (Therminol XP), electricity, and high pressure steam. The utilities as well as their quantity and function are outlined as follows:

High Pressure Steam

For the first reactor, external heat was required to initiate the reaction between HMDA, ADA, and water, as this is an endothermic reaction. Without the introduction of heat, the reaction energy required would not be met and would simply result in the mixing of unreacted components. To allow the reactor to reach the required reaction temperature of 250°C, the use of high pressure steam in the reactor jacket was required. High pressure steam was necessary, as it has a maximum temperature of 254°C, which was greater than the required temperature. The specific amount of high pressure steam needed within the reactor jacket is calculated below.

Where:

$$Flow = \frac{Q}{\lambda}$$
(6)

 λ = latent heat of vaporization (kJ/kg) Q= heat flow (kJ/day)

Hot Oil (Therminol XP)

For the evaporation unit, it was necessary to reach a temperature of 280°C to evaporate off 99% of the water present in excess from the first reaction, as well as the water produced by the reaction between HMDA and ADA. To reach this temperature, it was required to use a heat transfer medium because the desired temperature exceeded the maximum temperature of high-pressured steam. Because of this limitation, the use of the hot oil Therminol XP was deemed necessary. Therminol XP allowed for a maximum temperature of 315°C to be reached, which is more than the required temperature allowed for adequate energy transfer to evaporate the desired amount of water from the Nylon salt solution. To

determine the required amount of Therminol XP, a separate hot oil loop had to be created. This loop utilized a purchased thermal oil heater to increase temperatures to desired values. Because this was a closed thermal loop, the amount of Therminol XP was determined to be 110 gallons. This amount was determined in order to minimize storage of Therminol XP while allowing for a sufficient operating amount. This allowed the process to achieve proper heat transfer within the evaporation unit and remove the excess water in the Nylon salt solution.

Cooling Water

Once the vaporized diamine and water left the evaporation unit, it was desired to separate the two compounds to store diamine until distribution and sale. To achieve this, the exiting vapors had to be condensed into a liquid stream to eliminate two-phase flow. To accomplish this, a condenser was needed to reduce the temperature from 280°C to 109°C and reduce the pressure of the stream. The temperature of 109°C was the temperature at which water would condense to form a liquid. Due to its thermal properties and lower boiling point at the process pressure, water served as the compound of interest in this analysis. The use of a cooling heat transfer medium was required to reach the new desired temperature. For this process, the use of cooling water allowed the stream to reach the temperature needed to prevent two-phase flow into the binary flash drum where the components were separated. The process used to determine the amount of cooling water required to achieve the desired temperature is shown in Equation (7).

$$Flow_{CW} = \frac{Q}{C_p * \Delta T} \tag{7}$$

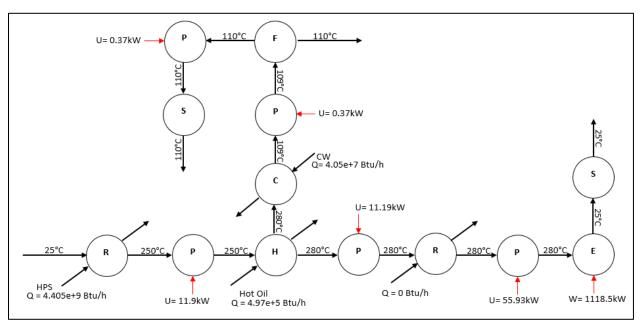
Where:

 $Flow_{CW}$ = cooling water mass flow rate (kg/hr) C_p = specific heat of water at desired temperature (kJ/kg°C) ΔT = temperature change within the cooling water stream (°C)

Once the mass flow rate of cooling water was calculated, the volumetric flow rate was determined from dimensional analysis.

Electricity

Throughout the process, equipment utilized electricity to power the motors and achieve process specifications. These pieces of equipment included: reactor agitators, pumps, an extruder, and a spinneret. When determining the amount of power needed for each piece of equipment, it was necessary to know the horsepower for each of the motors. This was then converted into kilowatts giving the individual energy requirements. For pumps, the purchased horsepower was calculated using pump and motor efficiencies, as well as the pump flowrates and desired pressure changes. When calculating the power needed to operate the reactor agitators, it was necessary to utilize the inlet and outlet flow rates, as well as the specific volume. This provided energy requirements for each reactor. Finally, for the extruder and spinneret, the energy requirements were determined based on the horsepower of the driving motor, which was converted to kilowatts.



Given all of these energy requirements, the following table of energy distribution was generated.

Figure 3: Energy Balance Flow Diagram

Unit	R-101	E-101	R-102	A-101	T-101	E-102	V-101
Name	CSTR	Evaporator	CSTR	Extruder	Storage Tank	Condenser	Flash Drum
HPS (1000/lb)	4738	-	-	-	-	-	
Therminol XP (gal)	-	110	-	-	-	-	
CW (gpm)	-	-	-	-	-	2466	
Electricity (kW)	12.28	-	11.28	53.35	-	-	
Unit	T-102	P-101	P-102	P-103	P-104	P-105	A-102
Name	Storage Tank	Pump	Pump	Pump	Pump	Pump	Spinneret
HPS	-	-	-	-	-	-	-
Therminol XP	-	-	-	-	-	-	-
Cooling Water	-	-	-	-	-	-	-
Electricity	-	11.19	0.37	0.37	55.93	11.19	49.65

Table 2: Utility Usage Batch Process

Table 3: Utility Usage Continuous Process

Unit	R-101	E-101	R-102	A-101	T-101	E-102	V-101
Name	CSTR	Evaporator	CSTR	Extruder	Storage Tank	Condenser	Flash Drum
HPS (1000/lb)	4653	-	-	-	-	-	-
Therminol XP	-	110	-	-	-	-	-
(gal)							
CW (gpm)	-	-	-	-	-	2466	-
Electricity (kW)	12.41	-	10.28	53.35	-	-	-
Unit	T-102	P-101	P-102	P-103	P-104	P-105	A-102
Name	Storage Tank	Pump	Pump	Pump	Pump	Pump	Spinneret
HPS	-	-	-	-	-	-	-
Therminol XP	-	-	-	-	-	-	-
Cooling Water	-	-	-	-	-	-	-
Electricity	-	11.19	0.37	0.37	55.93	11.19	49.65

V. Equipment List and Unit Descriptions

For this process design, there were several pieces of equipment necessary to achieve the production of a grass roots facility responsible for the manufacturing of Nylon 6 6. The specific function, specifications, and design methodologies are as follows.

Reaction Kinetics

As previously described in the Introduction section of this report, Nylon 6 6, which is a polymer that is made up of repeating monomers, is produced by polycondensation and step-growth polymerization reactions. Nylon salt is formed during the polycondensation reaction when two monomers in equimolar quantities, ADA and HMDA, react to form Nylon 6 6 and water. The reaction kinetics for the batch and continuous operation cases were modeled using Paul Flory's equal reactivity hypothesis, which assumes that the reactivities between the carboxylic acid (C) and amine (A) polymer end groups are independent of chain length:

$$R_1 - COOH + H_2N - R_2 \rightleftharpoons R_1 - CONH - R_2 + H_2O$$

$$C \qquad A \qquad L \qquad W$$
(8)

When the carboxylic and amine polymer end groups form, an amide linkage (L) and a water molecule (W) is produced. To model the change in functional group concentration as a function of time, the following differential equations were developed based on a previous study performed by [8]:

$$\frac{d[C]}{d(t)} = k_p \times \left([C] \times [A] - \frac{[L] \times [W]}{K_A} \right)$$
(10)

$$\frac{d[A]}{d(t)} = k_p \times \left([C] \times [A] - \frac{[L] \times [W]}{K_A} \right)$$
(11)

$$\frac{d[L]}{d(t)} = k_p \times \left([C] \times [A] - \frac{[L] \times [W]}{K_A} \right)$$
(12)

$$\frac{d[W]}{d(t)} = k_p \times \left([C] \times [A] - \frac{[L] \times [W]}{K_A} \right) - k_m \left([W] - [W_{eq}] \right)$$
(13)

Where:

[C] = concentration of carboxylic acid end groups from the ADA
 [A]= concentration of amine groups end groups from the HMDA
 [L]=concentration of amide linkage in polymer
 [W]=concentration of water

The parameters, k_p , K_A , k_m , W, W_{eq} , were estimated using correlations previously determined from experimental data obtained from Karimi's "A Kinetic Model for Non-Oxidative Thermal Degradation of Nylon 6 6", using the previously discussed temperatures and pressures.

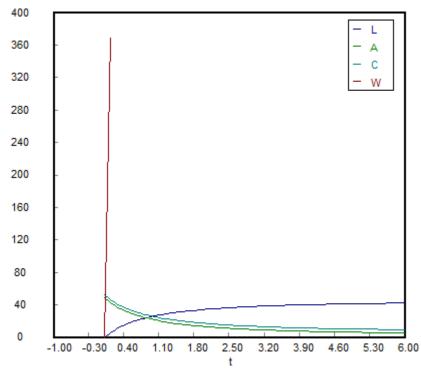


Figure 4: Functional Group Concentration Changes in Polycondensation as Reaction Time Increases (h)

The preliminary study on the change in functional group concentration with respect to time revealed that the concentration of water [W] greatly increased in comparison to the formation of amide bonds [L], while the initial concentrations of ADA [C] and HMDA [A] decreased as amide bonds [L] were formed.

The degree of polymerization, N, was calculated using Carothers' Equation, which describes the formation of linear polymers formed from two monomers:

$$\overline{X}_N = \frac{1}{1-p} \tag{14}$$

In order to form high-molecular weight Nylon 6 6, a conversion, p, of 99% was assumed [8]. Additionally, the average number of monomer units in a polymer molecule, \overline{X}_N , was assumed to be 2×N to represent the number of diamine units in diacid. To achieve a high degree of monomer conversion, a degree of polymerization of 50 was imperative.

The water was then removed to drive the reaction towards polymerization through the formation of amide bonds. High-molecular weight Nylon 6 6 was formed through a linear step-growth polymerization reaction. This section describes the reaction kinetics used to model polycondensation and step-growth polymerization reactions to size the batch reactor and CSTR.

Batch Reactor

Polycondensation and polymerization reactions for the production of Nylon 6 6 took place in batch reactors. The general design equation for a batch reactor in which the mole balance is in terms of conversion is the following [9]:

Where:

$$N_{A0}\frac{dx}{dt} = -r_A V \tag{15}$$

X= conversion defined as $\frac{moles \ reacted}{moles \ fed}$ N_{A0} = initial moles of species A t= time [s] r_A = rate law, or rate of disappearance of species A V= volume [m³]

The following assumptions were made in modeling the batch reactions:

- 1. Spatial variations in temperature and concentration were insignificant because the reaction components were well-mixed.
- 2. There was no inflow or outflow of components while the reaction was proceeding.
- 3. The volume was constant, $V=V_o$.

The design equation was used when modeling polycondensation and step-growth polymerization in batch reactors. Lastly, the material of construction chosen for the batch reactor was stainless steel clad because it has resistance to the chemical corrosion of both ADA and the abrasive properties of the Nylon salt. Stainless steel clad was favorable for the safety, reliability, and product lifetime of this process.

Batch Polycondensation

According to Figure 1, the polycondensation reaction may be expressed as:

ADA	+	HMDA	\rightarrow	NYLON 6 6	+	$2 H_2O$	(1	16)
А	+	В	\rightarrow	С	+	2 D		

Therefore, the following second order rate law was developed:

$$r_A = -k \times (C_A \times C_B)$$
(17)

Where:

$$k = \text{second order rate constant} \left[\frac{kg}{mol s} \right]$$
$$C_A = C_{A0} (1 - X) \left[\frac{mol}{m^3} \right]$$
$$C_B = C_{B0} (1 - X) \left[\frac{mol}{m^3} \right]$$

The reaction rate constant was obtained from *Table 10*, in a previously conducted study [8]. A conservative approach was considered by choosing the lower bound on the final estimate of a second order reaction rate constant. Therefore, the $4.11 \times 10^{-3} - 1.33 \times 10^{-3} \frac{kg}{mmol h}$ reaction rate constant for the polycondensation reaction was converted to $7.72 \times 10^{-4} \frac{kg}{mol s}$. Since the forward reaction rate

was larger than the reverse rate of reaction, it was assumed that the polycondensation proceeded forward. Furthermore, the initial concentration of the species was found by using the initial flow rates and assumed batch volume: $C_A = \frac{N_A}{V}$, $N_A = N_{A0} \times (1 - X)$, and $N_{A0} = F_{A0} * (t)$.

The polycondensation reaction of Nylon 6 6 is endothermic. Therefore, energy was applied to the jacketed vessel at 250 $^{\circ}$ C, which was the optimal temperature required to achieve the desired conversion [9]:

$$\frac{dT}{dt} = \frac{\dot{Q} - \dot{W}_s + (-\Delta H_{RX})(-r_A V)}{\sum N_i C_{Pi}}$$
(18)

Where:

 \dot{Q} = heat flow [kJ/s] \dot{W}_{s} = shaft work [kJ/s] ΔH_{Rx} = change in heat of reaction [kJ/kg] r_{A} = rate of reaction $\left[\frac{kg}{mol s}\right]$ $N_{i} = N_{A0}(\theta_{i} + v_{i}X)$ [mol] C_{Pi} = specific heat [kJ/kgK] v_{i} = volumetric flow rate [m³/s] θ_{i} = concentration of species i / concentration of species A

The heat flow from the high pressure steam to the inside of the reaction vessel, shaft work, and heat of reaction were determined from the following equations, and the physical properties for each component were obtained from literature:

$$\dot{Q} = m \times Cp \times (T_a - T) \tag{19}$$

$$\Delta H_{Rx} = \sum \Delta H_{f \, products}^{0} - \sum \Delta H_{f \, reactants}^{0}$$
⁽²⁰⁾

$$\dot{W}_{s} = -\sum_{i=1}^{n} F_{i} P \tilde{V}_{i} |_{in} + \sum_{i=1}^{n} F_{i} P \tilde{V}_{i} |_{iout}$$

$$\tag{21}$$

Where:

 \dot{m} = mass flow rate [kg/s] T_a = steam temperature [°C] T = desired reaction temperature [°C] ΔH_f^0 = heat of formation [kJ/mol] \tilde{V}_i = specific volume [m³/mol]

High pressure steam with a temperature of 253°C was used to heat the batch reactor. Ultimately, the energy equations were combined with the batch design equations to determine the time required to heat the reaction to the optimum reaction temperature and conversion. As shown in Figure 5, the temperature of the reactor reached 525 K, or 250°C, after approximately one minute of heating. The energy applied to the batch reactor maintains the heat at a desired temperature of 250°C until the reaction is complete.

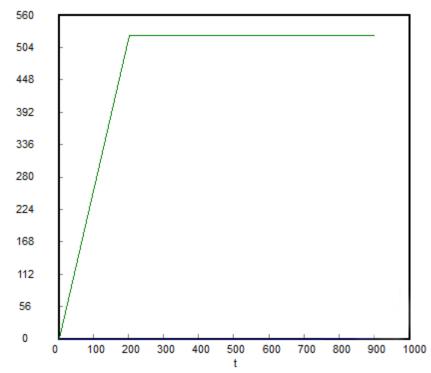
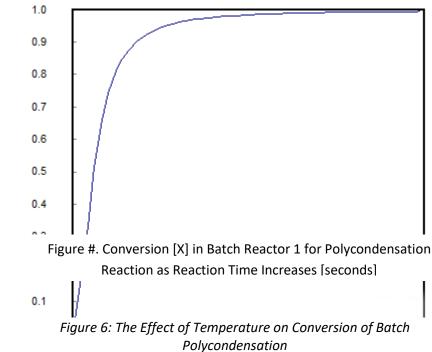


Figure 5: Temperature [K] Changes in Batch Reactor 1 for Polycondensation Reaction as Reaction Time Increases [sec]

Although the desired temperature is achieved in 1 minute, the reaction reaches a conversion of greater than 99% after 1.2 hours in a batch reactor volume of 27 m³. The volume was calculated by determining the volumetric flow of the components in the reactor per cycle and rounding to the next largest m³ to prevent overflow. In addition, the calculated time is justified with the preliminary study performed on functional group concentration in Figure 4, which displays the concentration of amide bonds [L] starting to level at approximately 1.2 hours. As shown in Figure 6, the rate of conversion is initially high and then the rate decreases as the reaction approaches completion. The complete raw data presented in Appendix # provides conversion values until 100% conversion is achieved. The target conversion assumed was 99.5%.



Heuristics for the time required to complete one batch cycle are provided in Table 4 [10]. The upper time bound for each step in the cycle was considered to allow adequate time for the reaction to proceed; therefore, the total reaction time, including the 1.2 hours required to achieve the desired conversion, was 5.2 hours.

Activity	Time (h)
1. Charge feed to reactor and agitate	1.5 - 3.0
2. Carry out reaction	(varies)
3. Empty and clean reactor	0.5 - 1.0
Total time excluding reaction	2.0 - 4.0

Table 4: Typical Cycle Times for a Batch Polymerization Process

All polymath simulations and results are provided in Appendix B.

Batch Polymerization

The step growth polymerization reaction occurred in the second batch reactor, where the heavy weight Nylon 6 6 oligomers were produced. This immediately followed the evaporation unit and was the destination of the molten Nylon salt leaving the evaporator. The step-growth polymerization reaction may be expressed as:

Nylon Salt
$$\rightarrow$$
 NYLON 6 6 + 2 H₂O (22)
A \rightarrow B + 2 C

This vessel was also responsible for removing any additional water. During this phase of the production process, it was assumed that the reaction occurred under adiabatic conditions as there was no additional heat or work added to the process. Therefore, the following first order rate law was developed:

$$r_A = -k \times C_A \tag{23}$$

The reaction rate constant was obtained from Table 10 in a previously conducted study [8]. As explained, a conservative approach was considered by choosing the final estimate of 2.29 x 10^{-3} hr⁻¹. Upon converting to the desired units, it was determined that the reaction rate constant for the stepgrowth polymerization reaction was 1.3×10^{-2} hr⁻¹. Since the forward reaction rate was larger than the reverse rate of reaction, it was also assumed that the polymerization reaction in the second batch reactor proceeded forward. Furthermore, the initial concentration of the species was found by using the initial flow rates and assumed batch volume: $C_A = \frac{N_A}{V}$, $N_A = N_{A0} \times (1 - X)$, and $N_{A0} = F_{A0} * (t)$.

The same energy balance was also used for this reactor; however, the reactor is adiabatic, $\dot{Q} = 0$, and the work done by the stirrer was negligible, $\dot{W}_s = 0$, because the Nylon melt flowing from the evaporator entered the batch reactor at 280°C. This was the ideal temperature for removal of water and for completely polymerizing the Nylon 6 6. The energy balance was then integrated and rearranged in order to obtain temperature as a function of conversion.

$$T = T_0 + \frac{[-\Delta H_{Rx}(T_0)]X}{C_{Pi} + X\Delta C_P} = T_0 \frac{[-\Delta H_{Rx}(T_0)]X}{\sum \theta_i C_{Pi} + XC_P}$$
(24)

The variables were described in the previous section; however, the property values changed for the second batch processing conditions and the species. The reaction temperature equation was combined with the design equation in Polymath. As shown in Figure 7 below, a conversion of 99.5% was achieved after 6.8 minutes because only 1% of the remaining water was removed.

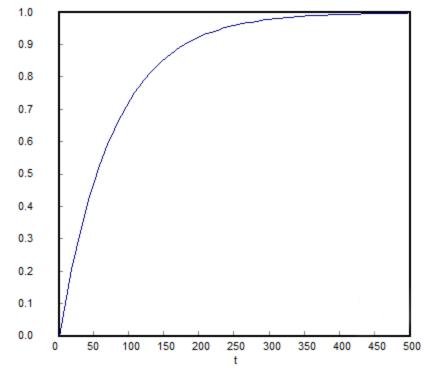


Figure 7: Conversion [X] in Batch Reactor 2 for Step-Growth Polymerization Reaction as Reaction Time Increases [seconds]

In addition, the temperature of the reaction reached a maximum value of 553°C. The volume was calculated to be 24 m³ by using the volumetric flow rate of the Nylon 6 6 per cycle rounding to the next largest m³ to prevent overflow. All polymath simulations and results are provided in Appendix B.

CSTR Reactor

Under continuous operation, polycondensation and polymerization reactions for the production of Nylon 6 6 occurred in CSTRs. The general design equation for a CSTR in which the mole balance in terms of conversion is the following [9]:

$$V = \frac{F_{A0}X}{(-r_A)_{exit}}$$
(25)

Where:

V= volume [m³] X= conversion defined as $\frac{moles reacted}{moles fed}$ F_{A0} = initial flow rate of species A r_A = rate law, or rate of disappearance of species A

The following assumptions were made in modeling CSTR reactions:

- 1. Spatial variations in temperature and concentration were insignificant because the reaction components were well-mixed.
- 2. The operation was steady state operation with continuous flow of reactants and products.
- 3. The density remained constant, $\rho = \rho_0$.
- 4. The volume was constant, $V=V_{o}$.

The design equation was used when modeling polycondensation and step-growth polymerization in CSTRs.

CSTR Polycondensation

The polycondensation rate laws and parameters were the same for both the batch and CSTR reactors. To determine the volume and temperature of the CSTR, a desired conversion of 99.5% was specified. Non-adiabatic heat effects were determined using the following equation:

$$T = T_c + \frac{\left[-\Delta H_{Rx}\right]X}{C_{Po}(1+\kappa)}$$
(26)

Where:

$$T_c = \frac{\kappa T_a + T_0}{(1+\kappa)} \tag{27}$$

$$\kappa = \frac{UA}{F_{A0}C_{p0}} \tag{28}$$

$$\dot{Q} = UA(T_a - T) \tag{29}$$

All fluid properties of the product stream and high pressure steam were evaluated at the average bulk fluid temperature. All calculations and equations are shown in Appendix C. Once the heat effects were combined with the CSTR design equation in Excel, it was determined that the CSTR volume at 99.5% was 16.8 m³.

CSTR Polymerization

The step-growth polymerization rate laws and parameters were the same for both the batch and CSTR reactors. It was also assumed that the CSTR was adiabatic; therefore, the design equation was used to determine the volume. All calculations and equations are shown in Appendix C. The volume of the CSTR at a conversion of 99.5% was 16.3 m³.

Evaporator

The Nylon salt solution produced in the first reactor was pumped to the evaporation unit where it was exposed to heat to remove the excess water. The evaporation unit was modeled as a forced circulation long tube evaporator due to the high viscosity and large amount of water present during the removal process. Although the price of this unit was considerably higher, it was deemed necessary due to the physical properties of the stream. The forced convection long tube evaporator consisted of a heat exchanger, pump and process vessel. To remove the desired 99% of water in the salt solution, it was necessary to increase the temperature from 250°C to 280°C. This increase in temperature to 280°C required the use of a hot oil heating loop to produce the necessary heat exchange for the process. This was due to the limited temperature of high pressure steam. The process needed to reach a temperature of 280°C to remove the excess water as well as the diamine.

The material of construction chosen for the pump, heat exchanger and process vessel was stainless steel clad because it has resistance to the chemical corrosion of Nylon salt solution. Stainless steel clad was favorable for its safety, reliability, and lifetime of this process. In determining the shell and tube side process material of the heat exchanger, it was determined that Therminol XP would flow tube side as it has a higher fouling rate and is more corrosive than the process fluid. Additionally, it was concluded that

the TEMA heat exchanger type most suitable for this application was AES floating head. To size the heat exchanger, an overall heat transfer coefficient was approximated based upon literature values [11]. It was also necessary to find other important values such as Therminol XP density, and specific heats, as well a correction factor from literature values based upon the operating conditions. The heat exchanger equations from literature and the assumed costing correlations accounted for the sizing of all pieces of equipment needed for the evaporation unit. The sizing procedure is described below and all calculations for sizing the evaporation unit are presented in Appendix 1A.

After obtaining the specific heat and mass flow rate from the material balance, the heat flow was calculated using the following equation:

Where:

 $Q_0 = Mass \ Flow * C_{p,Total} * \Delta T_{LM,CF}$ (30)

 Q_o = Heat Flow (kJ/day) $\Delta T_{LM,CF}$ = Log mean temperature difference (°C)

Upon calculating the heat flow, the heat transfer area was calculated:

$$A_o = \frac{Q_o}{\Delta T_{LM,CF} * U_o} \tag{31}$$

Where:

 A_o = Heat transfer area (m²) U_o = Overall heat transfer coefficient (kJ/m²day^oC)

Condenser

The vapor diamine and steam were condensed in a horizontal heat exchanger located downstream of the evaporation unit. In an effort to prevent two phase flow into the flash drum, the temperature was based upon the required temperature for the flash to occur. This involved reducing the condenser temperature to 109°C, as 110°C is the temperature at which water will vaporize at 3.8 barg. This process also involved reducing the pressure to 3.8 barg. To accomplish these temperature and pressure changes necessary to condense the inlet vapors, cooling water was utilized as the heat transfer fluid.

The material of construction chosen for both the shell and tube side was carbon steel because it has satisfactory resistance to the chemical corrosion of diamine and water; furthermore, it was economically favorable for its safety, reliability, and lifetime of this process. In determining the shell and tube side process material, it was determined that cooling water would flow tube side due to a higher fouling rate than the condensing steam and diamine. Additionally, it was concluded that the TEMA heat exchanger type most suitable for this application was an AES floating head condenser. To size the condenser, an overall heat transfer coefficient was approximated based upon literature values. The sizing procedure is described below and all calculations for sizing the condenser are presented in Appendix C.

First, the total specific heat of the vapor mixture was calculated using both the individual specific heat values and the appropriate composition of each compound in the stream.

$$C_{p,Total} = C_{p,Steam} X_{Steaam} + C_{p,Diamine} X_{Diamine}$$
(32)

After obtaining the total specific heat, the heat flow in (kJ/day) was calculated using the following equation:

$$Q_0 = Mass Flow * C_{p,Total} * \Delta T_{LM,CF}$$
(33)

Where:

 Q_o = Heat Flow (kJ/day) $\Delta T_{LM,CF}$ = Log mean temperature difference (°C)

Upon calculating the heat flow, the heat transfer area was calculated

$$A_o = \frac{Q_o}{\Delta T_{LM,CF} * U_o} \tag{34}$$

Where:

 A_o = Heat transfer area (m²) U_o = Overall heat transfer coefficient (kJ/m²day°C)

Flash Drums

The liquid diamine stream was separated from water in a vertical flash drum, which was located downstream of the condenser. Since the water has a higher volatility than diamine, the water from the liquid feed stream was vaporized and sent to wastewater treatment. The remaining liquid diamine was then sold as a byproduct. The material of construction chosen for the flash drum was carbon steel because it has satisfactory resistance to the chemical corrosion of diamine and water; furthermore, it was economically favorable for its safety, reliability, and lifetime of this process.

The temperature and pressure of the flash drum was determined using the NIST database in Aspen Plus V8.8. The Binary VLE 003 data for the diamine and water stream are presented in Appendix C. To achieve the desired separation, the flash drum was operated at 109°C and 3.8 barg. As per the empirical sizing method presented in Wankat, the flash drum had a volume of 4.3 m³ [12]. The sizing procedure is described below and all calculations for sizing the flash drums are presented in Appendix C.

First, the maximum permissible vapor velocity was calculated:

$$u_{perm} = K_{drum} \sqrt{\frac{\rho_L - \rho_V}{\rho_V}}$$
(35)

Where:

 u_{perm} = Permissible vapor velocity at maximum cross sectional area [kg/day] K_{drum} = Empirical constant dependent on type of drum [kg/day] ρ_L = Liquid density [kg/m³] ρ_V = Vapor density [kg/m³]

The liquid and vapor densities were calculated using the following equations, respectively:

$$\rho_L = \frac{\overline{MW_L}}{\overline{V_L}} \tag{36}$$

$$\rho_V = \frac{P \,\overline{MW_V}}{ZRT} \tag{37}$$

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Where:

$$\overline{MW_L} = x_D MW_D + x_H MW_H \text{ (average liquid molecular weight) [kg/mol]}$$

$$\overline{V_L} = x_D \frac{MW_D}{\rho_D} + x_H \frac{MW_H}{\rho_H} \text{ (specific volume) [m^3]}$$

$$P = \text{Feed pressure [barg]}$$

$$\overline{MW_V} = y_D MW_D + y_H MW_H$$

$$Z = \text{Compressibility Factor}$$

$$R = 0.008314 \text{ [m^3barg/molK]}$$

$$T = \text{Feed Temperature [K]}$$

The molecular weights and densities of diamine and water were obtained from literature. Water vapor was modeled as a non-ideal gas, since the pressure of the drum was greater than 10 barg, using the Redlich/Kwong equation developed for vapor/liquid equilibrium [12]:

$$Z = 1 + \beta - q\beta \frac{Z - \beta}{Z(Z + \beta)}$$
(38)

Where:

The reduced temperature and pressure of water vapor was calculated from the critical temperature and critical pressure, 374 °C and 221 barg, respectively, and the operating temperature and pressure of the flash drum. Lastly, the Solver function in Excel was used to determine the compressibility factor, Z. In addition, total vapor-liquid separation was assumed for component mole fractions ($x_D=1$; $y_H = 1$). The K_{drum} constant was graphically correlated for 85% flooding with a demister to reduce liquid entrainment in the vapor from 5% to 1% using the following equation [12]:

$$K_{drum} = c \exp[A + B \ln F_{l\nu} + C (\ln F_{l\nu})^2 + D(\ln F_{l\nu})^3 + E(\ln F_{l\nu})^4]$$
(39)

Where:

$$\begin{split} F_{lv} &= \frac{W_L}{W_V} \sqrt{\frac{\rho_V}{\rho_L}} \ (W_L \text{ and } W_V \text{ are liquid flow rates}) \\ c &= 1097.28 \text{ kg/day} \\ A, B, C, D, E &= \text{constants defined in Appendix C} \end{split}$$

Therefore, the cross sectional area of the drum was calculated using the following equation:

$$A_c = \frac{V * M W_V}{u_{perm} \rho_V} \tag{40}$$

Once the cross sectional area was determined, the diameter was calculated. The diameter was increased to the next largest 6-inch increment. An assumed ratio of total height to diameter of 3 was substituted into the volume of the flash drum, $V = 3\pi r^3$, resulting in a diameter of 1.2 m and a volume of 4.3 m³.

Storage Tank

The storage tank was used for the storage of the liquid diamine pumped out of the flash drum. The diamine was stored in the tank for a week at a time at which point it was sold. The material of construction chosen for the storage tank was carbon steel because it has satisfactory resistance to the

chemical corrosion caused by diamine; furthermore, it was economically favorable for its safety, reliability, and lifetime when utilized in this process.

The temperature and pressure of the storage tank were held at the conditions of the stream exiting the flash drum due to the stability of liquid diamine. As per the empirical sizing method presented in Wankat, the storage tank had a volume of 62 m³, a design temperature of 109°C, and a design pressure of 3.8 barg to allow for vapor/liquid expansion. The sizing procedure is described in Appendix C.

Upon knowing the density of diamine, as well as the total mass flow rate into the storage tank from the overall mass balance, it was possible to calculate the volumetric flow rate. From these values the volume per week was calculated and the tank was sized accordingly.

Extruder

The extrusion process involved the transforming of the molten Nylon 6 6 into either pellets or fibers that were strung out into spools using auxiliary features. Due to the large quantity of material processed daily, it was necessary to use a twin-screw extruder. The maximum screw speed for the extruder was 600RPM and the motor drive necessary to meet a daily production rate of 85 MM lb/yr was 1500HP AC [13]. Additionally, it was necessary to include a temperature control unit (TCU) with a nitride tool steel process section. An Allen Bradley electrical control system with an 8-0 adapter was used in the extruder design. In the event of producing pelletized Nylon 6 6, this served as the last step in the production process. As the Nylon 6 6 was sent through the extruder, it was sectioned off or cut into pellets to be sent to a storage tank. The material of construction chosen for the extruder was carbon steel because it has satisfactory resistance to the chemical corrosion of Nylon 6 6; furthermore, it was economically favorable for its safety, reliability, and lifetime of this process.

Spinneret

The spinneret was the last step in the production process when spun fibers of Nylon 6 6 were the desired product. The purpose of the spinner was to draw large amounts of Nylon 6 6 leaving the extruder, and using a series of wheels and spools, the Nylon 6 6 was spun into flexible fibers to be distributed and sold.

Pump

Throughout the process various pumps were required to move the streams to consecutive process vessels as well as to increase the pressure from one process vessel to the next. This involved moving process fluid from the first reactor to the evaporator, the evaporator to the second reactor, flash tank to the storage tank, and from the second reactor to the extruder. Additionally, all pumps were purchased and processed with a spare in the case of failure or maintenance. This was to ensure process safety and productivity/efficiency.

The material of construction chosen for each pump varied depending on the stage of the process. If a pump in the process encountered ADA or Nylon salt, stainless steel clad was required for the material of construction due to corrosive and abrasive properties. The material of construction for all other pumps was the cheaper option of carbon steel.

The temperature and pressure of each pump was determined in accordance to the exiting conditions of one process stream from a vessel, as well as the desired process temperature and pressure required in the ensuing equipment. As per the empirical sizing method presented in Wankat, the pumps were

designed to operate at a design pressure with a 50 psi increase to allow for a safety margin. The sizing procedure is described below and all calculations for sizing the flash drums are presented in Appendix C.

To determine the pressure of each pump, the pressure difference across the line was needed. The pressure change adjusted with a safety margin and the flow rate of the process stream that entered the pump was used in the following equation to calculate the hydraulic horsepower.

$$Hydraulic hP = \frac{F_i * \Delta P}{1715} \tag{41}$$

Where:

 F_i = inlet flow rate (kg/day) ΔP = pressure change (barg)

$$Brake hP = \frac{Hydraulic Hp}{\eta}$$
(42)

Where:

 η = pump efficiency (assumed to be 65%)

$$\eta_{motor} = (75 + 11.5 \log(BHP)) - \frac{1.5(\log(BHP))^2}{100}$$
(43)

BHP= Brake horsepower (hP) n_{motor}= motor efficiency (%)

$$Purchased hP = \frac{BHP}{n_{motor}}$$
(44)

Once the purchased horsepower was calculated, a standard pump that met the required pump horsepower but did not greatly exceed the size, was utilized. This produced the actual horsepower which was converted into an energy value that was used to determine the utility costs for the pump.

	CONTINUOU	S STIRRED TANK REACTOR 1	
Identification: Item Item No. No. Requ			Date: 3 March 2017 By: Team 2017
Function: Mixi	ng of ADA, HMDA and H_2O to	o initiate the polycondensation react	ion needed for polymerization
Operation: Cont	inuous		
Materials Handled: Quantity (kg/day) Composition:	Feed 130855.8	Outlet 130855	
HMDA ADA Water Nylon Salt Diamine Nylon 6 6 Therminol XP	54239.2 68208.9 8408.2	8408. 122447	
Stabilizer Temperature (°C)	250	255	
Design Data: Pressure: 12.4 Volume: 4.18 Diameter: 1.2 Duty: 12.28 kV	m ³ m		
Utilities: High Pressure S Controls: Flow control va Tolerances: Comments and Drawing			

VI. Equipment Specification Sheets

BATCH REACTOR 1					
Identification: Item Item No. No. Requ			Date: 3 March 2017 By: Team 2017		
Function: Mixin	ng of ADA, HMDA and H_2O to	initiate the polycondensation reaction ne	eded for polymerization		
Operation: Batc	h				
Materials Handled: Quantity (kg/day) Composition:	Feed 130855.8	<i>Outlet</i> 130855.8			
HMDA ADA Water Nylon Salt Diamine Nylon 6 6 Therminol XP	54239.2 68208.9 8408.2	8408.2 122447.6			
<i>Stabilizer</i> Temperature (°C)	250	255			
Design Data: Pressure: 12.4 Volume: 15 m Diameter: 1.9 Duty: 57.34kW	m				
Utilities: High Pressure S Controls: Flow control va Tolerances: Comments and Drawing					

CONTINUOUS STIRRED TANK REACTOR 2					
Identification: Item	CRT Reactor 2				
Item No	-		Date: 3 March 2017		
No. Req	uired 1		By: Team 2017		
Function: Exc	ess water removal and formation of	heavy weight oligomers through step gro	owth polymerization		
Operation: Con	tinuous				
Materials Handled:	Inlet Stream	Outlet Stream			
Quantity (kg/day)	105882.9	105882.9			
Composition:					
HMDA					
ADA					
Water		252			
Nylon Salt	105882.9				
Diamine					
Nylon 6 6		105631.1			
Therminol XP					
Stabilizer	200	200			
Temperature (°C)	280	280			
Design Data: Pressure: 12. Volume: 6.87 Area: 1.4 m Duty: 0 kW					
Utilities: NA Controls: Level Control Tolerances: Comments and Drawin	Valve and Steam Vent gs: See Process Flow Diagram				

	BATCH	REACTOR 2	
Identification: Item Item No No. Rec		Date: 3 March By: Team 2017	
Function: Exc	ess water removal and formation o	heavy weight oligomers through step growth polymerizati	on
Operation: Bat	ch		
Materials Handled: Quantity (kg/day) Composition:	Inlet Stream 105882.9	Outlet Stream 105882.9	
HMDA ADA Water Nylon Salt	105882.9	252	
Diamine Nylon 6 6 Therminol XP Stabilizer		105631.1	
Temperature (°C)	280	280	
Design Data: Pressure: 12. Volume: 15 r Area: 1.9 m Duty: 0 kW	43 barg n ³		
Utilities: NA Controls: Steam Vent Tolerances: Comments and Drawir	ngs: See Process Flow Diagram		

Date: 3 March 201 By: Team 2017
resent in the salt mixture
eam Liquid Stream 7 105884.23
105884.23 2
280
a

		CONDEN	SER	
Identification: Item Item No No. Req	Condenser . E-103 uired 1			Date: 3 March 2017 By: Team 2017
Function: Con	dense the vapor stream l	leaving the evapo	pration unit to allow for separation i	nto its components
Operation: Con	tinuous and Batch			
Materials Handled: Quantity (kg/day) Composition: HMDA	Inlet Stream 33728.7		Outlet Stream 33728.7	
ADA Water Nylon Salt Nylon Salt	24973		24973	
Diamine Nylon 6 6 Therminol XP Stabilizer	8756.2		8756.2	
Temperature (°C)	280		109	
Design Data: Pressure: 3.8 Area: 8.22 m ² Duty: 6.76e+ LMTD: 140.29 Correction Fa	7 Btu/day 9°F			
Controls: Temperature Tolerances:	at a flow rate of 4110.1 a Control gs: See Process Flow Diag			

	FLAS	SH DRUM	
Identification: Item Item No No. Req	Flash Drum p. V-101 uired 1		Date: 3 March 2017 By: Team 2017
Function: Sep	arate the condensed stream into its	components of $\mathrm{H_2O}$ and liquid diamine	
Operation: Con	tinuous and Batch		
Materials Handled: Quantity (kg/day) Composition: HMDA ADA	Input Stream 33728.7	Vapor Stream 24973	Liquid Stream 8756.2
Water Nylon Salt Diamine Nylon 6 6 Therminol XP Stabilizer	24973 8756.2	24973	8756.2
Temperature (°C)	109	110	110
Design Data: Pressure: 3.8 Volume: 2.86 Diameter: 1.0	m ³		
Controls: Temperature Tolerances:	surized drum allows separation to o and Pressure Controls gs: See Process Flow Diagram	ccur	

		STORAGE TANK	2	
Identification: Item Item No. R	5			Date: 3 March 2017 By: Team 2017
Function: S	Store the liquid diamine or	a weekly basis		
Operation : C	Continuous and Batch			
Materials Handled: Quantity (kg/day) Composition: HMDA ADA Water Nylon Salt	Inlet Stream 8756.2			
Diamine Nylon 6 6 Therminol XP Stabilizer	8756.2			
Temperature (°C)	110			
Design Data: Pressure: 3 Volume: 73 Diameter: Orientation Time in Ve	3.0 m ³ 3.1 m			
Utilities: NA Controls: Pressure Co Tolerances: Comments and Draw	ontrol vings: See Process Flow Di	agram		

	E	XTRUDER	
Identification: Item Item No No. Req			Date: 3 March 2017 By: Team 2017
Function: Soli	dification and shaping of the mol	en Nylon 6 6 into pelletized or fiber form	
Operation : Cor	ntinuous and Batch		
Materials Handled: Quantity (kg/day) Composition: HMDA ADA Water Nylon Salt	Inlet Stream 105631.1	Outlet Stream 105631.1	
Diamine Nylon 6 6 Therminol XP Stabilizer	105631.1	105631.1	
Temperature (°C)	280	280	
Motor/Drive Temperature Nitride Tool S	peed: 600 RPM : 1500 HP AC Control Unit (TCU) iteel Process Section Electrical Control System		
Controls: Temperature Tolerances:	oower heaters and motor and Flow Control gs: See Process Flow Diagram		

		STORAGE TA	NK 1	
Identification: Item Item No. R	<i>Equipment Nam</i> No. TK-101 equired	e		Date: 3 March 2017 By: Team 2017
Function: S	torage of the Nylon 6 6 p	ellets formed after th	ne extrusion proces	SS
Operation: C	Continuous			
Materials Handled: Quantity (kg/day) Composition: HMDA ADA Water Nylon Salt Diamine	Inlet Conditions 105631.1			
Nylon 6 6 Therminol XP Stabilizer Temperature (°F)	105631.1 290			
Design Data: Pressure: 3 Volume: 92 Diameter: Orientation	3.8 barg 2.6 m ³ 3.4 m	i emptied)	1	1
Utilities: NA Controls: Flow Contr Tolerances: Comments and Draw	ol vings: See Process Flow D	iagram		

		PUMP 1		
Identification: Item Item No No. Req				Date: 3 March 2017 By: Team 2017
Function: Pun	np nylon salt from the evapo	pration unit to the	second reactor	
Operation: Con	tinuous and Batch			
Materials Handled: Quantity (kg/day) Composition: HMDA	Inlet Stream 105884.23		Outlet Stream 105884.23	
ADA Water Nylon Salt Diamine Nylon 6 6 Therminol XP	105884.23		105884.23	
<i>Stabilizer</i> Temperature (°C)	280		280	
Shaft Power: Motor Efficie Purchased Ho Hydraulic Hor Actual Horsej Power Consu	ncy: 0.849 orsepower: 11.5 hp rsepower: 6.3 hp			
Utilities: Electricity Controls: Flow Transmi Tolerances: Comments and Drawin	tter, Pressure Indicator gs: See Process Flow Diagra	m		

		PUMP 2		
Identification: Item Item No No. Req				Date: 3 March 2017 By: Team 2017
Function: Pur	mp condensed fluid to the flas	h drum from the o	condenser	
Operation: 67%	6 Capacity Continuous			
Materials Handled: Quantity (kg/day) Composition: HMDA ADA	Input Stream 33728.73		Outlet Stream 33728.73	Liquid Stream
Water Nylon Salt Diamine	24973 8756.2		24973 8756.2	
Nylon 6 6 Therminol XP Stabilizer				
Temperature (°C)	109		109	
Shaft Power: Motor Efficie Purchased Ho Hydraulic Hor Actual Horsej	ncy: 0. 6758 o rsepower: 0.3731 hp r sepower: 0.1639 hp			
Utilities: Electricity Controls: Flow Transmi Tolerances:				

	P	PUMP 3	
Identification: Item Item No No. Req			Date: 3 March 2017 By: Team 2017
Function: Pur	nping of 1,6 hexanediamine from tl	he flash drum to the storage tank	
Operation: 679	6 Capacity Continuous		
Materials Handled: Quantity (kg/day) Composition: HMDA ADA Water	Inlet Stream 8756.2	Outlet Stream 8756.2	
Nylon Salt Diamine Nylon 6 6 Therminol XP Stabilizer	8756.2	8756.2	
Temperature (°C)	110	110	
Shaft Power: Motor Efficie Purchased Ho Hydraulic Ho Actual Horse			
Tolerances:	tter, Pressure Indicator I gs: See Process Flow Diagram		

		PUMP 4	
Identification: Item Item No No. Req			Date: 3 March 2017 By: Team 2017
Function: Pur	nping molten Nylon 6 6 from	he second reactor to the extruder	
Operation: 679	6 Capacity Continuous		
Materials Handled: Quantity (kg/day) Composition: HMDA ADA Water Nylon Salt	Inlet Stream 105631.1	Outlet Stream 105631.1	
Diamine Nylon 6 6 Therminol XP Stabilizer	105631.1	105631.1	
Temperature (°C)	280	280	
Shaft Power: Motor Efficie Purchased Ho Hydraulic Ho Actual Horse	ncy: 0.9089 orsepower: 70.87 hp rsepower: 45.09 hp		
Tolerances:	tter, Pressure Indicator gs: See Process Flow Diagram		

	Pl	JMP 5	
Identification: Item Item No No. Req			Date: 3 March 2017 By: Team 2017
Function: Cire	culation of nylon salt within the evap	poration unit to ensure removal of H_2O	
Operation: 67%	6 Capacity Continuous		
Materials Handled: Quantity (kg/day) Composition: HMDA ADA	Inlet Stream 130856.8	Outlet Stream 130856.8	
Water Nylon Salt Diamine Nylon 6 6 Therminol XP Stabilizer	8409.33 122447.5	8409.33 122447.5	
Temperature (°C)	280	280	
Shaft Power: Motor Efficie Purchased Ho Hydraulic Ho Actual Horse	ncy: 0.856 prsepower: 13.9 hp rsepower: 7.7 hp		
Utilities: Electricity Controls: Flow Transmi Tolerances: Comments and Drawin	tter, Pressure Indicator gs: See Process Flow Diagram		

CONTINUOUS STIRRED TANK REACTOR 1					
Identification: Item Item No. No. Requ			Date: 3 March 2017 By: Team 2017		
Function: Mixi	ng of ADA, HMDA and H_2O to	o initiate the polycondensation reac	tion needed for polymerization		
Operation: 67%	Capacity Continuous				
Materials Handled: Quantity (kg/day) Composition:	Feed 87673.78	Outle 87673			
HMDA ADA Water Nylon Salt Diamine Nylon 6 6 Therminol XP	36340.19 45700.01 5633.58	5633. 82039.			
<i>Stabilizer</i> Temperature (°C)	25	250			
Design Data: Pressure: 12.4 Volume: 4.18 Diameter: 1.2 Duty: 12.28 kV	m ³				
Utilities: High Pressure S Controls: Flow control v Tolerances: Comments and Drawing					

CONTINUOUS STIRRED TANK REACTOR 2				
Identification: Item	CRT Reactor 2			
Item No	o. R-102		Date: 3 March 2017	
No. Req	uired 1		By: Team 2017	
Function: Exc	ess water removal and formation of	heavy weight oligomers through step gi	rowth polymerization	
Operation: 67%	6 Capacity Continuous			
Materials Handled:	Inlet Stream	Outlet Stream		
Quantity (kg/day)	70942.43	70942.43		
Composition:				
HMDA				
ADA				
Water		169.01		
Nylon Salt	70942.43			
Diamine				
Nylon 6 6		70772.84		
Therminol XP				
Stabilizer				
Temperature (°C)	280	280		
Design Data: Pressure: 12. Volume: 6.87 Area: 1.4 m Duty: 0 kW Reaction Rate	m ³			
Utilities: NA				
Controls: Level Control	valve and Steam Vent			
Tolerances:				
comments and Drawin	gs: See Process Flow Diagram			

	EVA	PORATOR	
Identification: Item Item No No. Req			Date: 3 March 2017 By: Team 2017
Function: Ren	nove excess water from the nylon s	salt as well as any monomers present in t	he salt mixture
Operation: 67%	6 Capacity Continuous		
Materials Handled: Quantity (kg/day) Composition: HMDA ADA	Inlet Stream 87673.41	Vapor Stream 22598.67	Liquid Stream 70942.43
Water Nylon Salt Diamine Nylon 6 6 Therminol XP Stabilizer	5633.58 82039.83	16372 5866.87	70942.43
Temperature (°C)	250	280	280
Design Data: Pressure: 10 Volume: 0.87 Area: 0.407 n Diameter: 2. Correction Fa LMTD: 83.23	9 m ³ 1 ² 26 m I ctor : 0.995		
Controls: Temperature Tolerances:	ith Therminol XP to allow for prope Control, and flow control valve gs: See Process Flow Diagram	er heat exchange within the evaporation	unit

		CONDENS	ER	
Identification: Item Item No No. Req	Condenser . E-103 uired 1			Date: 3 March 2017 By: Team 2017
Function: Con	dense the vapor stream le	eaving the evapor	ation unit to allow for separation	into its components
Operation: 67%	6 Capacity Continuous			
Materials Handled: Quantity (kg/day) Composition: <i>HMDA</i>	Inlet Stream 22598.67		Outlet Stream 22598.67	
ADA Water Nylon Salt Nylon Salt	16372		16372	
, Diamine Nylon 6 6 Therminol XP Stabilizer	5866.87		5866.87	
Temperature (°C)	280		109	
Design Data: Pressure: 3.8 Area: 8.22 m ² Duty: 6.76e+ LMTD: 140.29 Correction Fa	7 Btu/day 9 °F			
Controls: Temperature Tolerances:	at a flow rate of 4110.1 a Control gs : See Process Flow Diag			

	FLAS	SH DRUM	
Identification: Item Item No No. Rec	Flash Drum p. V-101 quired 1		Date: 3 March 2017 By: Team 2017
Function: Sep	parate the condensed stream into its	components of $\mathrm{H_2O}$ and liquid diamine	
Operation: 679	% Capacity Continuous		
Materials Handled: Quantity (kg/day) Composition: <i>HMDA</i> ADA	Input Stream 22598.67	Vapor Stream 16372	Liquid Stream 5866.87
Water Nylon Salt Diamine Nylon 6 6 Therminol XP Stabilizer	16372 5866.87	16372	5866.87
Temperature (°C)	109	110	110
Design Data: Pressure: 3.8 Volume: 2.86 Diameter: 1.0	5 m ³		
Controls: Temperature Tolerances:	ssurized drum allows separation to or and Pressure Controls ngs: See Process Flow Diagram	ccur	

		STORAGE TANK	2	
	n Storage Tank 1 n No. TK-102 Required 1			Date: 3 March 2017 By: Team 2017
Function:	Store the liquid diamine on	a weekly basis		
Operation:	67% Capacity Continuous			
Materials Handled Quantity (kg/day) Composition: HMDA ADA Water Nylon Salt Diamine				
Nylon 6 6 Therminol XP Stabilizer Temperature (°C)	110			
	73.0 m ³			
Utilities: NA Controls: Pressure Tolerances: Comments and Dra	Control awings: See Process Flow Di	agram		

	EX	TRUDER	
Identification: Item Item No No. Rec			Date: 3 March 2017 By: Team 2017
		en Nylon 6 6 into pelletized or fiber form	
Operation: 679	% Capacity Continuous		
Materials Handled: Quantity (kg/day) Composition: HMDA ADA Water Nylon Salt Diamine	Inlet Stream 70772.84	Outlet Stream 70772.84	
Nylon 6 6 Therminol XP Stabilizer	70772.84	70772.84	
Temperature (°C)	280	280	
Motor/Drive Temperature Nitride Tool S	peed: 600 RPM : 1500 HP AC : Control Unit (TCU) Steel Process Section • Electrical Control System		
Controls: Temperature Tolerances:	power heaters and motor and Flow Control ngs: See Process Flow Diagram		

		STORAGE TAN	К 1	
Identification: Item Item No. R	<i>Equipment Nam</i> No. TK-101 Required	е		Date: 3 March 2017 By: Team 2017
Function: S	itorage of the Nylon 6 6 p	ellets formed after the	extrusion process	
Operation : 6	7% Capacity Continuous			
Materials Handled: Quantity (kg/day) Composition: HMDA ADA Water Nylon Salt Diamine Nylon 6 6 Therminol XP	<i>Inlet Conditions</i> 70772.84 70772.84			
<i>Stabilizer</i> Temperature (°F)	290			
Design Data: Pressure: 3 Volume: 9 Diameter: Orientatio Time in Ve	2.6 m ³ 3.4 m	emptied)		
Utilities: NA Controls: Flow Contr Tolerances: Comments and Drav	ol vings: See Process Flow D	iagram		

		PUMP 1		
Identification: Item Item No No. Req	-			Date: 3 March 2017 By: Team 2017
Function: Pum	np nylon salt from the evapora	ation unit to the seco	ond reactor	
Operation: 67%	6 Capacity Continuous			
Materials Handled: Quantity (kg/day) Composition: HMDA ADA	Inlet Stream 70942.43		Outlet Stream 70942.43	
Water Nylon Salt Diamine Nylon 6 6 Therminol XP Stabilizer	70942.43		70942.43	
Temperature (°C)	280		280	
Shaft Power: Motor Efficien Purchased Ho Hydraulic Hor Actual Horsen	ncy: 0.849 prsepower: 11.5 hp rsepower: 6.3 hp			
Utilities: Electricity Controls: Flow Transmit Tolerances: Comments and Drawing	tter, Pressure Indicator gs: See Process Flow Diagram			

		PUMP 2		
Identification: Item Item No No. Req				Date: 3 March 2017 By: Team 2017
Function: Pur	mp condensed fluid to the flas	h drum from the o	condenser	
Operation: 67%	6 Capacity Continuous			
Materials Handled: Quantity (kg/day) Composition: HMDA ADA	Input Stream 22598.67		Outlet Stream 22598.67	Liquid Stream
Water Nylon Salt	16372		16372	
Diamine Nylon 6 6 Therminol XP Stabilizer	5866.87		5866.87	
Temperature (°C)	109		109	
Shaft Power: Motor Efficie Purchased Ho Hydraulic Hor Actual Horsej	ncy: 0.6522 prsepower: 0.259 hp rsepower: 0.1098 hp			
Utilities: Electricity Controls: Flow Transmi Tolerances: Comments and Drawin	tter, Pressure Indicator gs: See Process Flow Diagram			

	F	PUMP 3	
Identification: Item Item No No. Req			Date: 3 March 2017 By: Team 2017
Function: Pun	nping of 1,6 hexanediamine from t	he flash drum to the storage tank	
Operation: 67%	6 Capacity Continuous		
Materials Handled: Quantity (kg/day) Composition: HMDA ADA Water	Inlet Stream 5866.87	Outlet Stream 5866.87	
Nylon Salt Diamine Nylon 6 6 Therminol XP Stabilizer	5866.87	5866.87	
Temperature (°C)	110	110	
Shaft Power: Motor Efficier Purchased Ho Hydraulic Hor Actual Horser	ncy: 0.5801 prsepower: 0.0931 hp rsepower: 0.0351 hp		
Utilities: Electricity Controls: Flow Transmit Tolerances: Comments and Drawin	tter, Pressure Indicator gs: See Process Flow Diagram		

		PUMP 4	
Identification: Item Item N No. Re	Pump 4 lo. P-104 equired 2		Date: 3 March 2017 By: Team 2017
Function: Pu	Imping molten Nylon 6 6 from the s	second reactor to the extruder	
Operation: 67	7% Capacity Continuous		
Materials Handled: Quantity (kg/day) Composition: HMDA ADA Water Nylon Salt	Inlet Stream 70772.84	Outlet Stream 70772.84	
Diamine Nylon 6 6 Therminol XP Stabilizer Temperature (°C)	70772.84	70772.84	
Design Data: Pressure Ch Shaft Power Motor Effici Purchased H Hydraulic H Actual Hors		1	•
Utilities: Electricity Controls: Flow Transn Tolerances:	nitter, Pressure Indicator ings: See Process Flow Diagram		

		PUMP 5	
Identification: Item Item No No. Rec			Date: 3 March 2017 By: Team 2017
Function: Cir	culation of nylon salt within the ev	vaporation unit to ensure removal of H_2O	
Operation: 679	% Capacity Continuous		
Materials Handled: Quantity (kg/day) Composition: HMDA ADA	Inlet Stream 87673.41	Outlet Stream 87673.41	
ADA Water Nylon Salt Diamine Nylon 6 6 Therminol XP Stabilizer Temperature (°C)	5633.58 82039.83	5633.58 82039.83	
Shaft Power: Motor Efficie Purchased Ho Hydraulic Ho Actual Horse	•		
Tolerances:	itter, Pressure Indicator ngs: See Process Flow Diagram		

VII. Equipment Cost Summary

Listed below are the estimated purchase costs (Cp), bare module costs (CBM), and total module costs (CTM) for all equipment required for the production of Nylon 6 6 in a continuous, batch and reduced capacity processes as well as the method used in determining each cost. The complete method breakdown will be further explained in section VIII *Fixed Capital Investment Summary*.

Unit	R-101	E-101	R-102	V-102	TK-101	E-103	V-101
Name	CSTR	Evaporator	CSTR	Extruder	Storage Tank	Condenser	Flash Drum
Price, USD (Cp)	\$716,000	\$499,000	\$700,000	\$532,000	\$313,000	\$78,000	\$124,000
(CBM)	\$1,502,000	\$1,271,000	\$1,468,000	\$733,000	\$737,000	\$208,000	\$314,000
(CTM)	\$1,773,000	\$1,500,000	\$1,733,000	\$950,000	\$870,000	\$246,000	\$371,000
Method of	Design Book	Design Book	Design Book	Quotation	Design Book	Design Book	Design Book
Pricing	Costing	Costing	Costing	from	Costing	Costing	Costing
	Parameters	Parameters	Parameters	Manufacturer	Parameters	Parameters	Parameters
Unit	TK-102	P-101	P-102	P-103	P-104	P-105	-
Name	Storage	Pump	Pump	Pump	Pump	Pump	-
	Tank						
Price, USD (Cp)	\$413,000	\$8,500	\$5,100	\$5,100	\$23,100	\$8,500	-
(CBM)	\$957,000	\$24,500	\$14,800	\$14,800	\$66,500	\$24,500	
(CTM)	\$1,130,00	\$28,900	\$17,400	\$17,400	\$78,400	\$28,900	
Method of	Design Book	Design Book	Design Book	Design Book	Design Book	Design Book	-
Pricing	Costing	Costing	Costing	Costing	Costing	Costing	
	Parameters	Parameters	Parameters	Parameters	Parameters	Parameters	

Table 5: Continuous Process with Pelletized Nylon 6 6

Unit	R-101	E-101	R-102	V-102	TK-101	E-103	V-101
Name	CSTR	Evaporator	CSTR	Extruder	Storage Tank	Condenser	Flash Drum
Price, USD (Cp)	\$716,000	\$499,000	\$700,000	\$532,000	\$313,000	\$78,000	\$124,000
(CBM)	\$1,502,000	\$1,271,000	\$1,468,000	\$733,000	\$737,000	\$208,000	\$314,000
(CTM)	\$1,773,000	\$1,500,000	\$1,733,000	\$950,000	\$870,000	\$246,000	\$371,000
Method of	Design Book	Design Book	Design Book	Quotation from	Design Book	Design Book	Design Book
Pricing	Costing	Costing	Costing	Manufacturer	Costing	Costing	Costing
	Parameters	Parameters	Parameters		Parameters	Parameters	Parameters
Unit	TK-102	P-101	P-102	P-103	P-104	P-105	S-102
Name	Storage Tank	Pump	Pump	Pump	Pump	Pump	Spinneret
Price, USD (Cp)	\$413,000	\$8,500	\$5,100	\$5,100	\$23,100	\$8,500	\$696,000
(CBM)	\$957,000	\$24,500	\$14,800	\$14,800	\$66,500	\$24,500	\$1,358,000
(CTM)	\$1,130,00	\$28,900	\$17,400	\$17,400	\$78,400	\$28,900	\$1,439,000
Method of	Design Book	Design Book	Design Book	Design Book	Design Book	Design Book	Quotation
Pricing	Costing	Costing	Costing	Costing	Costing	Costing	from
	Parameters	Parameters	Parameters	Parameters	Parameters	Parameters	Manufacturer

Table 5: Continuous Process with Spun Nylon 6 6

Unit	R-101	E-101	R-102	V-102	TK-101	E-103	V-101
Name	Batch Reactor	Evaporator	Batch Reactor	Extruder	Storage Tank	Condenser	Flash Drum
Price, USD (Cp)	\$1,052,000	\$499,000	\$955,000	\$532,000	\$313,000	\$78,000	\$124,000
(CBM)	\$2,173,000	\$1,271,000	\$1,981,000	\$733,000	\$737,000	\$208,000	\$314,000
(CTM)	\$2,564,000	\$1,500,000	\$2,338,000	\$950,000	\$870,000	\$246,000	\$371,000
Method of	Design Book	Design Book	Design Book	Quotation from	Design Book	Design Book	Design Book
Pricing	Costing	Costing	Costing	Manufacturer	Costing	Costing	Costing
	Parameters	Parameters	Parameters		Parameters	Parameters	Parameters
Unit	TK-102	P-101	P-102	P-103	P-104	P-105	-
Name	Storage Tank	Pump	Pump	Pump	Pump	Pump	-
Price, USD (Cp)	\$413,000	\$8,500	\$5,100	\$5,100	\$23,100	\$8,500	-
(CBM)	\$957,000	\$24,500	\$14,800	\$14,800	\$66,500	\$24,500	
(CTM)	\$1,130,00	\$28,900	\$17,400	\$17,400	\$78,400	\$28,900	
Method of	Design Book	Design Book	Design Book	Design Book	Design Book	Design Book	-
Pricing	Costing	Costing	Costing	Costing	Costing	Costing	
	Parameters	Parameters	Parameters	Parameters	Parameters	Parameters	

Table 6: Batch Process with Pelletized Nylon 6 6

Unit	R-101	E-101	R-102	V-102	TK-101	E-103	V-101
Name	Batch Reactor	Evaporator	Batch Reactor	Extruder	Storage Tank	Condenser	Flash Drum
Price, USD (Cp)	\$1,052,000	\$499,000	\$955,000	\$532,000	\$313,000	\$78,000	\$124,000
(CBM)	\$2,173,000	\$1,271,000	\$1,981,000	\$733,000	\$737,000	\$208,000	\$314,000
(CTM)	\$2,564,000	\$1,500,000	\$2,338,000	\$950,000	\$870,000	\$246,000	\$371,000
Method of	Design Book	Design Book	Design Book	Quotation from	Design Book	Design Book	Design Book
Pricing	Costing	Costing	Costing	Manufacturer	Costing	Costing	Costing
	Parameters	Parameters	Parameters		Parameters	Parameters	Parameters
Unit	TK-102	P-101	P-102	P-103	P-104	P-105	S-102
Name	Storage Tank	Pump	Pump	Pump	Pump	Pump	Spinneret
Price, USD (Cp)	\$413,000	\$8,500	\$5,100	\$5,100	\$23,100	\$8,500	\$696,000
(CBM)	\$957,000	\$24,500	\$14,800	\$14,800	\$66,500	\$24,500	\$1,358,000
(CTM)	\$1,130,00	\$28,900	\$17,400	\$17,400	\$78,400	\$28,900	\$1,439,000
Method of	Design Book	Design Book	Design Book	Design Book	Design Book	Design Book	Quotation
Pricing	Costing	Costing	Costing	Costing	Costing	Costing	from
	Parameters	Parameters	Parameters	Parameters	Parameters	Parameters	Manufacturer

Table 7: Batch Process with Spun Nylon 6 6

Unit	R-101	E-101	R-102	V-102	TK-101	E-103	V-101
Name	CSTR	Evaporator	CSTR	Extruder	Storage Tank	Condenser	Flash Drum
Price, USD (Cp)	\$716,000	\$499,000	\$700,000	\$532,000	\$313,000	\$78,000	\$124,000
(CBM)	\$1,502,000	\$1,271,000	\$1,468,000	\$733,000	\$737,000	\$208,000	\$314,000
(CTM)	\$1,773,000	\$1,500,000	\$1,733,000	\$950,000	\$870,000	\$246,000	\$371,000
Method of	Design Book	Design Book	Design Book	Quotation from	Design Book	Design Book	Design Book
Pricing	Costing	Costing	Costing	Manufacturer	Costing	Costing	Costing
	Parameters	Parameters	Parameters		Parameters	Parameters	Parameters
Unit	TK-102	P-101	P-102	P-103	P-104	P-105	-
Name	Storage Tank	Pump	Pump	Pump	Pump	Pump	-
Price, USD (Cp)	\$413,000	\$8,500	\$5,100	\$5,100	\$23,100	\$8,500	-
(CBM)	\$957,000	\$24,500	\$14,800	\$14,800	\$66,500	\$24,500	
(CTM)	\$1,130,00	\$28,900	\$17,400	\$17,400	\$78,400	\$28,900	
Method of	Design Book	Design Book	Design Book	Design Book	Design Book	Design Book	-
Pricing	Costing	Costing	Costing	Costing	Costing	Costing	
	Parameters	Parameters	Parameters	Parameters	Parameters	Parameters	

Table 8: 67% Capacity Process with Pelletized Nylon 6 6

Unit	R-101	E-101	R-102	V-102	TK-101	E-103	V-101
Name	CSTR	Evaporator	CSTR	Extruder	Storage Tank	Condenser	Flash Drum
Price, USD (Cp)	\$716,000	\$499,000	\$700,000	\$532,000	\$313,000	\$78,000	\$124,000
(CBM)	\$1,502,000	\$1,271,000	\$1,468,000	\$733,000	\$737,000	\$208,000	\$314,000
(CTM)	\$1,773,000	\$1,500,000	\$1,733,000	\$950,000	\$870,000	\$246,000	\$371,000
Method of	Design Book	Design Book	Design Book	Quotation from	Design Book	Design Book	Design Book
Pricing	Costing	Costing	Costing	Manufacturer	Costing	Costing	Costing
	Parameters	Parameters	Parameters		Parameters	Parameters	Parameters
Unit	TK-102	P-101	P-102	P-103	P-104	P-105	S-102
Name	Storage Tank	Pump	Pump	Pump	Pump	Pump	Spinneret
Price, USD (Cp)	\$413,000	\$8,500	\$5,100	\$5,100	\$23,100	\$8,500	\$696,000
(CBM)	\$957,000	\$24,500	\$14,800	\$14,800	\$66 <i>,</i> 500	\$24,500	\$1,358,000
(CTM)	\$1,130,00	\$28,900	\$17,400	\$17,400	\$78,400	\$28,900	\$1,439,000
Method of	Design Book	Design Book	Design Book	Design Book	Design Book	Design Book	Quotation
Pricing	Costing	Costing	Costing	Costing	Costing	Costing	from
	Parameters	Parameters	Parameters	Parameters	Parameters	Parameters	Manufacturer

Table 9: 67% Capacity Process with Spun Nylon 6 6

VIII. Fixed Capital Investment Summary

When estimating the prices of equipment to determine the fixed capital investment for a Nylon 6 6 grass roots production plant, the following methods were used.

Initially, the parameter of interest needed to be determined and calculated. The capacity or size parameters of interest for the equipment in this process are listed in Table 11 below.

Table 10: Equipment Parameters of Interest						
Equipment	Capacity	Units				
Heat Exchangers	Area	m²				
Process Vessels	Volume	m³				
Pumps	Power	kW				
Evaporators	Area	m²				
Reactors	Volume	m³				

Table 10: Equipment Parameters of Interest

Utilizing the following equation, the base purchase cost of a piece of equipment can be calculated.

$$C_p^o = 10^{\left(K_1 + K_2 \log(A) + K_3 [\log(A)]^2\right)}$$
(45)

Where:

K values = constants A = capacity or sizing parameter C_n^o = base purchase cost

After C_p^o was determined, the bare pressure factor (Fp) was calculated using one of the two methods below.

For a process vessel, the following equation was used when the thickness of the vessel was greater than 0.0063 m.

$$F_{P,vessel} = \frac{\frac{(P+1)D}{2[850-0.6(P+1)]} + 0.00315}{0.0063}$$
(46)

Where:

P= pressure (barg) D= diameter (m) F_p = pressure factor of the vessel

For all other process equipment the following was used.

$$F_p = 10^{(C_1 + C_2 \log(P) + C[\log(P)]^2)}$$
(47)

Where:

 F_p = is the pressure factor C values= constants P= pressure (barg)

Additionally, once the material of construction for a piece of equipment was determined, the material factor (Fm) was calculated according to the identification number and graph (Turton 2011).

Once the base purchase cost was determined, the material and pressure factors, and the bare module factor (F_{BM}) were calculated using the following,

$$F_{BM} = (B_1 + B_2 F_M F_P)$$
(48)

Where:

B values are constants from table A.2 [9]

Once the F_{BM} was calculated, the bare module capital cost (C_{BM}) was calculated using:

$$C_{BM} = F_{BM} C_p^o \tag{49}$$

Subsequently, contingency costs were calculated by multiplying C_{BM} by 0.15 and fees were calculated by multiplying C_{BM} by 0.03.

Finally, all values were escalated to 2017 prices using a CEPCI index ratio of 547/397 to adjust from 2001 values provided in Turton. Once C_{BM} , contingency and fees were escalated to 2017 prices, they were summed for the total module installed cost (C_{TM}).

In order to account for all additional costs associated with producing a grass roots facility, the following equation was used to find the grass roots cost (C_{GR}).

$$C_{GR} = C_{TM} + 0.5C_{BM}$$
(50)

Utilizing this procedure, all fixed capital costs were calculated according to the sizing and specification parameters provided. All values can be found in Tables 4-9 in section VII, *Equipment Cost Summary*.

IX. Safety, Health, and Environmental Considerations

Health, Safety and Environment, or HSE, are the rules and regulations created to help protect employees, the public, and the environment from harm. The two main objectives of HSE are to prevent incidents that may occur within the plant outside normal operating conditions and to decrease the negative effects of an incident.

Safety

The polymerization of ADA and HMDA to form Nylon 6 6 is a chemical process that required the implementation of process safety to mitigate hazards and accidents. This process involved the use of hazardous reactants and intermediates that could not be substituted or diluted. Due to the risks associated with these chemicals, there was no direct exposure to toxic materials unless equipment failure occurred and maintenance would be required. The formation process of Nylon 6 6 occurred mechanically and a DCS was utilized to avoid the handling of toxic chemicals.

Materials

The organic compound, HMDA, is the monomer used in the synthesis of the polymer Nylon 6 6 via polycondensation with ADA. Nylon salt is the intermediate for the formation of Nylon 6 6 and is not considered dangerous to the environment or human exposure. The byproduct of the evaporation of Nylon salt was diamine, which is the functional amine group that water was evaporated from in the polymerization reaction. These five materials presented a combination of safety hazards that required

plans of preventative action to avoid catastrophes. Table 12 shown below lists the properties of these chemicals.

Chemical	Stability	Flammability	Corrosiveness	Acute	Boiling Point
				Toxicity	(°C)
Adipic Acid	Stable	Combustible	Aqueous	Inhalation	337.5
		at high	solutions of	and	
		temperatures;	ADA are	ingestion;	
		combustion	corrosive	irritant to	
		products:		skin	
		carbon oxides			
		(CO, CO ₂)			
Hexamethyldiamine	Stable	Non	Corrosive	Harmful if	201.0
		flammable		ingested or	
				comes in	
				contact with	
				skin	
Nylon salt	Stable	Non	Not corrosive	Very low	N/A
		flammable			Decomposition
					before boiling
1, 6-hexanediamine	Stable	Combustible	Not available	Extremely	204.0
		at high		hazardous in	
		temperatures;		case of	
		combustion		contact with	
		products:		skin	
		carbon oxides			
		(CO, CO ₂) and			
		nitrogen			
		oxides (NO,			
		NO ₂)			
Nylon 6 6	Stable	Non	Not available	Irritation	342.0
		flammable		unlikely in	
				pellet form	

Table 11: Chemical Properties of Materials

As displayed in Table 12 HMDA is acutely toxic and is therefore exceedingly harmful if ingested or contacted with skin. This chemical could cause severe skin burns and eye damage, which indicated personnel interaction with HMDA would be limited. Similarly, diamine is extremely hazardous if contacted with skin or eyes and is harmful to the blood, kidneys, lungs, and liver. Consequently the handling of this chemical was also restricted. In contrast all chemicals involved in the formation of Nylon 6 6 are stable and are not shock sensitive. Additionally no carcinogen, mutagen, or teratogen effects were probable. Additional properties of each chemical are shown in the Material Safety Data Sheets (MSDS) located in Appendix E.

Reactors

Due to the high temperatures required for the polymerization of Nylon 6 6, the batch reactors and CSTRs were jacketed to minimize heat loss. A runaway reaction was not a concern for this process because the reaction is endothermic. Similarly, the feed streams, ADA and HMDA, did not overheat because there was a limit to how much heat transfer could occur in the reactor from the steam to the reactants. The high pressure steam temperature did not exceed the maximum design temperature. In order to monitor the conversion of ADA and HMDA to Nylon salt, a sample point was installed after the first reactor. If adequate mixing did not occur and the reactants were not completely converted, the risk of exposure to ADA or HMDA increased. A fume hood was installed at the sample point to prevent potential inhalation of these toxic chemicals.

In the scenario of impeller failure in the reactor, the desired 99.5% conversion of ADA and HMDA into Nylon salt would not be achieved due to the lack of mixing. If the impeller failed and then restarted, a uniform mixture would not form. One of the reactants could have potentially accumulated in the bottom of the reactor due to the difference in liquid densities. When restarting after impeller failure, the stirrer could potentially cause a vortex to occur in the liquid. In the presence of the vortex, the solid particles would be sent to the outside of the reactor by centrifugal forces, which would also decrease reactor conversion. The impeller motion was monitored by sensors that could alert the control room of any mishaps. For example, if the number of stirrer revolutions fell below the lower limit, the instrument would alert the control room of the issue, which could then be corrected without losing product. Likewise, if the number of stirrer revolutions exceeded the upper limit, typically due to a broken shaft, the stirrer instrument would alert the control room to perform an emergency shut down of the reactor [14]. In the case of an emergency shutdown with reactants that were not converted and were present in the reactor, a discharge tank was available to send the remaining reactants.

Originally a process design consisting of multiple CSTRs operating in series was considered to achieve maximum conversion, however, to maintain safe operating conditions, the design was simplified to one CSTR for the polycondensation stage and one CSTR for the polymerization phase. This simplification minimized potential leaks and failures by reducing the amount of operating equipment. Also a process design consisting of two large batch reactors, one for each phase, was considered; however, the reactor size was greatly increased due to the large production of Nylon 6 6 per day. Large production rates are best carried out in CSTRs.

In addition, a continuous process was selected rather than a batch process in order to minimize the onsite storage of hazardous chemicals between batch reactions. With continuous operation, less residence time was required because the reaction was constantly occurring. In turn, this required smaller amounts of reactants needed at a given time. Subsequently, in a continuous flow process, the raw materials were constantly reacting to form the Nylon salt, which prevented vapor and liquid buildup in the reactors.

Heat Exchangers

In regards to designing safe heat exchangers for this polymerization process, stainless steel was the selected material of construction due to its ability to withstand corrosion and fouling better than carbon steel. When corrosion and fouling were successfully minimized in heat exchangers, the risk of on-line failures or leaks was significantly reduced. These exchangers were equipped with relief valves, bypass piping to avoid overheating, and adequate drainage facilities to effectively dispose of waste water. It was essential to maintain the quality of the heat exchangers because of the flammable and corrosive

fluids that were transported through the equipment [15]. The most common failures of heat exchangers are due to corrosion from moisture at pipe connections, leakage around the baffles, and poor manufacture practices, which result in mechanical and thermal fatigue.

Storage

Although ADA is stable and only flammable if exposed to heat sources, dust generation can form an explosive mixture if it is dispersed in an adequate amount of air. With this in mind, the ADA is stored in a tightly closed tank to prevent the potential exposure to air. Similarly the HMDA and Nylon 6 6 were stored in tightly closed tanks to avoid environmental exposure. Also, the chemicals were stored below their atmospheric boiling points to prevent vaporization.

The storage tanks were positioned a safe distance away from the reactors, where the polycondensation and polymerization occurred, to avert contact with heat sources or ignition sites. In addition, stainless steel is the material of construction of the storage tanks because of its ability to resist corrosion. At the same time, the stainless steel was also more resistant to collapsing under vacuum conditions during liquid withdrawal. As a safeguard, safety relief valves and rupture disks were installed on all tanks. Considering that the reactants and byproduct of this synthesis were toxic if inhaled or contacted with skin, local exhaust ventilation was provided to each storage tank where workers could face forced interaction with the hazardous chemicals. For instance, empty containers of diamine posed a fire risk so the residue required evaporation under a fume hood to avoid fire and inhalation.

In the final step of polymerization, water was vented from the evaporator to allow for the production of Nylon 6 6. A fume hood was installed to prevent the potential inhalation of the Nylon 6 6. The diamine was the side product of this process, water was evaporated from this chemical in a flash drum and was sent to waste water to be treated. The diamine was sold immediately in order to avoid the accumulation of the hazardous chemical in the storage tank. Despite the desire to directly sell diamine after the separation from water, there needed to be a consistent liquid level in the tank to monitor the level and maintain control. For this reason, the storage tank for the diamine required a floating roof to eliminate evaporation losses of this flammable liquid and to prevent the formation of an explosive vapor mixture above liquid [15].

Each storage tank was also grounded in order to prevent charging and all tanks were clearly labeled with their chemical names, classification, hazards, and precautionary statements. Given that Nylon salt is an intermediate in the polymerization reaction, no storage tank was required.

Utilities

Failure of the utilities and ancillary systems would ensue when one or more of the utilities are lost. The electricity for this process plant was purchased from Calvert City, Kentucky, and was used to generate motor drives for lighting and general plant uses. Typically, storage tank issues or piping and valve malfunctions would be failures that cause the loss of cooling water, which is required to operate at lower temperatures [15]. Since this polymerization process is an endothermic reaction, the loss of cooling water was not threatening to the system.

Emergency Response

In the situation of a volatile toxic release, the release would require to be deluged with water. If a fire occurred and Nylon 6 6 burned, hazardous vapors, such as ammonia, carbon monoxide, traces of hydrogen cyanide, and aldehydes would be produced. In this occurrence, workers and anyone else in the vapor cloud path would be evacuated to a location upwind of the incident.

The first response to a chemical spill is containment. If there were victims affected by the spill, medical personnel with proper protective equipment would administer their assistance. Once people are clear of the spill site, a designated rescue team with the proper protective gear would collect the hazardous material in appropriate disposal containers. In the case of a small amount of spilt ADA, a waste disposal container would be required and water must be spread on the contaminated areas. Furthermore, if a large quantity of ADA was spilt, the same cleanup procedure would be implemented on a small spill. Also, the concentration of the spill would be checked to ensure it did not exceed the threshold limit value. In the event that a large amount of diamine spills, all sources of ignition must be eliminated right away. The spilt material must be avoided and water should be sprayed to reduce toxic vapors. Most importantly, entry of the toxic material into the sewer system or confined areas must be prevented and assistance for disposal should be contacted immediately.

Fire Safety

This polymerization process occurred at high temperatures, therefore all piping and equipment were insulated in order to minimize heat loss and prevent potential burns. Preferred insulation materials included foam glass or crimped aluminum sheeting [15]. Although the chemicals are reacting at high temperatures, all equipment and processes are operated above the auto ignition temperatures. In the case of a chemical fire that a fire water system would not be able to contain, a foam deluge system was provided to smother the fire.

Due to the continuous process, a closed venting system was implemented when conveying liquids in order to minimize tank breathing with varying liquid levels. Explosive dust generation is likely to occur if ADA is exposed to substantial amounts of air. It is essential to mitigate the exposure of ADA to air by implementing a closed venting system.

X. Other Important Consideration

Hazard and Operability Study (HAZOP)

This next section consists of a hazard and operability study for the polymerization process of Nylon 6 6, also known as a HAZOP. The purpose of this study is to identify potential hazards that may cause failure of pieces of equipment.

Functional Unit	: Polycondensation re	action of ADA, HMDA,	and H20 to form Nylo	on salt
Intended Funct	ion: convert reactants	to an intermediate		
Guideword	Deviation	Possible Causes	Consequences	Required Action(s)
NO	NO flow of feed	LICV (Level	Polycondensation	Send reactor
	water	Indicator Control	does not occur	content to
		Valve) closed		discharge tank
	NO agitation	Stirrer motor	No reaction,	Send reactor
		malfunction	potential for	content to
			accumulation of	discharge tank
			unreacted	
			materials	
		Power failure	No reaction	Send reactor
			occurs, possibility	content to
			of accumulation	discharge tank
			of unreacted	
			materials	
MORE	MORE agitation	Feed flow rates	Poor conversion	Increase the
		increase		impeller speed
	MORE	Steam FICV (Flow	No reaction	Open valve and
	temperature	Indicator Control		increase
		Valve) closed		temperature
LESS	LESS agitation	Stirrer motor	Vortex is created	Emergency
		malfunction	in reactor,	shutdown, send
			possibility of	reactor content to
			accumulation of	discharge tank
			unreacted	
			materials	
REVERSE	REVERSE flow	High back pressure	Intermediate	Emergency
			flows back into	shutdown, send
			reactor	reactor content to
				discharge tank

Table 12: HAZOP for Polycondensation Reaction

r			1			
Functional Uni	Functional Unit: Forced circulation evaporation of Nylon salt					
Intended Func	Intended Function: evaporate water and 1, 6-hexanediamine from Nylon salt					
Guideword	Deviation Possible Causes Consequences Required Action(s					
NO	NO flow of	Pump motor	Water and 1, 6-	Shut down pump,		
	Therminol XP	malfunction	hexanediamine do	start-up spare		
			not evaporate from	pump		
			Nylon salt			
MORE	MORE temperature	Fouling or plugging	Large water and 1,	Clean tubes		
		in the hot oil loop	6-hexanediamine			
			carryover			
LESS	LESS temperature	High Therminol XP	Pressure build-up	Decrease		
		flow	in the evaporator	Therminol XP flow		

Table 13: HAZOP for Evaporation

Table 14: HAZOP for Polymerization Reaction

	Tuble 14. The for Formenzation Reaction					
Functional Uni	Functional Unit: Polymerization reaction of Nylon salt to form Nylon 6 6					
Intended Func	Intended Function: evaporate remaining water from Nylon salt					
Guideword	Deviation	Possible Causes Consequences Required Act				
NO	NO steam flow	Steam FICV (Flow	Viscosity of Nylon	Emergency		
		Indicator Control	increases, plugging	shutdown, clean		
		Valve) closed	in the lines	the lines		
MORE	MORE temperature	Fouling in the	Water carryover in	Temperature		
		steam lines	the Nylon 6 6	Indicator		
			product	installation		
LESS	LESS inlet flow rate	Large water	Temperature is not	Decrease the flow		
		carryover in feed	hot enough to	rate of the inlet		
		from evaporator	evaporate water	stream using FICV		
AS WELL AS	Contaminants AS	Poor water	Corrosive steam	Send steam to		
	WELL AS feed	treatment		waste water		
	water					

Functional Un	Functional Unit: Flash drum separation of water and 1, 6-hexanediamine					
Intended Fund	Intended Function: separate water and 1, 6-hexanediamine					
Guideword	Deviation	Possible Causes Consequences Required Actio				
NO	NO level in flash	Massive leak from	Fire resulting from	Install leak proof		
	drum	drum	combustion	seals		
MORE	MORE temperature	N/A	1, 6-	Sample point of		
			hexanediamine	effluent water sent		
			carryover in water	to waste water		
			sent to waste			
			treatment			
LESS	LESS temperature	Smaller feed	Fire resulting from	Increase the feed		
		flowrate	combustion	flowrate using FICV		
REVERSE	REVERSE flow	High back pressure	Explosion resulting	Pressure relief		
			from pumping 1, 6-	valve relieves		
			hexanediamine	pressure		
			into drum			

Table 15: HAZOP for Flash Drum

The environmental perspective from HSE includes having a systematic approach for obeying environmental regulations, such as managing waste or air emissions to help plant sites reduce the company's carbon footprint. The negative impacts of chemical atmospheric releases applied in locust control programs include the risk of mortality of organisms and soil and surface water contamination. Risk is a function of the toxicity of the chemical release to atmosphere; the toxicity, severity of exposure, and its length shown by:

Risk = Toxicity x Severity of Exposure x Exposure Length

The degree of toxicity can either be acute or chronic. The development and symptoms of acute toxicity are revealed after short-term exposure to the chemical, which is more likely to affect employees who are cleaning equipment with potential chemical residue. However, chronic toxicity symptoms are experienced after a longer chemical exposure, such as those who have been around the chemicals for many years. Of course, the more toxic a chemical is (either acutely or chronically), the higher the potential risk will be. For this process, both ADA and HMDA are toxic, therefore, would not be open to atmosphere when sent to the first reactor. As a crystalline powder, it is easier to inhale and therefore needs to be closed off. The severity, or amount, of exposure is dependent on the atmospheric release rate and the amount of release vents within a near proximity. The length of the exposure is significantly influenced by the time period the chemical that is released to atmosphere [16].

There are several areas of concern that need to be addressed to have an environmentally efficient process. Water conservation and water quality are the most important aspects of a process in the sense of cost efficiency. Through wastewater treatment, all water throughout the system can be recycled by removing as much of the diamine as possible. The wastewater treatment will remove 60 % of contaminants from the wastewater, allowing oxygen back into the fluid. The second part of wastewater treatment will remove to rest of the potential solids and contaminants. Wastewater treatment needs to

be performed because it is very crucial from an industrial perspective because if wastewater is not properly treated, then the environment and human health can be negatively impacted such as oxygen depletion and off-specification Nylon 6 6 production [17].

The amount that was sent to wastewater treatment came from a flash drum, V-101, which separated diamine and water. Also, the second reactor, R-102, evaporated a small amount of water that needed to be treated, as well. The time required to treat the water was approximately 24 hours. It was then recycled back to be reused in the production of Nylon 6 6. In addition, any surface water such as process spills and storm water resulting from rain requires treatment due to possible accumulation from surrounding parking lots, roads, buildings, and soil.

Flares should be utilized throughout this process to provide an environmentally safe option for releasing the vapor from relief valves. Instead of direct release into the atmosphere, vapors from relief valves will be sent to a gas flare to keep air emissions and ambient air quality environmentally safe. Each pressurized vessel has its own flare for that unit, so the different released vapors at each pressurized vessel are not combined with different chemical vapors. Flares are determined to be the best option because they will safely burn excess hydrocarbon gases that cannot be recycled. By burning the excess hydrocarbon gases in the flare systems, water vapor and carbon dioxide will be produced and released to atmosphere, proving to be the more environmentally safe option. Any blowdown, at roughly 2% to 20% open, will also be vented to a flare to reset valve and limit environmental exposure. It is expected that there will occasionally be some product that does not meet all the specifications required to be able to sell to a customer. In preparation of having Nylon 6 6 produced that does not meet the specification requirements, such as having a lower molecular weight, it will be initially sought to find a source that can reclaim or reformulate the off-specification chemical. Nylon 6 6 is only classified as hazardous waste if it is not able to be reclaimed for its original purpose. However, if it will be used to produce a fuel or burned as one then they are wastes and are subject to the hazardous waste requirements.

It is crucial to keep the public informed about possible environmental laws before, after, and during the chemical process. This is to ensure that every precautionary measure is taken to reduce possible misunderstandings that may exist about the risks of a process.

Process controllability and instrumentation

Process controllability and instrumentation is one of the most important aspects of chemical process operability, because it can be used to assess the attainable operation of a given process and improve its dynamic performance.

As the pressure within a system increases, the probability of a potential leak or rupture increases as well, but the exact fail point is determined based off system design. If a sudden pressure rise does occur, such as an internal deflagration, hazardous material with be exposed to the air due to rupture of an over-pressurized vessel. However, piping and vessels can be designed for the over-pressurized system. The overall process is designed to withstand the maximum over-pressurization that could be generated by a process upset. The process equipment for this system was built at design pressure which was 50 psia above operating pressure. Therefore, even in the case of a process upset, there is a range that allowed operations to continue.

The process design included pressure relief valves which were used to control the pressure in a piece of equipment system so it does not build up and cause process upset or equipment failure. The pressure

valve will release pressure by allowing the pressurized fluid to flow out of the system. When the set pressure is exceeded, the relief valve is designed to open to a specific degree for a portion of the flow to be released to protect the pressure vessels from the limitations of their design. The relief valve will be routed through a piping system, a flare header, where hydrocarbons will be burned to produce water vapor and carbon dioxide. Bypass valves are external are also incorporated into the design and act as a relief valve to return the fluid discharged by a pump back to the inlet of the pump to protect the pump from extreme pressure. The bypass valve and bypass path are external and will be installed in the same path as the fluid flow.

It was determined that the designed temperature for the centrifugal pumps will stay relatively constant throughout the production of Nylon 6 6. Since this process is an endothermic reaction, if temperature change were to occur, it would only decrease in temperature. This feature significantly decreases the possibility of cavitation from occurring in the centrifugal pumps due to a temperature increase. Additionally, since medium and high pressure steam are used throughout the process, vacuum relief valves were not utilized to add either air into the equipment to control the degree of vacuum. Different emergency devices are required for this process such as relief vents and rupture disks. Rupture discs will be installed in series at the inlet of a relief valve on all pressurized vessels throughout the process. Rupture discs will be used with safety relief valves, and by isolating the valves from the process the plant will be able to save on valve maintenance and creating a pressure relief that is leak-resistant. The rupture disc acts as a barrier between the process and the valve and protects vessels from overpressurization. Rupture disc help increase or decrease the system pressure, but is not resealed after it has been broken. The process is free of equipment comprising of fluids that would react process fluid. Additionally, a primary reason for rupture discs to be installed in series with relief valves is to have minimal process release into the atmosphere. This meets EPA regulations and saves the site unnecessary costs. It also allows for valve's internals to be protected and minimally exposed to process contamination and, therefore, allowing longer periods between significant repairs. There is a pressure transmitter and vent between the rupture disc and relief valve will have continuous readings shown in the DCS system in the control room on site. There will be an automatic bleeder installed with every pressure indicator in addition to an excess flow check valve and pressure alarm. The pressure alarm will go off at when needed within the DCS system as well [18].

All discharges from vents, relief valves, and rupture disks will be located and sampled every 3 days to ensure all hazards are avoided and all process specifications are being maintained. Flare arrestors will be installed near the vents of the relief valves to allow vapor to pass through, but as a safety precaution, will stop a flame to prevent an incident involving a large fire or explosion from occurring. Incorporating flare arrestors into the process is crucial because it provides a layer of protection for equipment near piping and storage tanks, while significantly reducing the amount of catastrophic damage that may occur. In the detailed design phase, vents from relief devices routed to a safe location. All flare, blowdown, and off-gas system are capable of handling overpressure events, such as loss utilities and debottlenecking [19].

Emergency shut-down block valves are incorporated into the process and are placed at the discharge of tanks. They are usually the automatic standard block valves to meet process objectives. The valve, operator, and control cables are covered with insulation, so in an emergency, these valves would respectively close, or block the process, and plant site would shut down. This is primarily directed towards an emergency condition location and to those tanks or equipment whose contents have higher levels or hazards, such as the reaction vessels at this site. An automatic block valve is the first layer of

protection and once the alarm condition of high hazardous level of material is reached, the valve is shut by means through the DCS.

However, it is impractical to install emergency isolation valves to isolate every piece of equipment unless the possibility of a leak is significant or has potential serious consequences. The chemicals that are used throughout this process, HMDA and ADA, are a non-flammable component and have a low flammability level, respectively. Additionally, they have a longer chain length, and thereby are less volatile, resulting in an insignificant possibility of an explosive incident to occur.

Controls valves will react to a loss of control medium by increases head removal, such as increasing reflux, quench, and cooling water flow. There would be a reduction in pressure through open vents and slower turbine speeds. Over-pressurizing equipment and blowby were avoided by maintaining liquid level to avoid overcooling. Provisions in the preliminary design account for equipment failures and the fail-safe positions for each piece of equipment. Fail-safe position are predetermined positions that ultimately positioned to cause and provide minimal harm to other equipment, the environment, and the surrounding citizens. Many types of failures are possible within a plant setting; therefore, effective analysis for treating the failures was used for the following design.

The entire process contained equipment that was fail-safe, so if the plant lost power and all the equipment failed simultaneously, the process would shut down and turn to fail-safe positions because electricity was used and heat was needed for the process to proceed. All control valves will have the fail-safe position of fail-close to minimize any process fluid from traveling further through the system. All cooling water and air control valves would be fail-open to help minimize the destruction of the incident [20].

A Distributed Control System (DCS) is a control system within an operating room on plant site that contains a central location computerized control room for all the control system readings throughout the plant for operator observation. A central location for all control valve readings provide easier access for monitoring and supervising the overall process.

If sensor transmitters, indicators, alarms were faulty it would be detected through the DCS interface. The DCS control system will minimize deviations within an acceptable range in order to minimize any typographical error. The DCS interface in the operating room will provide backups for all outputs.

Most control system will be managed through the DCS interface, but all equipment can be manually changed as well on the chance the interface goes down. This is designed and compensated for by having manual pressure and temperature gauges next to the temperature and pressure indicators so operators can physically take measurements on the plant site until the equipment is secured once again.

Starting up a chemical plant has multiple steps. Initially, the preliminary design needs to be completed before the detailed design, procurement, assembly, precommissioning, and startup can take place. Every step in the startup process has its own significant role that leads to the success of a process.

Before startup can occur, the plant site must be inspected to ensure equipment specification and P&IDs in the detailed design are consistent. Prior to startup, mistakes are more likely to be fixed rather than after the process is already taking place. Different areas of inspection that need to be considered are: safety aspects, process vessels, instrumentation, and piping.

After the different forms of equipment have been examined and approved for startup, the commissioning of utilities (such as steam, cooling water, and air) need to be inspected next. All the process utilities must be put into service prior to inspection. Pipelines near the first reactor that will be utilizing steam should be heated up through high-pressure steam used in this process and cooled down several times. Cooling water lines should be flushed one at a time with cooling water through condensers and pumps, and instrument air lines must be blown through with instrument air.

Prior to start up, all pipelines and equipment must be cleaned through air blowing or water power flushing to remove any material that has been left behind during the construction phase, such as debris. If debris is left within pipeline and equipment, contamination may occur, which can eventually lead to clogging of piping or control valves, and equipment failure. The process vessels require thorough cleaning to prevent contamination of Nylon 6 6 production and ensure conversion of the reaction.

The next step that needs to be taken is the calibration of equipment, such as level indicators on the pressure vessels which are used to determine the relationship between measured and actual process values. Additionally, all process vessels have the potential to leak, which would result in damage and economic loss. To minimize the possibility of this occurring, it is crucial to carry out a tightness test before startup, such as the air or nitrogen bubble test. The test should take place on one area of the process at a time to identify any leaks. Formation of miniature bubbles during leaking connections should be tightened until bubbles disappear. Besides technical issues, successful written procedures and emphasis on safety are needed to minimize accidents and are the final elements needed to have an effective startup for this process [21].

XI. Manufacturing Costs

The operating factors for the process include, utilities, manufacturing, raw materials, and operations which are outlined in Table 17.

Cost Factor	Typical Factor
Feedstocks (raw materials)	
Hexamethyldiamine	\$2.50/kg
ADA	\$1.50/kg
Water	\$0.08/kg
Utilities	
Steam, 600 psig	\$4.75/1000 kg
Electricity (Calvert City, KY)	\$0.0545/kW
Cooling Water	\$120/annual gpm
Process Water	\$0.08/kg
Hot Oil	\$37.09/gal
Wastewater Treatment	\$0.15/lb organic material
Operations (labor-related)	
Operating Laborers	4.5(Operators/shift)
Labor Cost	\$64.690(operating laborers)
Direct Supervisory and Clerical Labor	\$35/operator hour
Maintenance and repairs	0.06 <i>C</i> _{TM}
Operating Supplies	0.009 <i>C</i> _{TM}
Operating Overhead	
Local Taxes and Insurance	0.032 <i>C</i> _{TM}
General plant overhead	0.036 <i>C_{TM}</i> +0.708 <i>C_{OL}</i>
Administrative expense	.009 <i>C_{TM}</i> +0.177 <i>C</i> _{OL}

Table 16: Operation Pricing Factors

After utilizing the operation costing factors, in addition to flow rates and consumption of utilities, the annual utility costs were calculated in Tables 18-24.

Tuble 17. Operating costs in co	intinuous i cilcuzcu siinulution
Utility	Cost
High Pressure Steam	\$22,500
Cooling Water	\$295,800
Hot Oil (Therminol XP)	\$4,080
Electricity	\$110,500
Total	\$432,880

Table 17: Operating Costs in Continuous Pelletized Simulation

Utility	Cost
High Pressure Steam	\$22,500
Cooling Water	\$295,800
Hot Oil (Therminol XP)	\$4,080
Electricity	\$119,100
Total	\$441,480

Table 18: Operating Costs in Continuous Spun Simulation

Table 19: Operating Costs in Batch Pelletized Simulation

Utility	Cost
High Pressure Steam	\$22,500
Cooling Water	\$295,800
Hot Oil (Therminol XP)	\$4,080
Electricity	\$110,500
Total	\$432,880

Table 20: Operating Costs in Batch Spun Simulation

Utility	Cost
High Pressure Steam	\$22,500
Cooling Water	\$295,800
Hot Oil (Therminol XP)	\$4,080
Electricity	\$119,100
Total	\$441,480

Table 21: Manufacturing and Other Operating Costs

	1 3
Manufacturing Costs	Cost
Waste Treatment	\$31,500
Direct Supervisory	\$1,609,000
Maintenance and Repairs	\$536,000
Operating Supplies	\$80,500
Local Taxes and Insurance	\$286,000
Plant Overhead Costs	\$909,000
Administration Cost	\$227,000
Operating Labor	\$830,000
Total/yr	\$4,510,000

Unit	R-101	E-101	R-102	A-101	T-101	E-102	V-101
Name	CSTR	Evaporator	CSTR	Extruder	Storage Tank	Condenser	Flash Drum
HPS (1000/lb)	\$22,500	-	-	-	-	-	-
Therminol XP	-	\$4,080	-	-	-	-	-
(gal)							
CW (gpm)	-	-	-	-	-	\$295,900	-
Electricity (kW)	\$18,900	-	\$14,900	\$27,100	-	-	-
Unit	T-102	P-101	P-102	P-103	P-104	P-105	A-102
Name	Storage Tank	Pump	Pump	Pump	Pump	Pump	Spinneret
HPS	-	-	-	-	-	-	-
Therminol XP	-	-	-	-	-	-	-
Cooling Water	-	-	-	-	-	-	-
Electricity	-	\$5,100	\$170	\$170	\$25,400	\$5,100	\$13,160

Table 22: Utility Usage Batch Process

Unit	R-101	E-101	R-102	A-101	T-101	E-102	V-101
Name	CSTR	Evaporator	CSTR	Extruder	Storage Tank	Condenser	Flash Drum
HPS (1000/lb)	\$22,500	-	-	-	-	-	-
Therminol XP	-	\$4,080	-	-	-	-	-
(gal)							
CW (gpm)	-	-	-	-	-	\$295,900	-
Electricity (kW)	\$18,900	-	\$14,900	\$27,100	-	-	-
Unit	T-102	P-101	P-102	P-103	P-104	P-105	A-102
Name	Storage Tank	Pump	Pump	Pump	Pump	Pump	Spinneret
HPS	-	-	-	-	-	-	-
Therminol XP	-	-	-	-	-	-	-
Cooling Water	-	-	-	-	-	-	-
Electricity	-	\$5,100	\$170	\$170	\$25,400	\$5,100	\$13,160

Table 23: Utility Usage for Continuous Process

XII. Economic Analysis

When performing economic analysis on each of the five scenarios, the following cash flow tables were produced for each of the cases and are presented below in Figures 7-11.

				Continu	ous Process, Pe	llet			-		
End of Year	0	1	2	3	4	5	6	7	8	9	10
Sale Price of Spun Nylon 6,67 (kg)		\$ 2.50	\$ 2.50	\$ 2.50	\$ 2.50	\$ 2.50	\$ 2.50	\$ 2.50	\$ 2.50	\$ 2.50	\$ 2.50
Amount of Nylon 6,6 (kg/yr)		18,357,678	36,715,357	36,715,357	36,715,357	36,715,357	36,715,357	36,715,357	36,715,357	36,715,357	36,715,357
Sale Price of 1,6 Hexanediamine/(kg)		\$ 1.19	\$ 1.19			\$ 1.19	\$ 1.19	\$ 1.19	\$ 1.19	\$ 1.19	\$ 1.19
Amount of 1,6 Hexanediamine (kg/yr)		1,518,109.64	3,036,219.29	3,036,219.29	3,036,219.29	3,036,219.29	3,036,219.29	3,036,219.29	3,036,219.29	3,036,219.29	3,036,219.29
Sales Revenue	-	47,700,746	95,401,493	95,401,493	95,401,493	95,401,493	95,401,493	95,401,493	95,401,493	95,401,493	95,401,493
+ Salvage Value											
 Royalties ("basis") 			-			-		-		-	-
Net Revenue		47,700,746	95,401,493	95,401,493	95,401,493	95,401,493	95,401,493	95,401,493	95,401,493	95,401,493	95,401,493
 Raw Material Costs 		(41,364,489)	(82,728,978)	(82,728,978)	(82,728,978)	(82,728,978)	(82,728,978)	(82,728,978)	(82,728,978)	(82,728,978)	(82,728,978)
 Other Op Costs 											
Cooling Water		(147,936)	(295,871)	(295,871)	(295,871)	(295,871)	(295,871)	(295,871)	(295,871)	(295,871)	(295,871)
Electricity		(55,261)	(110,523)	(110,523)	(110,523)	(110,523)	(110,523)	(110,523)	(110,523)	(110,523)	(110,523)
Low Pressure Steam		(22,507)	(22,507)	(22,507)	(22,507)	(22,507)	(22,507)	(22,507)	(22,507)	(22,507)	(22,507)
- Operating Labor		(415,016)	(830,032)	(830,032)	(830,032)	(830,032)	(830,032)	(830,032)	(830,032)	(830,032)	(830,032)
 Other Manufacturing Costs 		(1,824,309)	(3,648,617)	(3,648,617)	(3,648,617)	(3,648,617)	(3,648,617)	(3,648,617)	(3,648,617)	(3,648,617)	(3,648,617)
Depreciation		(634,599.83)	(2,284,559.38)	(1,827,647.50)	(1,462,118.00)	(1,170,202.08)	(935,400.15)	(831,325.77)	(831,325.77)	(832,594.97)	(831,325.77)
MACRS IOgr		a)	a.18	a 144	a.1152	0.0322	0.0737	0.0655	0.0655	0.0656	0.0655
Waste Treatment		(15,752)	(31,504)	(31,504)	(31,504)	(31,504)	(31,504)	(31,504)	(31,504)	(31,504)	(31,504)
· Writeoff		-			-		-	-	-	-	
Tazable Income		3,220,877	5,448,901	5,905,813	6,271,343	6,563,259	6,798,061	6,902,135	6,902,135	6,900,866	6,902,135
• Tax @ 40%		(1,288,351)	(2,179,561)	(2,362,325)	(2,508,537)	(2,625,304)	(2,719,224)	(2,760,854)	(2,760,854)	(2,760,346)	(2,760,854)
Net Income		1,932,526	3,269,341	3,543,488	3,762,806	3,937,955	4,078,836	4,141,281	4,141,281	4,140,520	4,141,281
 Depreciation 		634,600	2,284,559	1,827,648	1,462,118	1,170,202	935,400	831,326	831,326	832,595	831,326
+ Writeoff											
 Working Capital 		-	-		-	-	-		-		-
 Fixed Capital 	(12,691,997)		-		-	-	-				
Cash Flow	(12,691,997)	2,567,126	5,553,900	5,371,136	5,224,924	5,108,157	5,014,237	4,972,607	4,972,607	4,973,115	4,972,607
Discount Factor (P/Fi,,)	1.0000	0.8696	0.7561	0.6575	0.5718	0.4972	0.4342	0.3759	0.3269	0.2843	0.2843
Discounted Cash Flow	(12,691,997)	2,232,373	4,199,304	3,531,522	2,987,611	2,539,776	2,177,182	1,869,203	1,625,545	1,413,856	1,413,712
NP¥ @i'=	11,298,087										
PVC	(253,326,574)										
DCFROR=	34%										

Figure 8: Economic Analysis for Continuous Pellet Process

				Continu	ous Process, Spu	IN					
End of Year	0	1	2	3	4	5	6	7	8	9	10
Sale Price of Spun Nylon 6,67 (kg)		\$ 4.15	\$ 4.15	\$ 4.15	\$ 4.15	\$ 4.15	\$ 4.15	\$ 4.15	\$ 4.15	\$ 4.15	\$ 4.15
Amount of Nylon 6,6 (kg/yr)		18,357,678	36,715,357	36,715,357	36,715,357	36,715,357	36,715,357	36,715,357	36,715,357	36,715,357	36,715,357
Sale Price of 1,6 Hexanediamine/(kg)		\$ 1.19									
Amount of 1,6 Hexanediamine (kg/yr)		1,518,109.64	3,036,219.29	3,036,219.29	3,036,219.29	3,036,219.29	3,036,219.29	3,036,219.29	3,036,219.29	3,036,219.29	3,036,219.29
Sales Revenue		77,990,916	155,981,831	155,981,831	155,981,831	155,981,831	155,981,831	155,981,831	155,981,831	155,981,831	155,981,831
+ Salvage Value					-		-	-			-
 Royalties ("basis") 					-					-	-
Net Revenue		77,990,916	155,981,831	155,981,831	155,981,831	155,981,831	155,981,831	155,981,831	155,981,831	155,981,831	155,981,831
Raw Material Costs		(41,364,489)	(82,728,978)	(82,728,978)	(82,728,978)	(82,728,978)	(82,728,978)	(82,728,978)	[82,728,978]	(82,728,978)	(82,728,978)
 Other Op Costs 					-		-	-		-	
Cooling Water		(147,936)	(295,871)	(295,871)	(295,871)	(295,871)	(295,871)	(295,871)	(295,871)		(295,871)
Electricity		(66,521)	(133,043)	(133,043)	(133,043)	(133,043)	(133,043)	(133,043)	(133,043)	(133,043)	(133,043)
Low Pressure Steam		(11,254)	(22,507)	(22,507)	(22,507)	(22,507)	(22,507)	(22,507)	(22,507)		(22,507)
- Operating Labor		(415,016)	(830,032)	(830,032)	(830,032)	(830,032)	(830,032)	(830,032)	(830,032)	(830,032)	(830,032)
 Other Manufacturing Costs 		(1,874,748)	(3,749,496)	(3,749,496)	(3,749,496)	(3,749,496)	(3,749,496)	(3,749,496)	(3,749,496)	(3,749,496)	(3,749,496)
Depreciation		(650,771.66)	(2,342,777.96)	(1,874,222.37)	(1,499,377.90)	(1,200,022.93)	(959,237.42)	(852,510.87)	(852,510.87)	(853,812.41)	(852,510.87)
MACRS I0 yr		ai	0.18	Q.144	Q.1152	0.0322	0.0737	0.0655	0.0655	0.0656	0.0655
 Waste Treatment 		(15,752)	(31,504)	(31,504)	(31,504)	(31,504)	(31,504)	(31,504)	(31,504)	(31,504)	(31,504)
· Writeoff								-			-
Tazable Income		33,444,428	65,847,622	66,316,178	66,691,022	66,990,377	67,231,163	67,337,889	67,337,889	67,336,588	67,337,889
• Tax @ 40%		(13,377,771)	(26,339,049)	(26,526,471)	(26,676,409)	(26,796,151)	(26,892,465)	(26,935,156)	(26,935,156)	(26,934,635)	(26,935,156)
Net Income		20,066,657	39,508,573	39,789,707	40,014,613	40,194,226	40,338,698	40,402,734	40,402,734	40,401,953	40,402,734
+ Depreciation		650,772	2,342,778	1,874,222	1,499,378	1,200,023	959,237	852,511	852,511	853,812	852,511
+ Writeoff					-		-	-			-
 Working Capital 											
 Fixed Capital 	(13,015,433)	-	-								-
Cash Flow	(13,015,433)	20,717,429	41,851,351	41,663,929	41,513,991	41,394,249	41,297,935	41,255,245	41,255,245	41,255,765	41,255,245
Discount Factor (P/Fi,,)	1.0000	0.8696	0.7561	0.6575	0.5718	0.4972	0.4342	0.3759	0.3269	0.2843	0.2843
Discounted Cash Flow	(13,015,433)	18,015,876	31,643,807	27,394,033	23,737,700	20,581,221	17,931,563	15,507,846	13,486,339	11,729,014	11,728,866
NPV @i'=	178,740,833										
PVC	(253,927,442)										
DCFROR=	211%										

Figure 9: Economic Analysis for Continuous Spun Process

				Batch Pro	ocess, Pellet						
End of Year	0	1	2	3	4	5	6	7	8	9	10
Sale Price of Spun Nylon 6,67 (kg)		\$ 2.50	\$ 2.50	\$ 2.50	\$ 2.50	\$ 2.50	\$ 2.50	\$ 2.50	\$ 2.50	\$ 2.50	\$ 2.50
Amount of Nylon 6,6 (kg/yr)		18,357,678	36,715,357	36,715,357	36,715,357	36,715,357	36,715,357	36,715,357	36,715,357	36,715,357	36,715,357
Sale Price of 1,6 Hexanediamine/(kg)		\$ 1.19	\$ 1.19	\$ 1.19	\$ 1.19	\$ 1.19	\$ 1.19	\$ 1.19	\$ 1.19	\$ 1.19	\$ 1.19
Amount of 1,6 Hexanediamine (kg/yr)		1,518,109.64	3,036,219.29	3,036,219.29	3,036,219.29	3,036,219.29	3,036,219.29	3,036,219.29	3,036,219.29	3,036,219.29	3,036,219.29
Sales Revenue		47,700,746	95,401,493	95,401,493	95,401,493	95,401,493	95,401,493	95,401,493	95,401,493	95,401,493	95,401,493
+ Salvage Value											
 Royalties ("basis") 			-		-		-	-	-	-	-
Net Revenue		47,700,746	95,401,493	95,401,493	95,401,493	95,401,493	95,401,493	95,401,493	95,401,493	95,401,493	95,401,493
 Raw Material Costs 		(41,364,489)	(82,728,978)	(82,728,978)	(82,728,978)	(82,728,978)	(82,728,978)	(82,728,978)	(82,728,978)	(82,728,978)	(82,728,978)
 Other Op Costs 					-	-				-	
Cooling Water		(147,936)	(295,871)	(295,871)	(295,871)	(295,871)	(295,871)	(295,871)	(295,871)	(295,871)	(295,871)
Electricity		(59,561)	(119,121)	(119,121)	(119,121)	(119,121)	(119,121)	(119,121)	(119,121)	(119,121)	(119,121)
Low Pressure Steam		(11,254)	(22,507)	(22,507)	(22,507)	(22,507)	(22,507)	(22,507)	(22,507)	(22,507)	(22,507)
- Operating Labor		(415,016)	(830,032)	(830,032)	(830,032)	(830,032)	(830,032)	(830,032)	(830,032)	(830,032)	(830,032)
 Other Manufacturing Costs 		(2,237,670)	(4,475,340)	(4,475,340)	(4,475,340)	(4,475,340)	(4,475,340)	(4,475,340)	(4,475,340)	(4,475,340)	(4,475,340)
Depreciation		(815,125.74)	(2,934,452.67)	(2,347,562.14)	(1,878,049.71)	(1,503,091.87)	(1,201,495.34)	(1,067,814.72)	(1,067,814.72)	(1,069,444.97)	(1,067,814.72)
MACRS I0 ju		a)	a.18	Q.144	a 1152	0.0922	0.0737	0.0655	0.0655	0.0656	0.0655
 Waste Treatment 		(15,752)	(31,504)	(31,504)	(31,504)	(31,504)	(31,504)	(31,504)	(31,504)	(31,504)	(31,504)
· Writeoff			-		-	-			-		
Tazable Income		2,633,944	3,963,687	4,550,577	5,020,090	5,395,048	5,696,644	5,830,325	5,830,325	5,828,695	5,830,325
- Tax @ 40%		(1,053,578)	(1,585,475)	(1,820,231)	(2,008,036)	(2,158,019)	(2,278,658)	(2,332,130)	(2,332,130)	(2,331,478)	(2,332,130)
Net Income		1,580,366	2,378,212	2,730,346	3,012,054	3,237,029	3,417,987	3,498,195	3,498,195	3,497,217	3,498,195
 Depreciation 		815,126	2,934,453	2,347,562	1,878,050	1,503,092	1,201,495	1,067,815	1,067,815	1,069,445	1,067,815
 Writeoff 		-			-	-	-		-	-	
 Working Capital 					-	-				-	
 Fixed Capital 	(16,302,515)				-				-		-
Cash Flow	(16,302,515)	2,395,492	5,312,665	5,077,909	4,890,104	4,740,121	4,619,482	4,566,010	4,566,010	4,566,662	4,566,010
Discount Factor (P/F _{i,*})	1.0000	0.8696	0.7561	0.6575	0.5718	0.4972	0.4342	0.3759	0.3269	0.2843	0.2843
Discounted Cash Flow	(16,302,515)	2,083,120	4,016,906	3,338,725	2,796,161	2,356,788	2,005,779	1,716,363	1,492,629	1,298,302	1,298,117
NPV @i'=	6,100,374										
PVC	(258,530,158)										
DCFROR=	23%										

Figure 10: Economic Analysis for Batch Pellet Process

				Batch	Process, Spun						
End of Year	0	1	2	3	4	5	6	7	8	9	10
Sale Price of Spun Nylon 6,67 (kg)		\$ 4.15	\$ 4.15	\$ 4.15	\$ 4.15	\$ 4.15	\$ 4.15	\$ 4.15	\$ 4.15	\$ 4.15	\$ 4.15
Amount of Nylon 6,6 (kg/yr)		18,357,678	36,715,357	36,715,357	36,715,357	36,715,357	36,715,357	36,715,357	36,715,357	36,715,357	36,715,357
Sale Price of 1,6 Hexanediamine/(kg)		\$ 1.19	\$ 1.19	\$ 1.19	\$ 1.19	\$ 1.19	\$ 1.19	\$ 1.19	\$ 1.19	\$ 1.19	\$ 1.19
Amount of 1,6 Hexanediamine (kg/yr)		1,518,109.64	3,036,219.29	3,036,219.29	3,036,219.29	3,036,219.29	3,036,219.29	3,036,219.29	3,036,219.29	3,036,219.29	3,036,219.29
Sales Revenue		77,990,916	155,981,831	155,981,831	155,981,831	155,981,831	155,981,831	155,981,831	155,981,831	155,981,831	155,981,831
+ Salvage Value			-				-		-		
 Royalties ("basis") 		-	-		-	-	-		-	-	
Net Revenue		77,990,916	155,981,831	155,981,831	155,981,831	155,981,831	155,981,831	155,981,831	155,981,831	155,981,831	155,981,831
Raw Material Costs		(41,364,489)	(82,728,978)	(82,728,978)	(82,728,978)	(82,728,978)	(82,728,978)	(82,728,978)	(82,728,978)	(82,728,978)	(82,728,978)
 Other Op Costs 		-	-				-		-		
Cooling Water		(147,936)	(295,871)	(295,871)	(295,871)	(295,871)	(295,871)	(295,871)	(295,871)	(295,871)	(295,871)
Electricity		(55,261)	(110,523)	(110,523)	(110,523)	(110,523)	(110,523)	(110,523)	(110,523)	(110,523)	(110,523)
Low Pressure Steam		(11,254)	(22,507)	(22,507)	(22,507)	(22,507)	(22,507)	(22,507)	(22,507)	(22,507)	(22,507)
- Operating Labor		(415,016)	(830,032)	(830,032)	(830,032)	(830,032)	(830,032)	(830,032)	(830,032)	(830,032)	(830,032)
 Other Manufacturing Costs 		(1,824,309)	(3,648,617)	(3,648,617)	(3,648,617)	(3,648,617)	(3,648,617)	(3,648,617)	(3,648,617)	(3,648,617)	(3,648,617)
Depreciation		(831,297.57)	(2,992,671.25)	(2,394,137.00)	(1,915,309.60)	(1,532,912.72)	(1,225,332.62)	(1,088,999.82)	(1,088,999.82)	(1,090,662.41)	(1,088,999.82)
MACRS I0 yr		@1	0.18	0.144	0.1152	0.0322	0.0737	0.0655	0.0655	0.0656	0.0655
 Waste Treatment 		(15,752)	(31,504)	(31,504)	(31,504)	(31,504)	(31,504)	(31,504)	(31,504)	(31,504)	(31,504)
 Vriteoff 		-	-			-	-		-	-	
Tazable Income		33,325,602	65,321,128	65,919,663	66,398,490	66,780,887	67,088,467	67,224,800	67,224,800	67,223,137	67,224,800
• Tax @ 40%		(13,330,241)	(26,128,451)	(26,367,865)	(26,559,396)	(26,712,355)	(26,835,387)	(26,889,920)	(26,889,920)	(26,889,255)	(26,889,920)
Net Income		19,995,361	39,192,677	39,551,798	39,839,094	40,068,532	40,253,080	40,334,880	40,334,880	40,333,882	40,334,880
+ Depreciation		831,298	2,992,671	2,394,137	1,915,310	1,532,913	1,225,333	1,089,000	1,089,000	1,090,662	1,089,000
+ Writeoff		-	-				-		-		
 Working Capital 							-		-		
 Fixed Capital 	(16,625,951)						-		-		
Cash Flow	(16,625,951)	20,826,659	42,185,348	41,945,935	41,754,404	41,601,445	41,478,413	41,423,880	41,423,880	41,424,545	41,423,880
Discount Factor (P/Fi,,)	1.0000	0.8696	0.7561	0.6575	0.5718	0.4972	0.4342	0.3759	0.3269	0.2843	0.2843
Discounted Cash Flow	(16,625,951)	18,110,863	31,896,342	27,579,452	23,875,168	20,684,238	18,009,927	15,571,236	13,541,466	11,776,998	11,776,809
NPY @i'=	176,196,548										
PVC	(256,471,728)										
DCFROR=	172%										

Figure 11: Economic Analysis for Batch Spun Process

				67% Continu	ous Process, Pe	llet					
End of Year	0	1	2	3	4	5	6	7	8	9	10
Sale Price of Spun Nylon 6,67 (kg)		\$ 4.15	\$ 4.15	\$ 4.15	\$ 4.15	\$ 4.15	\$ 4.15	\$ 4.15	\$ 4.15	\$ 4.15	\$ 4.15
Amount of Nylon 6,6 (kg/yr)		12,299,645	24,599,289	24,599,289	24,599,289	24,599,289	24,599,289	24,599,289	24,599,289	24,599,289	24,599,289
Sale Price of 1,6 Hexanediamine/(kg)		\$ 1.19	\$ 1.19	\$ 1.19	\$ 1.19	\$ 1.19	\$ 1.19	\$ 1.19	\$ 1.19	\$ 1.19	\$ 1.19
Amount of 1,6 Hexanediamine (kg/yr)		1,017,133.46	2,034,266.92	2,034,266.92	2,034,266.92	2,034,266.92	2,034,266.92	2,034,266.92	2,034,266.92	2,034,266.92	2,034,266.92
Sales Revenue		52,253,914	104,507,827	104,507,827	104,507,827	104,507,827	104,507,827	104,507,827	104,507,827	104,507,827	104,507,827
+ Salvage Value			-								
 Royalties ("basis") 		-	-								-
Net Revenue		52,253,914	104,507,827	104,507,827	104,507,827	104,507,827	104,507,827	104,507,827	104,507,827	104,507,827	104,507,827
 Raw Material Costs 		(41,364,489)	(82,728,978)	(82,728,978)	(82,728,978)	(82,728,978)	(82,728,978)	(82,728,978)	(82,728,978)	(82,728,978)	(82,728,978)
 Other Op Costs 		-	-								-
Cooling Water		(147,936)	(295,871)	(295,871)	(295,871)	(295,871)	(295,871)	(295,871)	(295,871)	(295,871)	(295,871)
Electricity		(55,261)	(110,523)	(110,523)	(110,523)	(110,523)	(110,523)	(110,523)	(110,523)	(110,523)	(110,523)
Low Pressure Steam		(22,507)	(22,507)	(22,507)	(22,507)	(22,507)	(22,507)	(22,507)	(22,507)	(22,507)	(22,507)
- Operating Labor		(415,016)	(830,032)	(830,032)	(830,032)	(830,032)	(830,032)	(830,032)	(830,032)	(830,032)	(830,032)
 Other Manufacturing Costs 		(1,824,309)	(3,648,617)	(3,648,617)	(3,648,617)	(3,648,617)	(3,648,617)	(3,648,617)	(3,648,617)	(3,648,617)	(3,648,617)
Depreciation		(634,599.83)	(2,284,559.38)	(1,827,647.50)	(1,462,118.00)	(1,170,202.08)	(935,400.15)	(831,325.77)	(831,325.77)	(832,594.97)	(831,325.77)
MACRS I0 yr		@1	0.18	0.144	0.1152	0.0322	0.0737	0.0655	0.0655	0.0656	0.0655
 Waste Treatment 		(15,203)	(30,405)	(30,405)	(30,405)	(30,405)	(30,405)	(30,405)	(30,405)	(30,405)	(30,405)
 Writeoff 			-		-			•		-	-
Tazable Income		7,774,593	14,556,334	15,013,246	15,378,776	15,670,691	15,905,493	16,009,568	16,009,568	16,008,299	16,009,568
· Tax @ 40%		(3,109,837)	(5,822,534)	(6,005,298)	(6,151,510)	(6,268,277)	(6,362,197)	(6,403,827)	(6,403,827)	(6,403,319)	(6,403,827)
Net Income		4,664,756	8,733,800	9,007,948	9,227,265	9,402,415	9,543,296	9,605,741	9,605,741	9,604,979	9,605,741
+ Depreciation		634,600	2,284,559	1,827,648	1,462,118	1,170,202	935,400	831,326	831,326	832,595	831,326
+ Writeoff		-	-		-			•		-	-
 Working Capital 		-	-	-			-			-	-
Fixed Capital	(12,691,997)				-	-		•		-	-
Cash Flow	(12,691,997)	5,299,356	11,018,360	10,835,595	10,689,383	10,572,617	10,478,696	10,437,066	10,437,066	10,437,574	10,437,066
Discount Factor (P/Fi,,)	1.0000	0.8696	0.7561	0.6575	0.5718	0.4972	0.4342	0.3759	0.3269	0.2843	0.2843
Discounted Cash Flow	(12,691,997)	4,608,320	8,330,982	7,124,404	6,112,189	5,256,705	4,549,850	3,923,293	3,411,877	2,967,402	2,967,258
NP¥ @i'=	36,560,284										
PVC	(12,691,997)										
DCFROR=	67%										

Figure 12: Economic Analysis for 67% Continuous Pellet Process

Breakeven Analysis

The breakeven processing cost for each case is presented in Table 25, below. This is the minimum cost that the plant could sell the Nylon 6 6 for in order to breakeven. If the manufacturing plant would want to negotiate a long-term sales agreement, the lowest price that Nylon 6 6 could be sold for in the most optimum case, continuous operation to produce pellets, was \$2.39 because at this price, the NPV would be 0. Therefore, the company would not profit; however, long-term commitment from customers could be established.

Case	Breakeven Processing	Original Price [\$]	Difference [\$]	
	Cost of Nylon 6 6 [\$]			
Batch, pellet	\$2.42	\$2.50	\$0.08	
Batch, spun	\$2.41	\$4.15	\$1.74	
Continuous, pellet	\$2.39	\$2.50	\$0.11	
Continuous, spun	\$2.40	\$4.15	\$1.75	

Table 24: Breakeven Processing Cost for Manufacturing Nylon 6 6

Although the continuous process which produces pellets has the lowest breakeven processing cost, the selling price of spun Nylon 6 6 produced by continuous operation would decrease by \$1.75. Ultimately, purchase cost of spun Nylon 6 6 fibers would result in a better negotiation for the customer.

DCFROR Analysis

When performing further analysis on the five scenarios and performing a DCFROR analysis for each, it was evident that the continuous process with spun Nylon 6 6 produced the greatest rate of return with a DCFROR of 211%.

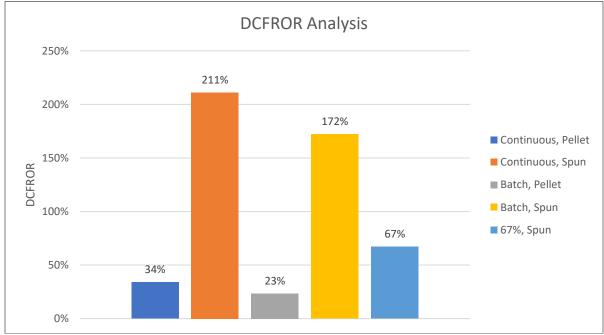


Figure 4: DCFROR Analysis

NPV Analysis

Similarly, when performing an NPV analysis on each of the five production scenarios, the continuous process with spun fibers of Nylon 6 6 still presented the greatest net present value of approximately \$178,000,000.

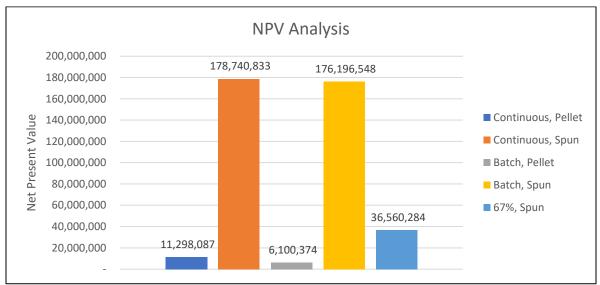


Figure 14: NPV Analysis

Payback Period Analysis

When performing a payback period analysis on the four processing methods, it was determined the continuous production of Nylon 6 6 fibers yielded the shortest payback period with a return on investment at 1.6 years.

TUDIE 25. FUYDUCK FETIDU							
Payback Period	Years						
Batch, pellet	5.18						
Batch, spun	1.57						
Continuous, pellet	3.84						
Continuous, spun	1.57						

Table	25:	Pa	vback	Period
rubic	20.	1 4	ybuck	i criou

Present Worth Cost Analysis

Performing a present worth cost analysis on the selected case, it was evident there was a minimum value for the present worth cost. When selecting a variable to change within the simulation, the maximum temperature of the evaporation unit was selected. However, the temperature range for which the evaporation unit could operate was between 280°C and 300°C. Even though the lowest present worth cost occurred at 270°C, the lowest present worth cost within the acceptable range of temperature values occurred at 280°C. For this reason, the optimized evaporation unit temperature selected was 280°C. Additionally, the present worth cost was calculated at 260°C to determine if the present worth cost did in fact increase. This increase could be attributed to the area of the evaporation unit not reaching the minimum value for the capacity (5m²) of the costing constants for a forced circulation evaporator.

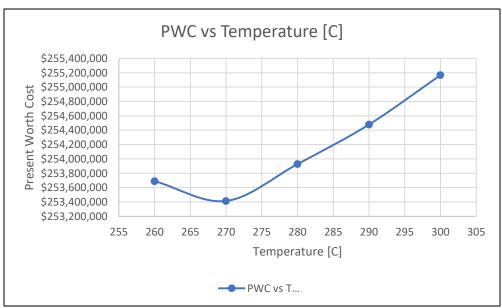


Figure 55: Effect of Temperature on Present Worth Cost

Sensitivity Analysis

A sensitivity analysis was performed to identify the extent to which the critical variables considerably affect the profitability measure of the proposed Nylon 6 6 manufacturing process. The following variables were altered: initial capital investment, cost of raw materials, selling price of Nylon 6 6 product, and income tax rate. The ranges of variation for each variable were obtained from a 10-year plant life forecast in Table 10.1 of Turton in Appendix F [21]. Each variable was changed for all four proposed cases: batch pellet, batch spun, continuous pellet, and continuous spun. Therefore, the profitability was evaluated by observing changes in discounted cash flow rate of return (DCFROR) and net present value (NPV) for the best and worst case scenarios with respect to the original DCFROR.

The sensitivity analysis for the batch, pellet process is shown in Figure 15. When compared to the 28% DCFROR base case scenario, the results indicated that the raw material costs of the process affected the profitability the most due to a 111% difference in the DCFROR range. Although the potential for an increase in profitability would be economically favorable, the worst case scenario was analyzed in order to determine whether the process would still be economically viable in the event that all variables were undesirably affected. Upon incorporating each parameter which yielded the lowest DCFROR in the cash flow diagram, it was determined that the worst case scenario for the batch, pellet process would yield a negative NPV. Therefore, there would be risk involved with this process in the event that the variables changed unfavorably, which resulted in an economically unviable option.

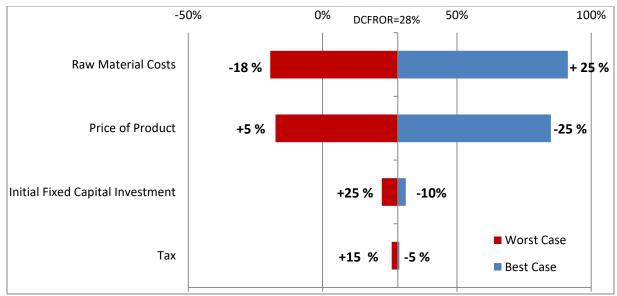


Figure 16: Sensitivity Analysis for Batch Pellet Process

The sensitivity analysis for the batch, spun process is shown in Figure 16. When compared to the 188% DCFROR base case scenario, the results indicated that the selling price of Nylon 6 6 affected the profitability of the process the most due to a 279% difference in the DCFROR range. If the price of the product was decreased by 45% due to fluctuations in chemical market prices from \$4.15 to \$2.28, then a DCFROR of -21% indicated that the process was economically unfavorable. Therefore, this process yielded a negative NPV when evaluated at the overall worst case scenario for all changes in variables, which was not viable.

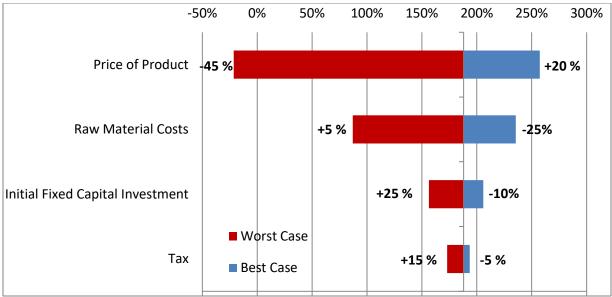


Figure 17: Sensitivity Analysis for Batch Spun Process

The sensitivity analysis for the continuous, pellet process is shown in Figure 17. When compared to the 34% DCFROR base case scenario, the results indicated that the raw material costs affected the profitability of the process the most due to a 145% difference in the DCFROR range. When evaluated at the worst case scenario, this process yielded a negative NPV value, which was also economically unfavorable.

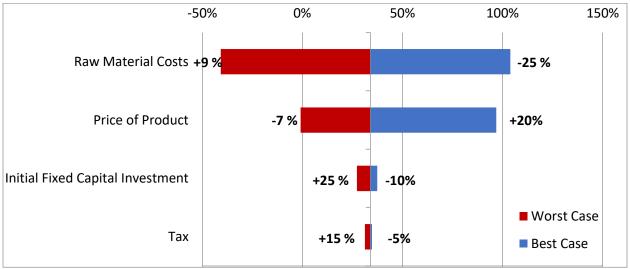


Figure 186: Sensitivity Analysis for Continuous Pellet Process

Lastly, the sensitivity analysis for the continuous, spun process, which was determined to be the optimum case of the four, is shown in Figure 18. When compared to the 211% DCFROR base case scenario, the results indicated that the selling price of the product affected the profitability of the process the most due to a 316% difference in the DCFROR range. When evaluated at the worst case scenario, this process yielded a negative NPV value, which was also economically unfavorable.

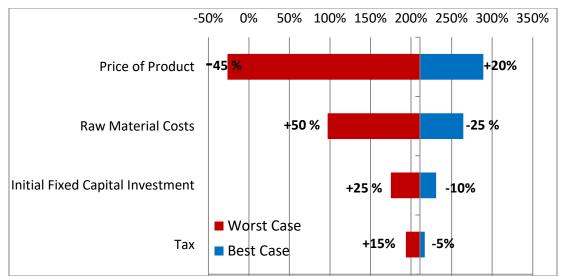


Figure 19: Sensitivity Analysis for Continuous Spun Process

As shown in the previous plots, the sensitivity ranges for initial fixed capital investment and tax do not considerably affect the profitability measure of each process. An analysis was performed on these sensitivity variables to provide further insight as to what may happen to the profitability of the process if economic changes influenced the income tax or cost of the equipment. On the contrary, the price of the product and raw material could have a significant effect on the economic viability of the process. For the processes that produced Nylon 6 6 fibers by extrusion and spinning, the price of the product had a greater effect on the profitability of the process than cost of raw materials because nylon fibers sell for a higher price than Nylon pellets. On the other hand, processes which produce Nylon 6 6 pellets were affected more by the raw material costs. The ranges of variation for the cost of raw materials and price of product for each case were adjusted to account for the feasibility of the process parameters, which contributed to the significant difference in base DCFROR % presented in the sensitivity charts.

XIII. Conclusions and Recommendations

For this project, the objective was to analyze the industrial processes for the production of Nylon 6 6. Through this analysis, a side product of the monomer, diamine was generated as well as the production of Nylon 6 6, and both are sold as product streams from the production process.

As economic analyses was performed on both the batch and continuous production process through the comparison of two different productions products for each process type. Through these analyses, it was determined the continuous production process proved to be the more economically viable option. This was contributed to the fact that the continuous process accounts for many of the limitations present in the batch production process. These limitations overcome include reduction in reaction vessel size attributed to reduced process time. Additionally, the turnaround between batches was eliminated and productions specifications are met with reduced initial capital investment and a reduction in annual operating costs.

Additionally, within each production case, it was found that the production of spun Nylon 6 6 was more economically favorable due to the increased sale price of the product. While there were additional fixed capital investment costs involved with the production of spun Nylon 6 6 fibers, due to the consistence in

production rates each year, the increased sale price allows for greater annual profits leading to a greater rate of return.

Because the continuous case with the production of spun Nylon 6 6 fibers was found to be the most economically viable option, it served as the basis for all optimization in order to achieve the lowest present worth cost. Through reducing the present worth costs, the resulting net present value will increase, which is the desired parameter in determining economic viability between projects. While all production scenarios proved to be economically viable options, the optimized continuous spun fiber process yielded a higher DCFROR, a smaller payback period, a lower breakeven revenue requirement, and a decreased sensitivity due to fluctuations in sale price, raw material costs, initial tax rate, and initial fixed capital investment.

For this project analysis, in comparing both the continuous and batch process with two product type variations, it was determined that the more favorable scenarios were those with the continuous production of Nylon 6 6. Proceeding with the continuous production of Nylon 6 6. Is the recommended course of action in the development of a grass roots Nylon 6 6 production facility. In the continuous production of spun fibers, the present worth cost and DCFROF were more economically attractive than that of any other production method or product.

Through further analysis the continuous production of spun fibers, it is recommended that the production process proceed with maximum the optimized evaporation unit temperature. Out of several design parameters, this was found to have the greatest impact on the utilities and total purchase costs of equipment within the proposed facility. Given the temperature constraints of a value between 280 and 300°C, it was found the use of the lower limit resulted in the lowest present worth cost. This indicated the optimized conditions through finding a balance between equipment costs and utilities (condenser and evaporator duties) for the process. This produced a discount cash flow rate of return of 211%. Additionally, with an initial capital investment of \$13,015,000 and a net present value of \$178,000,000 it was found that following the optimized case, the company will achieve the greatest rate of return upon investment.

Safety of the process and sustainability were taken into consideration in order to minimize potential hazards and to achieve manufacturing specifications. Nylon 6 6 is synthesized from ADA and HMDA which are flammable reactants that may cause irritation to skin and the respiratory system if not properly contained. Due to potential dust accumulation of ADA, tightly sealed storage tanks are utilized to reduce exposure to air. The fundamental safety concept for this process was to make the operation inherently safer and to mitigate hazards. The primary process risk is the production of diamine, an extremely hazardous intermediate. This component will be removed from the system with water during the polymerization process; however, it is too toxic for wastewater treatment standards. Therefore, it will be sold as a byproduct from a floating-roof storage tank to prevent the evaporation of the liquid and avoid the formation of an explosive vapor. In addition, it is recommended that the process is operated within specified design temperatures and pressures. Temperature and flow rates will be fixed at specified set-points in order to control reaction pressure, conversion, and product quality. In the event of a disturbance, sensors will trigger alarms within the DCS, alerting operators of the fluctuation within the system. It is recommended that operators override sensor limits during unsteady-state operation in start-up due to a instantaneous impulse change. These conditions were determined through physical property databases in Aspen Plus and further justified from previously conducted experimental data obtained from literature. To effectively control the process, a DCS is implemented into the design

instrumentation of the process. Lastly, to inherently design a safe plant layout, it is recommended that products be isolated from the process reactors and heat sources.

Areas in which the design could be improved are through the purchase of more efficient pumps, and possibly utilizing a more efficient heat transfer medium. When analyzing the utility costs, the use of a more efficient pump would lead to decreased annual energy consumption, while the use of a refrigerant other than cooling water the flow rate needed to achieve the same rate of heat transfer would decrease thus reducing annual consumption. Beyond adjusting the simulation to allow for decreased utility costs, the group is confident in the economic evaluation of the various production scenarios to produce Nylon 6 6 and the advancement and implementation of the optimized case.

XIV. Acknowledgements

The group would like to thank Paul Rodgers and David Frankenburg for their contributions in extruder and spinneret economic analysis.

XV. Bibliography

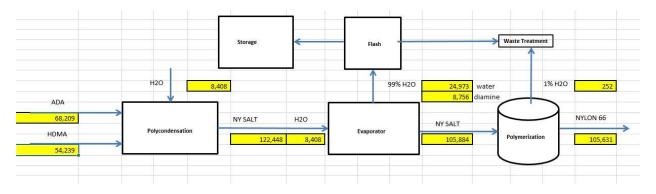
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XIX. Appendix

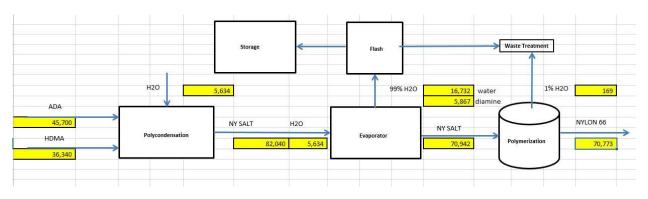




Specif	fied	lb/yr	kg/day
m _{out}	Nylon 66	8.5.E+07	105,631
Component	Properties	g/mol	kg/mol
Repeat MW	Nylon 66	226.32	0.226
MW	Ny Salt	262.35	0.262
MW	ADA	146.1412	0.146
MW	HDMA	116.21	0.116
MW	H2O	18.01528	0.018

m _{component}	kg/day		
ADA	68,209		
HDMA	54,239		
NY SALT	122,448		
H2O (IN)	8,408		
H2O (TOTOUT)	25,225		
H2O FORMED POLY	16,817		

Material Balance for 100% Capacity

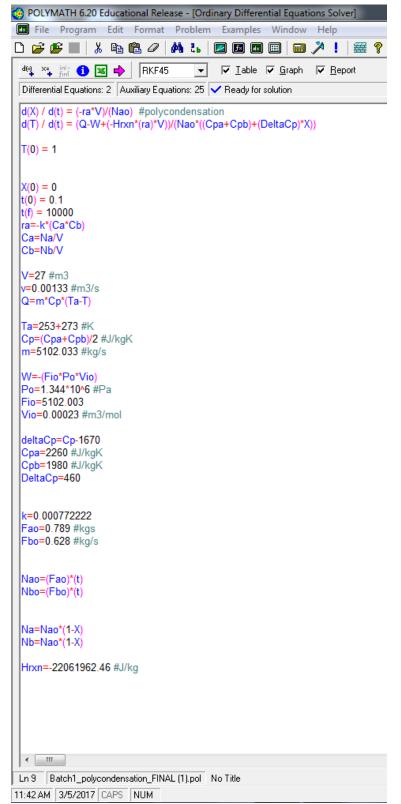


Specit	fied	lb/yr	kg/day	67% Turndown
m _{out}	Nylon 66	8.5.E+07	105,631	70,772.84
Component	Properties	g/mol	kg/mol	
Repeat MW	Nylon 66	226.32	0.226	2
MW	Ny Salt	262.35	0.262	
MW	ADA	146.1412	0.146	2
MW HDMA		116.21	0.116	
MW H2O		18.01528	0.018	

m _{component}	kg/day	
ADA	45,700	
HDMA	36,340	
NY SALT	82,040	
H2O (IN)	5,634	
H2O (TOTOUT)	16,901	
H2O FORMED POLY	11,267	

Material Balance for 67% Turndown

Appendix B: Batch Polymath

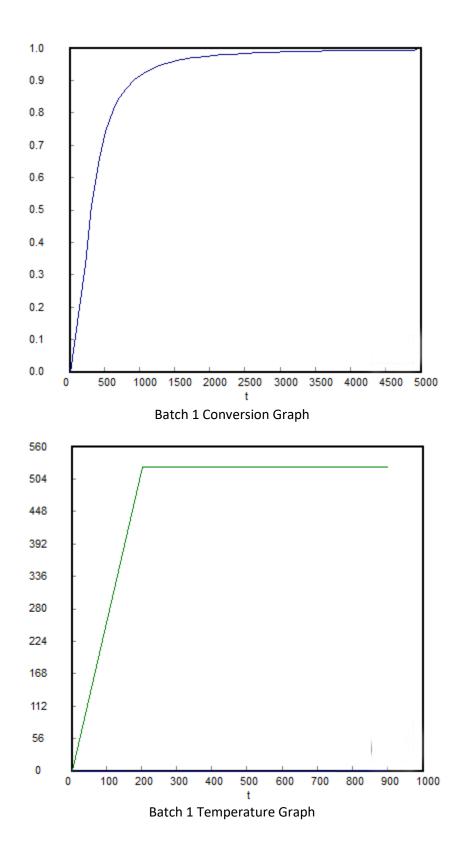


Batch 1 Polymath Code

	Variable	Initial value	Minimal value	Maximal value	Final value
1	Ca	0.0029222	0.0029222	4.349662	0.2587635
2	Cb	0.0029222	0.0029222	4.349662	0.2587635
3	Ср	2120.	2120.	2120.	2120.
4	Сра	2260.	2260.	2260.	2260.
5	Cpb	1980.	1980.	1980.	1980.
6	deltaCp	450.	450.	450.	450.
7	DeltaCp	460.	460.	460.	460.
8	Fao	0.789	0.789	0.789	0.789
9	Fbo	0.628	0.628	0.628	0.628
10	Fio	5102.003	5102.003	5102.003	5102.003
11	Hrxn	-2.206E+07	-2.206E+07	-2.206E+07	-2.206E+07
12	k	0.0007722	0.0007722	0.0007722	0.0007722
13	m	5102.033	5102.033	5102.033	5102.033
14	Na	0.0789	0.0789	117.4409	6.986616
15	Nao	0.0789	0.0789	7890.	7890.
16	Nb	0.0789	0.0789	117.4409	6.986616
17	Nbo	0.0628	0.0628	6280.	6280.
18	Ро	1.344E+06	1.344E+06	1.344E+06	1.344E+06
19	Q	5.679E+09	-1.546E+06	5.679E+09	-1.546E+06
20	ra	-6.594E-09	-0.0146101	-6.594E-09	-5.171E-05
21	t	0.1	0.1	10000.	10000.
22	Т	1.	1.	526.143	526.143
23	Ta	526.	526.	526.	526.
24	V	27.	27.	27.	27.
25	v	0.00133	0.00133	0.00133	0.00133
26	Vio	0.00023	0.00023	0.00023	0.00023
27	W	-1.577E+06	-1.577E+06	-1.577E+06	-1.577E+06
28	Х	0	0	0.9991145	0.9991145

Calculated values of DEQ variables

Batch 1 Polymath Solutions



🚱 POLYMATH 6.20 Educational Release - [Ordinary Differential Equations Solver]
💌 File Program Edit Format Problem Examples Window Help
D 🖆 🗳 🖬 👗 🛍 🖉 🛤 🐍 🛛 🖾 💷 📖 🏓 🥍 ! 🚟 💡
dia ×, mi 🕇 🗷 🔶 RKF45 🔽 Iable 🗸 Graph 🗸 Report
Differential Equations: 1 Auxiliary Equations: 12 🗸 Ready for solution
$\label{eq:constraint} \begin{array}{l} d(X) \ / \ d(t) = (-ra^*V) / (Nao) \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \$
X(0) = 0
t(0) = 0.1 t(f) = 800
ra=-k*Ca
Ca=Na/V
To=280+273.15 #K
V=24 #m3
Cpa=1150 #J/kgK
DeltaCp=5.05*1000
k=0.0130 #k=A*EXP(-E/(R*T))
#R=8.314 #J/molK
Fao=1.22551192 #kg/s #E=92048
#A=1
Nao=(Fao)*(t)
Na=Nao*(1-X)
Hrx=31596855 #J/kg
<
Ln 16 Batch2_Polymerization_FINAL.pol No Title

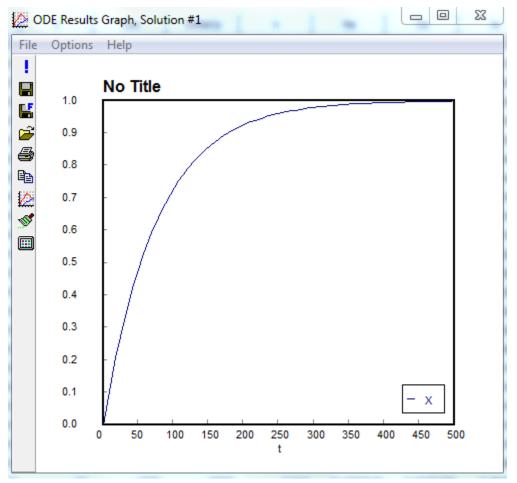
11:57 AM 3/5/2017 CAPS NUM

Batch 2 Polymath Code

	Variable	Initial value	Minimal value	Maximal value	Final value
1	Ca	0.0051063	0.0012448	1.446688	0.0012448
2	Сра	1150.	1150.	1150.	1150.
3	DeltaCp	5050.	5050.	5050.	5050.
4	Fao	1.225512	1.225512	1.225512	1.225512
5	Hrx	3.16E+07	3.16E+07	3.16E+07	3.16E+07
6	k	0.013	0.013	0.013	0.013
7	Na	0.1225512	0.0298751	34.72052	0.0298751
8	Nao	0.1225512	0.1225512	980.4095	980.4095
9	ra	-6.638E-05	-0.0188069	-1.618E-05	-1.618E-05
10	t	0.1	0.1	800.	800.
11	Т	553.15	-4543.088	553.15	-4543.088
12	To	553.15	553.15	553.15	553.15
13	V	24.	24.	24.	24.
14	X	0	0	0.9999695	0.9999695

Calculated values of DEQ variables

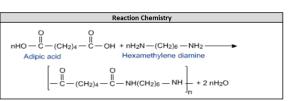
Batch 2 Code Solutions

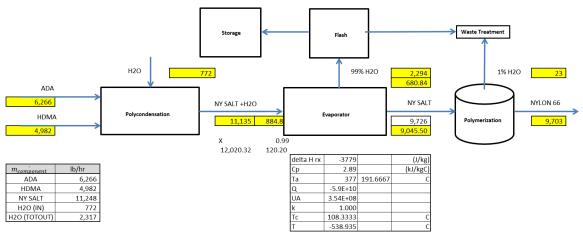


Batch 2 Conversion Graph

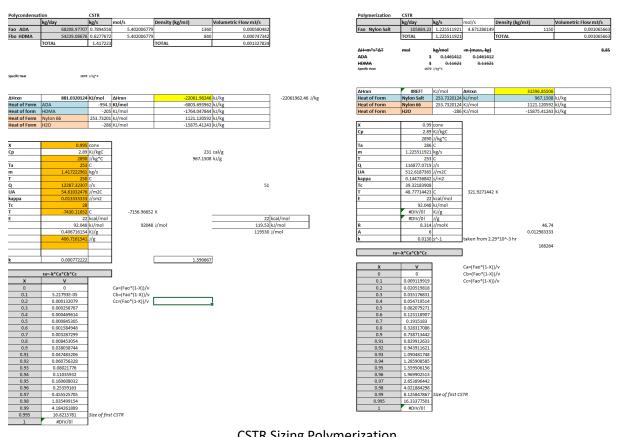
Appendix C: Continuous Process (CSTR)

Speci	fied	lb/yr	lb/hr		
mout	Nylon 66	8.5.E+07	9,703		
Component	Properties	g/mol	lb/mol		
Repeat MW	Nylon 66	226.32	0.499		
MW	Ny Salt	262.35	0.578		
MW	ADA	146.1412	0.322		
MW	HDMA	116.21	0.256		
MW	H2O	18.01528	0.040		





CSTR Material Balance





Determine Vapor Pr	ressure of V	Vater
p=exp[(a1t+a2t^1.5+a3t^3+a4t^3	.5+a5t^4+a	6t^7.5)*(Tc/T)]*pc
Тс	К	647.096
Рс	kPa	22064
a1		-7.85951783
a2		1.84408259
a3		-11.7866497
a4		22.6807411
a5		-15.9618719
a6		1.80122502
Т	С	300
Т	К	573.15
t	1-T/Tc	0.114273616
р	kPa	8587.867486
Р	psia	1245.567124
Р	psig	1230.867124

CSTR Vapor Pressure of Water

Reactor Sizir	ng and Costing: Evaporator	
	ditions and Specifications	
	nlet Conditions	
Mass Flow HMDA, (kg/day)	-	
Mass Flow Adipic Acid, (kg/day) Mass Flow Water, (kg/day)	16817	
Mass Flow Nylon Salt, (kg/day)	122447.5	
Mass Flow Nylon 6,6, (kg/day)		
Temperature, C	250	338.5C= BP at 1 atn
Pressure, (barg)	10.00	
Total Flow, (kg/day)	139264.5	
	utlet Conditions	
Mass Flow HMDA, (kg/day)	-	
Mass Flow Adipic Acid, (kg/day)	-	
Mass Flow Water, (kg/day) Mass Flow Nylon Salt, (kg/day)	24973 105884.23	
Mass Flow Diamine, (kg/day)	8756.22	
Mass Flow Nylon 6,6, (kg/day)	8730.22	
Temperature, C	280	338.5C= BP at 1 atn
F	536	556.50- 51 40 1 40
Pressure, (barg)	10.000	
Temperature of Hot Oil, F	599.000	Low Pressure Steam
C	315.000	Low Tressure Steam
Total Flow, (kg/day)	139613.0	
	ing of Equipment	
Volume, (ft ³)	183.4796701	
		2012 5
m3 Disputtor (ft)	5.195560775	2013.56
Diameter, (ft)	4.270305425	
m	1.301589094	
Heat Flow (Qo), Btu/hr	497,240.43	m/latent hea
Uo. Btu/hrFft ²	400	Literature 400-2000
Delta T, F	54.000	changed to Fahrenheit
LMTD, CF, F	86.8	
LMTD, F	87.23	
Delta T (Hot in Cold Out), F	63.0	
Delta T (Hot Out Cold in), F Correction Factor	0.995	
Area, (ft ²)	14.3221348	
m2	1.3305693	
	prrelation- Evaporator	
Purchase Cost, Cp	362448.503	Cpo*Fp*Fm
Installed Cost, CBM	\$ 922,571.86	Cpo*FBN
Equipment Purchase Cost, Cp0	\$ 116,945.80	87891.54938
K1 from Table A.1	5.0238	
K2 from Table A.1	0.3475	
K3 from Table A.1	0.0703	
Area, (m2)	1.330569292	
Presure Factor, FP	1.00	
C1 from Table A.2	0.15780	
C2 from Table A.2	-0.29920	
C3 from Table A.3	0.14130	
Material of Construction Factor, FM from Figure A.18	3.1	Vertical Process Vessel (SS
Identification Number	20	Vertical Process Vessel (SS
Bare Module Factor, FBM B1 from Table A.4	7.890701031	B1(B2*Fm*Fp Vertical Process Vessel
B2 from Table A.4	1.82	Vertical Process Vessel
Contingency, Ccont	138385.7795	0.15*CBN
Fee, Cfee	27677.1559	0.03*CBN
	2016 Costs	
Chemical Engineering Plant Cost Index in 2016	547	
Chemical Engineering Plant Cost Index in 2012	397	
Purchase Cost, Cp	\$ 499,393.78	Cp*(CEPCI ₂₀₁₆ /CEPCI ₂₀₁₂
Installed Cost, CBM	\$ 1,271,150.65	CBM*(CEPCI ₂₀₁₆ /CEPCI ₂₀₁₂
Total Contengency	\$ 190,672.60	
Total Fees	\$ 38,134.52	
СТМ	\$ 1,499,957.77	CBM+Confengency+Fee

	sting: Condenser from Evaporat ditions and Specifications	
	Side Information	
In	let Conditions	
Inlet Process Temp, C	280	536
Pressure, psia	159.7	
Pressure, (barg)	10.00 tlet Conditions	
Outlet Process Temp, C	109	228.2
Pressure, psia	70.0	2201
Shell Side Design Pressure, barg	3.8	
	Side Information	
	let Conditions	
Inlet Cooling WaterTemp, F	87	
Inlet Cooling WaterTemp, C	30.56	
	tlet Conditions	
Outlet Steam Temp, F	120.0	
Outlet Steam Temp, C	48.9	
	Design Specs ment Description	
Equipment Type	HEX	
Equipment Description	Tubular	
Tube Material	Stainless	
Shell Material	Stainless	
Tube Side	Cooling Water	
Shell Side	Process	
НЕХ ТЕМА Туре	AES	
Equipment Description	Floating Head	
	EX Calculations	
2	2195.1	.652/.688btu/lbl
Density of Cooling Water, (lb/m ³)		.652/.688Dtu/ID
Mass Flow Input Process Stream, (lb/day) Cp Steam, (btu/lbF)	307794.1356	Engineering Teelbox
Cp Diamine, (btu/lbF)	1 202275 05	Engineering Toolbo
	1.20237E-06 0.23	
X _{Diamine}		Mass Balance Entering
	0.77	Mass Balance Entering
Total Cp, (btu/lbF) Heat Flow (Qo), Btu/day	0.770000277 40527268	Calculated m*Cp*LMTE
Area of Heat Transfer (A0), m2	53.13726	1.20237E-06
	55.15720	1.202372-00
Overall Heat Transfer Coefficient (U0), Btu/hrft ² F	1200.0	
Btu/dayft ² F	28800.0	
Btu/daym ² F	2675.6	
Velocity 30-50, (ft/s)	50.0	
ft/hr	180000.0	
m/hr	54864.0	
LMTD, CF, (F)	285.1	
LMTD, CF, C	140.6	
LMTD, C	141.29	
Delta T (Hot in Cold Out)	231.1	
Delta T (Hot Out Cold in)	78.4	
Correction Factor	0.995	
	Correlation- HEX	
Purchase Cost, Cp	\$ 55,405.91 \$ 148,570	
Installed Cost, CBM Equipment Purchase Cost, Cp0	\$ 148,570 \$ 20,475	
K1 from Table A.1	4.8306	
K2 from Table A.1	-0.8509	
K3 from Table A.1	0.3187	
Area,m2	53	
Presure Factor, FP	1.00	
C1 from Table A.2	0.03881	
C2 from Table A.2	-0.11272	
C3 from Table A.3	0.08183	
Material of Construction Factor, FM from Figure A.18	2.7	
Identification Number	5	
Bare Module Factor, FBM	7.26	
B1 from Table A.4	2.25	Vertical Process Vessel
B2 from Table A.4	1.85	Vertical Process Vessel
Contingency, Ccont	22285.52584	0.15*CBN
Fee, Cfee	4457.105167 2016 Costs	0.03*CBN
Chemical Engineering Plant Cost Index in 2016	547	
Chemical Engineering Plant Cost Index in 2012	397	
Purchase Cost, Cp	\$ 76,340.14	Cp*(CEPCI ₂₀₁₆ /CEPCI ₂₀₁₂
Installed Cost, CBM	204704.998	CBM*(CEPCI ₂₀₁₆ /CEPCI ₂₀₁₂
Total Contengency	30705.7497	1011
Total Fees	6141.149941	
СТМ	\$ 241,551.90	CBM+Confengency+Fee

		Binary VLE 003		
No.	Liquid mole fraction HEXAM-01	Temperature (K)	Vapor mole fraction HEXAM-01	Total pressure (N/sqm)
1	0.0544	373.72425	0.0011	93859
2	0.0731	363.02639	0.0008	66514.5
3	0.1023	362.82643	0.0015	62728.2
4	0.1114	375.72385	0.0013	97192
5	0.1312	372.82443	0.0026	89326
6	0.1337	372.72445	0.0021	94565.6
7	0.141	372.32453	0.0025	88592.7
8	0.1826	372.62447	0.0103	84153.1
9	0.1864	362.92641	0.0021	55915.4
10	0.3776	373.02439	0.0123	57981.9
11	0.414	363.32633	0.0137	37303.6
12	0.431	363.12637	0.0309	
13	0.4663	383.32233	0.0236	73274
14	0.4909	383.32233	0.0274	68821
15	0.531	363.12637		26771.1
16	0.5487	384.12217	0.04	56929
17	0.5716	372.92441	0.0415	36010.4
18	0.6666	383.72225	0.0576	47356.1
19	0.723	383.12237	0.0847	39036.8
20	0.8225	383.12237	0.1528	25477.9
21	0.876	373.02439	0.2978	9705.9
22	0.9282	383.12237	0.3381	14412.1
23	0.9632	383.12237	0.5981	8412.6

Property	Component	U	nits
Mass Flowrate	Diamine	8,756.00	kg/day
Mass Flowrate	H2O	24,973	kg/day
MW	Diamine	0.116475263	kg/mol
MW	H2O	0.018015328	
Molar Flowrate	Diamine	75,174.76	0.
Molar Flowrate	H2O	1386194.45	
xD	Diamine		.99
xH	H2O		.01
уD	Diamine		.01
уН	H2O	0	.99
Density	Diamine	840	kg/m3
Density	H2O	999.9988107	kg/m3
Avg MW	Liquid	0.115490664	kg/mol
Specific Vol	Liquid	0.000137455	m3
Density	Liquid	840.2097009	kg/m3
Avg MW	Vapor	0.018999928	kg/mol
Density	Vapor	0.050338354	kg/m3
Pressure	Flash Drum	0.08413	bar
Pressure	Flash Drum	8.413	kPa
R	Gas Constant	0.008314	m3*kPa/molK
Temp	Flash Drum	109	С
Temp	Flash Drum	382.15	К
V	H2O vapor	1386194.45	mol/day
Wv	H2O vapor	26337.59406	kg/day
L	Diamine liquid	75,174.76	mol/day
WI	Diamine liquid	8,681.98	kg/day
Flv	Flash Drum	0.002	551517
Kdrum	Flash Drum	0.152326074	ft/s
K drum	Flash Drum	4011.461449	m/day
Const	Flash Drum	1	ft/s
Const	Flash Drum	26334.7	m/day
A	Constant	-1.877	478097
В	Constant	-0.81	458046
С	Constant	-0.187	074409
D	Constant	-0.014	522867
E	Constant	-0.001	014852
U perm	Vapor Velocity	19.67911575	ft/s
U perm	Vapor Velocity	518243.6095	m/day
A	Cross Sec Area	1.009585578	m2
D	vertical drum	1.133774352	m
D	vertical drum	44.63680962	
D	6 inch increment	48	in
D	vertical drum	1.2192	m
Volume	V=pir2*h	4.270079867	m3

F	Redlich Kwo	ng
Тс	647.1	К
Рс	22.06	Мра
	22060	kPa
Tr	0.590558	
Pr	0.000381	
Z=B+Z(Z+B)*((1+B-	-Z)/(qB))
q	10.87186	
В	5.6E-05	
Z	0.999447	6.73E-08
الم ما		

Redlich Kwong Vaules

Reactor Sizing and Co	sting: Jacketed/CSTR 1 (A	jitated)
Process Cond	itions and Specifications	
Inl	et Conditions	
Mass Flow HMDA, (kg/day)	54239.17058	
Mass Flow Adipic Acid, (kg/day)	68208.897	
Aass Flow Water, (kg/day)	8408.234904	
1ass Flow Nylon Salt, (kg/day)		
lass Flow Nylon 6,6, (kg/day)	- 25	
emperature, C	25 tlet Conditions	
lass Flow HMDA, (kg/day)	tiet conditions	
lass Flow HMDA, (kg/day) lass Flow Adipic Acid, (kg/day)		
lass Flow Water, (kg/day)	8408.23	
Ass Flow Nylon Salt, (kg/day)	122447.6	
lass Flow Nylon 6,6, (kg/day)		
emperature, C	255	
	g of Equipment	
otal Mass Flow Out, (kg/day)	130855.83	
DA	0.52	Mass Balance
ada HMDA	0.41	Mass Balance
HMDA	0.06	Mass Balance
H20 Hensity ADA, (kg/m ³)	1359.998997	Literature
Density ADA, (kg/m ³)	1359.998997 840	Literature
Density HMDA, (kg/m ³)	999.997995	Literature
		Literature
ensity, (kg/m³)	1112	
otal Flow Rate, (kg/hr)	5452.345937	
(m³/day)	4.904955996	Density/Mass Flow Rate
me in Vessel, (hr)	-	Reaction Time
(day)		hr/24
eaction Rate, (lb/mol/s)	6.0475	From Literature 95% Confidence
olume, (m³)	16.82	Material Balance
iameter, (m)	1.9	
′D	3	Heuristic
ressure, (psia)	145	Pressure of Vessel-Literature
esign Pressure, (psia)	195	
(barg)	12.43	
uty, (kW)	12.283	Shaft Work
	keted/Batch Reactor (Aji	
urchase Cost, Cp	519966.8581	Cpo*Fp*Fm
nstalled Cost, CBM	1090399.487	Cpo*FBM
quipment Purchase Cost, Cp0	57093.6887	
K1 from Table A.1	4.1052	Volume Min: 0.1 m ³ Max: 35 m ³
K2 from Table A.1	0.5320	Volume Min: 0.1 m ³ Max: 35 m ³
K3 from Table A.1	-0.0005	Volume Min: 0.1 m ³ Max: 35 m ³
Volume,m3	16.82	
resure Factor, FP	2.937824624	
C1 from Table A.2	0	
C2 from Table A.2	0	
C3 from Table A.3	0	
1aterial of Construction Factor, FM from Figure A.18	3.1	Vertical Process Vessel (SS clad)
Identification Number	20	Vertical Process Vessel (SS clad)
are Module Factor, FBM	19.09842422	B1(B2*Fm*Fp)
B1 from Table A.4	2.25	Vertical Process Vessel
B2 from Table A.4	1.85	Vertical Process Vessel
ontingency, Ccont	163559.9231	0.15*CBM 0.03*CBM
e, Cfee	32711.98461 2016 Costs	0.03*CBM
nemical Engineering Plant Cost Index in 2017	547	
Chemical Engineering Plant Cost Index in 2012	397	
urchase Cost, Cp	\$ 716,427.89	Cp*(CEPCI ₂₀₁₆ /CEPCI ₂₀₁₂)
nstalled Cost, CBM	\$ 1,502,389.22	CBM*(CEPCI ₂₀₁₆ /CEPCI ₂₀₁₂)
otal Contengency	225358.3827	
	45071.67653	
otal Fees TM	\$ 1,772,819.28	CBM+Confengency+Fees

Reactor Sizing	and Costing: Evaporator	
Process Condi	itions and Specifications	
Inle	et Conditions	
Mass Flow HMDA, (kg/day)	-	
Mass Flow Adipic Acid, (kg/day)		
Mass Flow Water, (kg/day)	16817	
Mass Flow Nylon Salt, (kg/day) Mass Flow Nylon 6,6, (kg/day)	122447.5	
Temperature, C	250	338.5C= BP at 1 atm
Pressure, (barg)	10.00	550.50- 51 41 1 411
Total Flow, (kg/day)	139264.5	
	let Conditions	
Mass Flow HMDA, (kg/day)	-	
Mass Flow Adipic Acid, (kg/day)	-	
Mass Flow Water, (kg/day)	24973	
Mass Flow Nylon Salt, (kg/day)	105884.23	
Mass Flow Diamine, (kg/day)	8756.22	
Mass Flow Nylon 6,6, (kg/day)		
Temperature, C	280	338.5C= BP at 1 atm
F	536	
Pressure, (barg)	10.000	1 m m m
Temperature of Hot Oil, F	599.000	Low Pressure Steam
C C	315.000	
Total Flow, (kg/day)	139613.0	
Volume, (ft ³)	g of Equipment	
	183.4796701	
m3	5.195560775	2013.56
Diameter, (ft)	4.270305425	
m	1.301589094	
Heat Flow (Qo), Btu/hr	497,240.43	m/latent heat
Uo. Btu/hrFft ²	400	Literature 400-2000
Delta T, F	54.000	changed to Fahrenheit
LMTD, CF, F	86.8	
LMTD, F	87.23	
Delta T (Hot in Cold Out), F	63.0	
Delta T (Hot Out Cold in), F Correction Factor	0.995	
Area, (ft ²)	14.3221348	
m2	1.3305693	
	elation- Evaporator	
Purchase Cost, Cp	362448.503	Cpo*Fp*Fm
Installed Cost, CBM	\$ 922,571.86	Cpo*FBM
Equipment Purchase Cost, Cp0	\$ 116,945.80	87891.54938
K1 from Table A.1	5.0238	
K2 from Table A.1	0.3475	
K3 from Table A.1	0.0703	
Area, (m2)	1.330569292	
Presure Factor, FP	1.00	
C1 from Table A.2	0.15780	
C2 from Table A.2	-0.29920 0.14130	
C3 from Table A.3 Material of Construction Factor, FM from Figure A.18	3.1	Vertical Process Vessel (SS)
Identification Number	3.1	Vertical Process Vessel (SS) Vertical Process Vessel (SS)
Bare Module Factor, FBM	7.890701031	B1(B2*Fm*Fp)
B1 from Table A.4	2.25	Vertical Process Vessel
B2 from Table A.4	1.82	Vertical Process Vessel
Contingency, Ccont	138385.7795	0.15*CBM
Fee, Cfee	27677.1559	0.03*CBM
	2016 Costs	
Chemical Engineering Plant Cost Index in 2016	547	
Chemical Engineering Plant Cost Index in 2012	397	
Purchase Cost, Cp	\$ 499,393.78	Cp*(CEPCI ₂₀₁₆ /CEPCI ₂₀₁₂)
Installed Cost, CBM	\$ 1,271,150.65	CBM*(CEPCI ₂₀₁₆ /CEPCI ₂₀₁₂)
Total Contengency	\$ 190,672.60	
Total Fees	\$ 38,134.52	-
СТМ	\$ 1,499,957.77	CBM+Confengency+Fees

Reactor Sizing and Cost	ing: Flash Drum		Storage	Tank (Diamine)	
Process Conditions and				tions and Specifications	
Inlet Conditi				t Conditions	
Mass Flow HMDA, (kg/day)	-		Mass Flow HMDA, (kg/day)	-	
Mass Flow Adipic Acid, (kg/day)	-		Mass Flow Adipic Acid, (kg/day)	-	
Mass Flow Water, (kg/day)	24973		Mass Flow Water, (kg/day)	-	
Mass Flow Nylon Salt, (kg/day)	-		Mass Flow Nylon Salt, (kg/day)	-	
Mass Flow Nylon 6,6, (kg/day)	-		Mass Flow Nylon 6,6, (kg/day)	-	
Mas Flow Diamine, (kg/day)	8756.2	342C= BP at 20 psia	Mas Flow Diamine, (kg/day)	8756.22	
Temperature, C	109	55.2	Temperature, C	110	338.5C= BP at 1 atm
Pressure, (barg) Total Flow, (kg/day)	3.812 33728.72756	55.3	Pressure, (barg) Total Flow, (kg/day)	3.80 8756.22	
Outlet Condi				of Equipment	
Mass Flow HMDA, (kg/day)	-		X _{Diamine}	0.23	Mass Balance
Mass Flow Adipic Acid, (kg/day)			Density Diamine, (kg/m ³)	839.599	Literature
Mass Flow Water, (kg/day)	24972.50756		Total Flow Rate, (kg/day)	8756.22	Electrotere
Mass Flow Nylon Salt, (kg/day)	-		(m ³ /day)	10.42905264	Density/Mass Flow Rate
Mass Flow Nylon 6,6, (kg/day)			(m ³ /week)	73.00336849	
Mas Flow Diamine, (kg/day)	8756.22	342C= BP at 20 psia	Time in Vessel, (hr)	168	Store for a Week
Temperature, C	110	109.32C= BP at 20 psia	(day)	7	hr/24
Pressure, (barg)	0.084	bi dt 20 psia	Reaction Rate, ()	+ +	111/24
Total Flow, (kg/day)	33728.72756		Volume, (m ³)	73.00336849	Fixed roof
			Diameter, (m)	3.1	Fixed Tool
Sizing of Equip Overall Temp, C	109		L/D	3.1	Heuristic
Overall Pressure, (barg)	0.084		Orientation	3	Vertical
X _{Diamine}	0.23	Mass Balance	Pressure, (psia)	145	Pressure of Vessel-Literature
X _{H20}	0.77	Mass Balance	Design Pressure, (psia)	195	
Density Diamine, (kg/m ³)	0.116	Literature	(barg)	12.43	
Density Water, (kg/m ³)	0.018	Literature		eted/Batch Reactor (Ajitat	
Density, (kg/m ³)	0.0407		Purchase Cost, Cp	227484.6077	Cpo*Fp*Fm
(ft ³ /day)	2.257028728	Density/Mass Flow Rate	Installed Cost, CBM	535184.2713	Cpo*FBM
(m³/day)	79.70634847	Conversion	Equipment Purchase Cost, Cp0	50816.7765	
Volume, (m ³)	4.27		K1 from Table A.1	3.4974	Volume Min: 0.1 m ³ Max: 35 m ³
Diameter, (m)	1.219192399		K2 from Table A.1	0.4485	Volume Min: 0.1 m ³ Max: 35 m ³
Pressure, (psia)	20	Pressure of Vessel-	K3 from Table A.1	0.1074	Volume Min: 0.1 m ³ Max: 35 m ³
Design Pressure, (psia)	70		Volume,m3	73.00336849	
(barg)	3.81280228		Presure Factor, FP	4.47656509	
Cost Correlation- E			C1 from Table A.2	0	
Purchase Cost, Cp	89708.39275	Cpo*Fp*Fm	C2 from Table A.2	0	
Installed Cost, CBM	227986.1914	Cpo*FBM	C3 from Table A.3	0	
Equipment Purchase Cost, Cp0	27566.96214		Material of Construction Factor, FM from Figure A.18	1	Vertical Process Vessel (SS clad)
K1 from Table A.1	4.1052	Min: 0.1 m ³ Max: 35 m ³	Identification Number	18	Vertical Process Vessel (SS clad)
K2 from Table A.1	0.5320	Min: 0.1 m ³ Max: 35 m ³	Bare Module Factor, FBM	10.53164542	B1(B2*Fm*Fp)
K3 from Table A.1	-0.0005	Min: 0.1 m ³ Max: 35 m ³	B1 from Table A.4	2.25	Vertical Process Vessel
Volume,m3	4.27		B2 from Table A.4	1.85	Vertical Process Vessel
Presure Factor, FP C1 from Table A.2	1.049741755		Contingency, Ccont Fee, Cfee	80277.6407 16055.52814	0.15*CBM 0.03*CBM
C2 from Table A.2	0			16055.52814	0.03 °CBM
C3 from Table A.3	0		Chemical Engineering Plant Cost Index in 2016	547	
Material of Construction Factor, FM from Figure A.18	3.1	Vertical Process Vessel (SS)	Chemical Engineering Plant Cost Index in 2012	397	
Identification Number	20	Vertical Process Vessel (SS)	Purchase Cost, Cp	\$ 313,435.97	Cp*(CEPCI ₂₀₁₆ /CEPCI ₂₀₁₂)
Bare Module Factor, FBM	8.270268963	B1(B2*Fm*Fp)	Installed Cost, CBM	737394.9532	CBM*(CEPCI ₂₀₁₆ /CEPCI ₂₀₁₂)
B1 from Table A.4	2.25	Vertical Process Vessel	Total Contengency	110609.243	
B2 from Table A.4	1.85	Vertical Process Vessel	Total Fees	22121.8486	
Contingency, Ccont	34197.92871	0.15*CBM	CTM	\$ 870,126.04	CBM+Confengency+Fees
Fee, Cfee	6839.585743	0.03*CBM			
2016 Cos					
Chemical Engineering Plant Cost Index in 2016	547				
Chemical Engineering Plant Cost Index in 2012	397				
Purchase Cost, Cp	\$ 123,603.25	Cp*(CEPCI ₂₀₁₆ /CEPCI ₂₀₁₂)			
Installed Cost, CBM	314127.0698	CBM*(CEPCI ₂₀₁₆ /CEPCI ₂₀₁₂)			
Total Contengency	47119.06047				
Total Fees	9423.812094				
CTM	\$ 370,669.94	CBM+Confengency+Fees			

Reactor Sizing and Costir	a: Condenser from Eva	porator	Postor Sign and Cott	ing: lackated/CSTP 2 (Ai	tated
	ons and Specifications	polator	Process Condit	ions and Specifications	lated
	le Information			Conditions	
	Conditions		Mass Flow HMDA, (kg/day)	-	
Inlet Process Temp, C	280	536	Mass Flow Adipic Acid, (kg/day)	-	
Pressure, psia	159.7		Mass Flow Water, (kg/day)	-	
Pressure, (barg)	10.00		Mass Flow Nylon Salt, (kg/day)	105884.23	
Outlet Process Temp, C	t Conditions 109	228.2	Mass Flow Nylon 6,6, (kg/day) Temperature, C	280	
Pressure, psia	70.0			et Conditions	
Shell Side Design Pressure, barg	3.8		Mass Flow HMDA, (kg/day)	0	
Tube Sid	le Information		Mass Flow Adipic Acid, (kg/day)	0	
	Conditions		Mass Flow Water, (kg/day)	252.25	
Inlet Cooling WaterTemp, F	87		Mass Flow Nylon Salt, (kg/day)	-	
Inlet Cooling WaterTemp, C	30.56		Mass Flow Nylon 6,6, (kg/day)	105631.1	
	t Conditions		Temperature, C	280	
Outlet Steam Temp, F	120.0			of Equipment	
Outlet Steam Temp, C	48.9		Total Mass Flow Out, (kg/hr)	4411.80625	
	sign Specs		X _{Nylon 66}	0.99762	Mass Balance
Equipment Type	ent Description HEX		Density Nylon 66, (kg/m3)	0.00238 1139.999166	Mass Balance Literature
Equipment Description	Tubular			999.997995	
Tube Material	Stainless		Density Water, (kg/m3)	999.997995	Literature
Shell Material	Stainless		Density, (kg/m3) Total Flow Rate, (kg/hr)	4411.842917	
Tube Side	Cooling Water		(m ³ /day)	3.871171957	Density/Mass Flow Rate
Shell Side	Process		Time in Vessel, (hr)	5.6711/1937	Reaction Time
HEX TEMA Type	AES		(day)		hr/24
Equipment Description	Floating Head		Reaction Rate Constant, (kg/mol/s)		From Literature 95% Confidence
	Calculations		Volume, (m ³)	16.33	From Literature 95% Confidence Levenspiel Plot
Density of Cooling Water, (lb/m ³)	2195.1	.652/.688btu/lbF	Diameter, (m)	10.55	Levelispier Plot
Mass Flow Input Process Stream, (Ib/day)	307794.1356	.0527.0008(4)101	L/D	1.5	Heuristic
Cp Steam, (btu/lbF)	307754.1330	Engineering Toolbox	Pressure, (psia)	145	Pressure of Vessel-Literature
Cp Diamine, (btu/lbF)	1.20237E-06	JCT Document	Design Pressure, (psia)	195	Pressure of Vessel-Eiterature
X _{Diamine}	0.23	Mass Balance Entering	(barg)	12.43	
X _{H2O}	0.77	Mass Balance Entering	Duty, (J/s)	0	Adiabatic
Total Cp, (btu/lbF)	0.770000277	Calculated	Cost Correlation- Jacke	ted/Batch Reactor (Ajit	
Heat Flow (Qo), Btu/day	40527268	m*Cp*LMTD	Purchase Cost, Cp	507705.6675	Cpo*Fp*Fm
Area of Heat Transfer (A0), m2	53.13726	1.20237E-06	Installed Cost, CBM	1065716.161	Cpo*FBM
			Equipment Purchase Cost, Cp0	56204.7451	
Overall Heat Transfer Coefficient (U0), Btu/hrft ² F	1200.0		K1 from Table A.1	4.1052	Volume Min: 0.1 m ³ Max: 35 m ³
Btu/dayft ² F	28800.0		K2 from Table A.1	0.5320	Volume Min: 0.1 m ³ Max: 35 m ³
Btu/daym ² F	2675.6		K3 from Table A.1	-0.0005	Volume Min: 0.1 m ³ Max: 35 m ³
Velocity 30-50, (ft/s)	50.0		Volume,m3	16.33	
ft/hr	180000.0		Presure Factor, FP	2.913918059	
m/hr	54864.0		C1 from Table A.2	0	
LMTD, CF, (F)	285.1		C2 from Table A.2	0	
LMTD, CF, C LMTD, C	140.6 141.29		C3 from Table A.3 Material of Construction Factor, FM from Figure A.18	0	Vertical Process Vessel (SS clad)
Delta T (Hot in Cold Out)	231.1		Identification Number	5.1	Vertical Process Vessel (SS clad) Vertical Process Vessel (SS clad)
Delta T (Hot Out Cold in)	78.4		Bare Module Factor, FBM	18.96132007	B1(B2*Fm*Fp)
Correction Factor	0.995		B1 from Table A.4	2.25	Vertical Process Vessel
	rrelation- HEX		B2 from Table A.4	1.85	Vertical Process Vessel
Purchase Cost, Cp	\$ 55,405.91		Contingency, Ccont	159857.4242	0.15*CBM
Installed Cost, CBM	\$ 148,570		Fee, Cfee	31971.48484	0.03*CBM
Equipment Purchase Cost, Cp0 K1 from Table A.1	\$ 20,475		21	016 Costs 547	
K1 from Table A.1 K2 from Table A.1	4.8306		Chemical Engineering Plant Cost Index in 2016 Chemical Engineering Plant Cost Index in 2012	547	
K3 from Table A.1	-0.8509		Purchase Cost, Cp	\$ 699,534.01	Cp*(CEPCI ₂₀₁₆ /CEPCI ₂₀₁₂)
Area.m2	53		Installed Cost, CBM	1468379.698	CBM*(CEPCI ₂₀₁₆ /CEPCI ₂₀₁₂)
Presure Factor, FP	1.00		Total Contengency	220256.9548	(
C1 from Table A.2	0.03881		Total Fees	44051.39095	
C2 from Table A.2	-0.11272		СТМ	\$ 1,732,688.04	CBM+Confengency+Fees
C3 from Table A.3	0.08183				
Material of Construction Factor, FM from Figure A.18	2.7				
Identification Number	5				
Bare Module Factor, FBM	7.26				
B1 from Table A.4	2.25	Vertical Process Vessel			
B2 from Table A.4	1.85	Vertical Process Vessel			
Contingency, Ccont Fee, Cfee	22285.52584 4457.105167	0.15*CBM 0.03*CBM			
	4457.105187 16 Costs	0.05 (CBW			
Chemical Engineering Plant Cost Index in 2016	547				
Chemical Engineering Plant Cost Index in 2012	397				
Purchase Cost, Cp	\$ 76,340.14	Cp*(CEPCI ₂₀₁₆ /CEPCI ₂₀₁₂)			
Installed Cost, CBM	204704.998	CBM*(CEPCI ₂₀₁₆ /CEPCI ₂₀₁₂)			
Total Contengency	30705.7497				
Total Fees	6141.149941	(m)			
CTM	\$ 241,551.90	CBM+Confengency+Fees			

	ninnerett			Costing: Extruder	and Co	Reactor Sizing an
		Pressure, (barg)		and Specifications		
	49.653	kW		nditions		
Quoted P	\$ 985,462.00	CBM		105,631		Nylon 6,6 Flow Rates, (kg/day)
Quotean	\$ 505,402.00	com		1.223		kg/s
	\$ 1,357,802.81	CBM		280		emperature, C
	\$ 40,734.08	Contengency		51.352		W
	\$ 40,734.08	Fees	Peters and Timmerhause	Twin Screw		ype of Extruder
	\$ 1,439,270.97	CTM				ressure, (barg)
	ĺ		Top Price	\$ 130,000.00	\$	p based on Flow
				532303.36		BM
						TM
	e Tank (Pellets)			15969.1008		ees
	ions and Specifications			79845.504		ontengency
	t Conditions		2016 Adjusted Price		\$	p based on Flow
	-	Mass Flow HMDA, (kg/day)	2016 Adjusted Price		\$	BM
	-	Mass Flow Adipic Acid, (kg/day)	2016 Adjusted Price		\$	djusted Fees
	-	Mass Flow Water, (kg/day)	2016 Adjusted Price		\$	ijusted Contengency
	-	Mass Flow Nylon Salt, (kg/day)	949,890.00	\$ 949,900.04	\$	M
	105631.1	Mass Flow Nylon 6,6, (kg/day)				
	0.00	Mas Flow Diamine, (kg/day)				
338.5C= BP at 1 a	290	Temperature, C		20 1000100 BP	1	
	3.80	Pressure, (barg)		rate, lb/min		
	105631.10	Total Flow, (kg/day)	2 103		10	
	of Equipment					
Mass Bala	0.23	Xouring			1111	
Literat	1140.000	Density Nylon 6,6, (kg/m ³)				
Literat	105631.10	Total Flow Rate, (kg/day)			1111-	
						v
Density/Mass Flow R	92.65885965	(m³/day)				9 too poer 105 Screw extruder
	92.65885965	(m ³ /week)		Screw press	s s	2 10 ⁵
Store for a We	168	Time in Vessel, (hr)				Screw extruder
hr	7	(day)	type extruder	Ro		2
		Reaction Rate, ()				
	92.65885965	Volume, (m ³)		4 799 - 4		
	3.4	Diameter, (m)				Pug mill extruder
Heuri	3	L/D	Jan. 2002	to ne and wrolds	+11	
Verti		Orientation	1 10	10-1	10	10^4 10^{-3} 10^{-2}
Pressure of Vessel-Literat	145	Pressure, (psia)	() Longitude and in the	w rate, kg/s	flow r	Solids ff
	195	Design Pressure, (psia)		and the second se	-	in the second
	12.43	(barg)				
	eted/Batch Reactor (Ajitated)					
Cpo*Fp*	299763.7031	Purchase Cost, Cp		Dil Heater	al Oil	Therma
Cpo*F	694916.5006	Installed Cost, CBM		49.653		v
	62379.39998	Equipment Purchase Cost, Cp0	Alibaba Quoted Price		Ś	M
	3.4974	K1 from Table A.1	Alloud Quoted Thee	20,000.00	Ť	
	0.4485	K2 from Table A.1		\$ 27,556.68	Ś	BM
	0.1074	K3 from Table A.1			Ś	ontengency
	92.65885965	Volume,m3			\$	es .
	4.805491928	Presure Factor, FP			\$	M
	0	C1 from Table A.2			1	
	0	C2 from Table A.2				
	0	C3 from Table A.3				
Vertical Process Vessel (SS cl	1	Material of Construction Factor, FM from Figure A.18				
Vertical Process Vessel (SS cl	18	Identification Number				
B1(B2*Fm*	11.14016007	Bare Module Factor, FBM				
Vertical Process Ves	2.25	B1 from Table A.4				
Vertical Process Ves	1.85	B2 from Table A.4				
0.15*C	104237.4751	Contingency, Ccont				
0.03*0	20847.49502	Fee, Cfee				
	016 Costs	2				
	547	Chemical Engineering Plant Cost Index in 2016				
	397	Chemical Engineering Plant Cost Index in 2012				
		Purchase Cost, Cp				
Cp*(CEPCI ₂₀₁₆ /CEPCI	\$ 413,024.55	Purchase Cost, Cp				
					-	
Cp*(CEPCI ₂₀₁₆ /CEPCI ₂ CBM*(CEPCI ₂₀₁₆ /CEPCI ₂	\$ 957,479.41	Installed Cost, CBM				
	\$ 957,479.41					

	Evaporator to CSTR 2	
sign Specs	T	
Pressure Change, (barg)	2.43	
ate, (lb/day)	105884	
Inlet flowrate, (lb/hr)	4412	-
raulic Power, hp	6.3	
ft Power, Brake hp	9.6	
Pump Efficiency	0.65	Set by Design Grou
chased Power, hp	11.3	
Motor Efficiency	0.849	Cat has Dealers Course
Actual Purchase Power, hp Actual Purchase Power, kW	11.19	Set by Design Grou
np pressure, barg	2.4	
пр Туре	Centrifugal	Set by Design Grou
np Material	Carbon Steel	Set by Design Grou
t Correlation- Pump		
chase Cost, Cp	6174.896583	
alled Cost, CBM	17770.23583	
ipment Purchase Cost, Cp0	4116.597722	
K1 from Table A.1	3.3892	
K2 from Table A.1 K3 from Table A.1	0.0536	
Shaft Power, KW	0.1538	
sure Factor, FP	1.00	
C1 from Table A.2	0.00000	
C2 from Table A.2	0.00000	Pressure >10
C3 from Table A.3	0.00000	
terial of Construction Factor, FM from Figure A.18	1.5	
Identification Number	38	
e Module Factor, FBM	4.32	
B1 from Table A.4 B2 from Table A.4	1.89	
tingency, Ccont	2665.535374	
Cfee	533.1070748	•
6 Costs		
mical Engineering Plant Cost Index in 2016	547	
nical Engineering Plant Cost Index in 2012	397	
hase Cost, Cp	\$ 8,508	
lled Cost, CBM	\$ 24,484	
Continuous Count		
	\$ 3,673	
I Fees, Cfee	\$ 3,673 \$ 735	
Il Fees, Cfee Il Module Capital, CTM Pump 3: Fl gn Specs	\$ 3,673	
i Fees, Cfee al Module Capital, CTM Pump 3: Fl gn Specs Pressure Change, (barg)	\$ 3,673 \$ 735 \$ 28,892	
I Fees, Cfee I Module Capital, CTM Pump 3: Fl gn Specs Pressure Change, (barg)	\$ 3,673 \$ 735 \$ 28,892 ash to Storage Tank 0.165	
I Fees, Cfee I Module Capital, CTM Pump 3: FI gn Specs Pressure Change, (barg) Intel: flowrate, (llb/hr) Linlet: flowrate, (llb/hr) Linlet: flowrate, (llb/hr)	\$ 3,673 \$ 735 \$ 28,892 ash to Storage Tank 0.165 8756 365 0.0351	
I Fees, Cfee I Module Capital, CTM Pump 3: Fl gin Specs Pressure Change, (barg) vrate, (Ib/day) Inlet flowrate, (Ib/hr) raulic Power, Pap Ft Power, Fap Ft P	\$ 3,673 \$ 735 \$ 735 \$ 28,892 ash to Storage Tank 0.165 8756 365 0.0351 0.0351	
I Fees, Cfee I Module Capital, CTM Pump 3: Fl gn Specs Pressure Change, (barg) rvrate, (lb(/day) Intel flowrate, (lb(/hr) raulic Power, hp Ft Power, hp Pump Efficiency	\$ 3,673 \$ 735 \$ 28,892 ash to Storage Tank 0.165 8756 365 0.0351 0.0340 0.0540 0.65	Set by Design Group
al Fees, Cfee al Module Capital, CTM Pump 3: FI gen Specs Pressure Change, (barg) wrate, (lh/day) Inlet flowrate, (lb/hr) aulic Power, hp ft Power, bp Pump Efficiency hased Power, hp	\$ 3.673 \$ 735 \$ 28.892 s 28.892 ash to Storage Tank 0.165 8756 305 0.0351 0.0540 0.65 0.0931	Set by Design Group
I Fees, Clee al Module Capital, CTM Pump 3: Fl gn Specs Pressure Change, (barg) wrate, (lb/day) intel flowrate, (lb/hr) raulic Power, hp Flower, Brake hp Pump Efficiency chased Power, hp Motor Efficiency	\$ 3.673 \$ 735 \$ 28,892 ash to Storage Tank 0.165 8756 0.0351 0.0340 0.0540 0.0540 0.0531 0.0540 0.0540 0.0540 0.0540	
al Fees, Cfee al Module Capital, CTM Pump 3: Fil gin Specs Pressure Change, (barg) Interf floware, (lip/hr) Interf floware, (lip/hr) Interf floware, hp Int Power, hp Motor Efficiency Actual Purchase Power, hp	\$ 3.673 \$ 735 \$ 28,892 sh to Storage Tank 0.165 8756 305 0.0351 0.058 0.0580 0.0581 0.05801 0.55	Set by Design Group Set by Design Group
I Fees, Cfee I Module Capital, CTM Pump 3: Fl gn Specs Pressure Change, (barg) rate, (Ib/dny) Inlet flowrate, (Ib/hr) aulic Power, Brake hp Pump Efficiency Pump Efficiency Motor Efficiency Actual Purchase Power, hp Actual Purchase Power, hp	\$ 3,673 \$ 735 \$ 28,892 ash to Storage Tank 0.165 8756 365 0.0351 0.0560 0.0351 0.05801 0.5801 0.5801 0.37	
I Fees, Cfee I Module Capital, CTM Pump 3: Fl gn Specs Pressure Change, (barg) Pressure Change, (barg) Intel flowrate, (liphr) raulic Power, hp Power, hp Power, hp Pump Efficiency Passed Power, hp Motor Efficiency Actual Purchase Power, hp Actual Purchase Power, kW po pressure, Barg	\$ 3,673 \$ 7,85 \$ 2,882 ash to Storage Tank 0.165 8756 365 0.0351 0.0350 0.0350 0.0540 0.65 0.0540 0.550 0.5 0.5 0.5 0.5 0.65 0.5 0.5 0.65	Set by Design Group
I Fees, Cfee I Module Capital, CTM Pump 3: Fl gin Specs Pressure Change, (barg) vrate, (Ib/day) Intel flowrate, (Ib/hr) Intel flowrate, (Ib/hr) Intel flowrate, Ib/hr) Andro Ffliciency Pump Efficiency Actual Purchase Power, hp Actual Purchase Power, kW Actual Purchase Power, kW Purchase Power, kW	\$ 3,673 \$ 735 \$ 28,892 ash to Storage Tank 0.165 8756 365 0.0351 0.0560 0.0351 0.05801 0.5801 0.5801 0.37	
I Fees, Cfee I Module Capital, CTM Pump 3: Fl gn Specs Pressure Change, (barg) rinter, (lb/day) Inter, (lb/day) Inter, (lb/hr) raulic Power, Apa, (lb/hr) Pump Efficiency Passure, (lb/hr) Motor Efficiency Actual Purchase Power, Mp Actual Purchase Power, Mp pressure, barg p Type p Material	\$ 3.673 \$ 735 \$ 28.892 \$ 28.892 ash to Storage Tank 0.165 8756 365 0.0351 0.0540 0.65 0.05801 0.5801 0.37 0.165 Centrifugal	Set by Design Group Set by Design Group
I Fees, Cfee I Hockule Capital, CTM Pump 3: Fl gn Specs Pressure Change, (barg) rrate, (Ib/dry) Intel flowrate, (Ib/hr) Intel flowrate, (Ib/hr) Intel flowrate, (Ib/hr) Intel flowrate, Ib/hr) Pump Efficiency Pump Efficiency Actual Purchase Power, hp Actual Purchase Power, hp Actual Purchase Power, hp porture, barg pp Space pp Material Correlation-Pump Correlation-Pump	\$ 3,673 \$ 735 \$ 28,892 ash to Storage Tank 0.165 8756 0.051 0.0540 0.0541	Set by Design Group Set by Design Group
IFees, Cfee I Module Capital, CTM Pump 3: Fl gn Specs Pressure Change, (barg) rate, (lb/day) Initel Towrate, (lb/hr) aulic Power, Ang Pump Efficiency Pump Efficiency Actual Purchase Power, hp Actual Purchase Power, kp Actual Purchase Power, kw Do pressure, Barg P Type P Material Correlation-Pump Base Cost, Cp Iied Cost, Cp	\$ 3,673 \$ 735 \$ 28,892 ash to Storage Tank 0.165 8,756 0.0351 0.0351 0.0351 0.0351 0.0351 0.0351 0.0351 0.0351 0.0351 0.0540 0.5801 0.37 0.165 Carbon Steel 3720.150868 10705.92152	Set by Design Group Set by Design Group
li Fees, Clee li Module Capital, CTM Pump 3: Fl gn Specs Pressure Change, (barg) rate, (bl/dy) Inlet flowrate, (lb/hr) aulic Power, Brake hp Pump Efficiency Pump Efficiency Actual Purchase Power, hp Actual Purchase Power, hp Actual Purchase Power, hp Actual Purchase Power, kW p ressure, Barg p Type p Material Correlation - Pump hade Cost, Cp Jiele Cost, CBM pumet Purchase Cost, Cp0	\$ 3.673 \$ 735 \$ 28,892 \$ 28,892 sash to Storage Tank 0.165 8756 365 0.0331 0.0540 0.65 0.0530 0.65 0.05801 0.65 Centrifugal Centrifugal Carbon Steel 3720.150868 10705.92152 2480.00579	Set by Design Group Set by Design Group
I Fees, Cfee I Module Capital, CTM Pump 3: Fl gn Specs Pressure Change, (barg) rete, (b)d/uy) Intel flowrate, (b)d/uy) Intel flowrate, (b)d/uy Intel flowrate, (b)d/uy Intel flowrate, (b)d/uy Pump Efficiency Flower, Parke hp Pump Efficiency Actual Purchase Power, hp Actual Purchase Power, M poressure, barg portype por	\$ 3,673 \$ 735 \$ 28,892 ash to Storage Tank 0.165 8756 0.0351 0.0540 0.5801 0.5801 0.5801 0.37 0.165 Centrifugal Carbon Steel 3720.150868 10705.92152 2480.100579 3.8927	Set by Design Group Set by Design Group
I Fees, Cfee I Module Capital, CTM Pump 3: FI gn Specs Pressure Change, (barg) autic Power, Parket, (bl/dhy) autic Power, Parket, Pp Pump Efficiency Natore Tiffciency Actual Purchase Power, Np Cartual Purchase Power, NP Correlation-Pump Parket al Correlation-Pump Pase Cost, Cp I from Table A.1 I from Table A.1	\$ 3.673 \$ 735 \$ 28,892 \$ 28,892 \$ 28,892 \$ 28,892 \$ 28,892 \$ 0.165 \$ 385 0.0.165 3756 0.0351 0.0540 0.05801 0.05801 0.0.165 Centrifugal Carbon Steel 3720.150868 10705.32152 2480.100579 3.8892 0.0536	Set by Design Group Set by Design Group
IFees, Cfee IModule Capital, CTM Pump 3: FI enspects Pressure Change, (barg) rest, (bl/day) intet flowrate, (bl/hr) aulic Power, Parke, (bl/hr) aulic Power, Rake, hp Pump Efficiency Pump Efficiency Actual Purchase Power, hp Actual Purchase Power, hp Actual Purchase Power, hp Paterial Orarelation-Pump Paterial Correlation-Pump Naterial Correlation-Pump Na	\$ 3,673 \$ 735 \$ 28,892 sh to Storage Tank 0.165 8776 0.051 0.0540 0.0541 0.0541 0.0541 0.0541 0.0541 0.0541 0.0541 0.0541 0.0541 0.0541 0.0541 0.0541 0.0541 0.0541 0.0541 0.0541 0.1551 3720.150868 10705.92152 2480.100579 3.3892 0.0536 0.5356	Set by Design Group Set by Design Group
IFees, Cfee I Module Capital, CTM Pump 3: FI strong Change, (barg) Pressure Change, (barg) rate, (lb/day) Initel Towrate, (lb/hr) aulic Power, Ang, Le Power, KW	\$ 3.673 \$ 735 \$ 28,892 \$ 28,892 \$ 28,892 \$ 28,892 \$ 0.165 8756 365 0.0351 0.0351 0.0931 0.5801 0.03801 0.65 Centrifugal Carbon Steel 10705.92152 2480100579 2480100579 3.3892 0.0536 0.0536 0.1538 0.1538	Set by Design Group Set by Design Group
I Fees, Cfee I Module Capital, CTM Pump 3: FI pressure Change, (barg) rate, (Ib/Any) inlet flowrate, (Ib/Any) inlet flowrate, (Ib/Any) Inlet flowrate, (Ib/Any) Inlet flowrate, (Ib/Any) Pump Efficiency Pump Efficiency Actual Purchase Power, hp Actual Purchase Power, hp Actual Purchase Power, hp Actual Purchase Power, My D pressure, Darg D Type D Material Correlation-Pump Inase Cost, Cp I form Table A.1 3 from Table A.1 Ant Power, KW Pump Efficiency Pump Addition Pump Purchase Power, KW Pump Pump Addition Pump Pump Pump Pump Addition Pump	\$ 3,673 \$ 735 \$ 28,892 sh to Storage Tank 0.165 8776 0.051 0.0540 0.0541 0.0541 0.0541 0.0541 0.0541 0.0541 0.0541 0.0541 0.0541 0.0541 0.0541 0.0541 0.0541 0.0541 0.0541 0.0541 0.1551 3720.150868 10705.92152 2480.100579 3.3892 0.0536 0.5356	Set by Design Group Set by Design Group
Fees, Cfee Module Capital, CTM Pump 3: FI rn Specs Pressure Change, (barg) rate, (lb/dny) Iniet flowrate, (lb/hr) Iniet flowrate, (lb/hr) Iniet flowrate, (lb/hr) Pump Efficiency Rade Power, hp Motor Efficiency Actual Purchase Power, hp Actual Purchase Power, hp Actual Purchase Power, hp Cartelation-Pump Do Page Do Naterial Correlation-Pump Sae Cost, Cp Ied Cost, CBM Somen Purchase Cost, Cp0 I from Table A.1 S f	\$ 3.673 \$ 735 \$ 28.892 \$ 28.892 ash to Storage Tank 0.0165 8726 365 0.0351 0.0540 0.65 0.0541 0.0540 0.65 0.0541 0.501 0.37 0.150 3720.150868 10705.92152 0.0536 0.0536 0.0536 0.0538 0.1533 0.4 1.00	Set by Design Group Set by Design Group
Fees, Cfee Module Capital, CTM Pump 3: FI A Specs Pressure Change, (barg) ate, (lb/day) ate, (lb/day) ate, (lb/day) Nullic Power, Pap Power, Brake Pp Pump Efficiency Power, Pap Motor Efficiency Actual Purchase Power, Np Actual Purchase Power, Np Atexial Correlation-Pump ase Cost, Cp Ied Cost, CSM ment Purchase Cost, Cp0 Irform Table A.1 Aim Power, KW re Factor, FP CL from Table A.2 C2 from Table A.3	\$ 3,673 \$ 735 \$ 28,892 ash to Storage Tank 0.165 8756 365 0.0351 0.0540 0.0551 0.0540 0.0551 0.0351 0.0540 0.0540 0.0541 0.0540 0.0541 0.5801 0.5801 0.377 0.1655 3720.150868 10705.92152 2480.100579 3.3892 0.0538 0.1538 0.1538 0.4538 0.44 1.04	Set by Design Group Set by Design Group Set by Design Group
Fees, Cfee Module Capital, CTM Pump 3: Fl Specs Pressure Ohange, (barg) ate, (lb/day) dite, (lb/day) dite, (lb/day) dite, Power, Braken, Power, Pomer, Braken, Power, Pomer, Pome	\$ 3.673 \$ 735 \$ 28,892 \$ 28,892 \$ 28,892 \$ 28,892 \$ 0.165 \$ 385 0.0.0540 0.0540 0.0540 0.0540 0.05801 0.05801 0.0.65 Centrifugal Carbon Steel 3720.150868 10705.92152 2480.100579 3.8892 0.0536 0.0536 0.4 1.000 0.40000 0.00000 0.00000	Set by Design Group Set by Design Group Set by Design Group
Fees, Cfee Module Capital, CTM Pump 3: FI A Specs Pressure Change, (barg) ate, (lb/day) inlet flowrate, (lb/hr) uille Power, Bra Ho Power, Brake hp Pump Efficiency ased Power, hp Motor Efficiency Actual Purchase Power, hp Actual Purchase Power, hp Actual Purchase Power, hp Actual Purchase Power, hp Actual Purchase Power, kW Urpersure, barg Type Material Carrelation-Pump ase Cost, Cp led Cost, CBM memet Purchase Cost, Cp0 1: from Table A.1 3: from Table A.1 3: from Table A.1 3: from Table A.1 3: from Table A.2 C2 from Table A.2 C2 from Table A.2 C3: from Table A.2	\$ 3.673 \$ 735 \$ 28.892 \$ 28.892 ash to Storage Tank 0.0165 8726 0.0351 0.0351 0.0540 0.65 0.0531 0.0540 0.65 0.0371 0.165 Carbon Steel 00705.92152 0.0356 0.0556 0.0556 0.0556 0.0556 0.0556 0.0556 0.0556 0.0556 0.0556 0.0556 0.0556 0.0556 0.0556 0.0556 0.00000 0.00000 0.00000 0.00000 0.00000	Set by Design Group Set by Design Group Set by Design Group
Fees, Cfee Module Capital, CTM Pump 3: Fl A Specs Pressure Change, (barg) ate, (lb/day) ate, (lb/day) uilc Power, Bap Power, Back to Dever, Bap Power, Back to Dever, Bap Power, Back to Dever, Bap Moort Efficiency Actual Purchase Power, Mp Actual Purchase Cower, Mp Actual Purcha	\$ 3.673 \$ 735 \$ 28,892 \$ 28,892 \$ 5 28,892 \$ 5 28,892 \$ 5 28,892 \$ 5 28,892 \$ 6 500 \$ 0.165 \$ 8756 \$ 0.0531 \$ 0.0540 \$ 0.651 \$ 0.0931 \$ 0.501 \$ 0.501 \$ 0.501 \$ 0.501 \$ 0.501 \$ 0.501 \$ 0.501 \$ 0.501 \$ 0.501 \$ 0.501 \$ 0.501 \$ 0.501 \$ 0.501 \$ 0.501 \$ 0.501 \$ 0.501 \$ 0.502 \$ 0.753 \$ 0.753 \$ 0.00000 \$ 0.00000 \$ 0.00000 \$ 0.00000 \$ 0.00000 \$ 0.00000 \$ 0.00000 \$ 0.00000 \$ 0.00000 \$ 0.00000 \$ 0.00000 \$ 0.000	Set by Design Group Set by Design Group Set by Design Group
Fees, Cfee Module Capital, CTM Pump 3: Fi ris Specs Pressure Change, (barg) arta([bf/dny) Intel flowrate, (lb/hr) Intel flowrate, (lb/hr) Intel flowrate, (lb/hr) Intel flowrate, (lb/hr) Pump Efficiency Rade Power, hp Motor Efficiency Actual Purchase Power, hp Actual Purchase P	\$ 3.673 \$ 735 \$ 28,892 \$ 28,892 \$ 28,892 \$ 28,892 \$ 28,892 \$ 385 0.0165 8756 \$ 3031 0.0540 0.65 0.0531 0.0540 0.05801 0.65 Centrifugal Centrifugal Carbon Steel 3720.150868 10705.92152 2480.100579 3.3892 0.4536 0.0556 0.4 1.000 0.00000 0.00000 1.53 38 38 4.32 1.89	Set by Design Group Set by Design Group Set by Design Group
If ees, Cfee If Active Change, Clear If Active Change, Clear Pressure Change, (barg) Pressure Change, (barg) Inite flowrate, (b(hr) Pump Efficiency Actual Purchase Power, hp Actual Purchase Power, hp Actual Purchase Power, hp Actual Purchase Power, hp Interfail Prope Ip Type Ip Type Ip Addrefail Correlation-Pump Interfail Correlation-Pump Interfail Correlation-Pump Interfail Correlation-Pump Interfail Correlation-Pump Interfail Correlation-Pump Interfail Correlation-Pump Correlation-Pump Interfail Correlation-Pump Interfail Correlation-Pump Correlation-Pump Interfail Correlation-Pump Correlation-Pump Correlation-Pump Interfail Correlation-Pump Correlatio	\$ 3,673 \$ 735 \$ 28,892 s to Storage Tank 0.0165 8776 300 0.0351 0.0351 0.0351 0.0351 0.0351 0.0351 0.0351 0.050 0.0351 0.0351 0.0351 0.0351 0.370 0.3801 0.0455 Carbon Steel 3720.150868 10705.92152 2480.100579 3.3892 0.4538 0.4 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00	Set by Design Group Set by Design Group Set by Design Group
al Fees, Cfee al Module Capital, CTM Pump 3: Fl ign Specs Pressure Change, (barg) wrate, (lb/day) Inlet: flowrate, (lb/hr) Iraulic Power, hp Fower, Faske hp Pump Efficiency Actual Purchase Power, hp Catual Purchase Power, hp Actual Purchase Power, NY Actual Purchase Power, NY Actual Purchase Power, NY Actual Purchase Power, NY Catron Table A.1 Staf Power, RVM Sure Factor, FP C1 from Table A.2 C3 from Table A.3 Identification Number Module Factor, FBM B1 from Table A.4 E2 from Table A.4	\$ 3.673 \$ 735 \$ 28,892 \$ 28,892 \$ 28,892 \$ 5 \$ 365 0.165 8756 0.0351 0.0351 0.0351 0.0540 0.0580 0.0931 0.0580 0.0531 0.015 0.165 Centrifugal Centrifugal Carbon Steel 10705 92152 2480.100579 3.3892 0.0536 0.4 1.000 0.00000 0.0536 0.4 1.000 3.892 0.4 3.20 1.5 38 0.4 3.2 1.5 3.8 0.4 3.2 1.5 3.8 1.5 3.8 1.5 3.8 1.5 3.8 1.5 3.8 1.5 3.8 1.5 3.8 <t< td=""><td>Set by Design Group Set by Design Group Set by Design Group</td></t<>	Set by Design Group Set by Design Group Set by Design Group
If Fees, Cfee If Gee, Cfee If Gee, Cfee If Gee, Charge, Charge	\$ 3,673 \$ 735 \$ 28,892 s to Storage Tank 0.0165 8776 300 0.0351 0.0351 0.0351 0.0351 0.0351 0.0351 0.0351 0.050 0.0351 0.0351 0.0351 0.0351 0.370 0.3801 0.0455 Carbon Steel 3720.150868 10705.92152 2480.100579 3.3892 0.4538 0.4 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00	Set by Design Group Set by Design Group Set by Design Group
If ees, Cfee If Adule Capital, CTM Pump 3: FI Pressure Change, (barg) Pressure Change, (barg) rete, (lb/day) Intel flowrate, (lb/hr) raulic Power, Rote, (lb/hr) Pump Efficiency Pump Efficiency Pump Efficiency Actual Purchase Power, Np Indeed Soft, CBM pumer Pador, FG Correlation- Pump Asse Cost, Cp Ison Table A.1 Saftom Table A.1 Saftom Table A.2 Caf from Table A.2 Caf from Table A.3 erial of Construction Factor, FM from Figure A.18 Identification Number Module Tactor, FBM Saftom Table A.4 Saftom T	\$ 3.673 \$ 735 \$ 28,892 \$ 28,892 \$ 28,892 \$ 5 \$ 365 0.165 8756 0.0351 0.0351 0.0351 0.0540 0.0580 0.0931 0.0580 0.0531 0.015 0.165 Centrifugal Centrifugal Carbon Steel 10705 92152 2480.100579 3.3892 0.0536 0.4 1.000 0.00000 0.0536 0.4 1.000 3.892 0.4 3.20 1.5 38 0.4 3.2 1.5 3.8 0.4 3.2 1.5 3.8 1.5 3.8 1.5 3.8 1.5 3.8 1.5 3.8 1.5 3.8 1.5 3.8 <t< td=""><td>Set by Design Group Set by Design Group Set by Design Group</td></t<>	Set by Design Group Set by Design Group Set by Design Group
al Fees, Cice al Module Capital, CTM Pump 3: Fl gin Specs Pressure Change, (barg) wrate, (lb/dy) Inlet flowrate, (lb/hr) Inlet flowrate, (lb/hr) Inlet flowrate, (lb/hr) Inlet flowrer, Brake hp Pump Efficiency Actual Purchase Power, hp Motor Efficiency Actual Purchase Power, hp Actual Purchase Power, NP Actual Purchase Power, NP popsense, barg po Type pap Material Correlation-Pump Chase Cost, Cp alled Cost, CBM Dipment Purchase Cost, Cp Alled Sch All Schorn Table A.1 K3 from Table A.1 K3 from Table A.2 C3 from Table A.2 C3 from Table A.3 Etrial of Construction Factor, FBM B1 from Table A.4 B2 from Table A.4 Cife Cost	\$ 3.673 \$ 735 \$ 28,892 \$ 28,892 \$ 28,892 \$ 28,892 \$ 28,892 \$ 0.155 \$ 0.0165 \$ 305 \$ 0.0331 \$ 0.050 \$ 0.0351 \$ 0.0351 \$ 0.6361 \$ 0.155 \$ Carbon Steel \$ 3720.150868 \$ 0.0536 \$ 0.0536 \$ 0.0536 \$ 0.0536 \$ 0.0536 \$ 0.0536 \$ 0.0536 \$ 0.4 \$ 1.00 \$ 3.892 \$ 3.89 \$ 3.89 \$ 3.39 \$ 1.43 \$ 1.35	Set by Design Group Set by Design Group Set by Design Group
ign Specs Pressure Change, (barg) Pressure Change, (barg) wrate, (llv/dav) linet flowrate, (llv/hr) fraulic Power, hp fr Dower, hp fr Dower, hp Motor Efficiency Actual Purchase Power, hp Actual Purchase Power, hp Actual Purchase Power, kW mp pressure, barg mp Type mp Type mp Material t Correlation-Pump Chase Cost, Cp0 lialed Cost, CB0 lialed Cost, CB0 lialed Cost, CB0 lialed Cost, CB0 liangent Purchase Cost, Cp0 Lift from Table A.1 SAf from Table A.1 C1 from Table A.2 C2 from Table A.2 C3 from Table A.3 treial of Costruction Factor, FM from Figure A.18	\$ 3.673 \$ 735 \$ 28.892 \$ 28.892 \$ 28.892 \$ 28.892 \$ 0.165 \$ 3726 \$ 0.0351 \$ 0.0351 \$ 0.0351 \$ 0.65 \$ 0.63 \$ 0.65 \$ 0.67 \$ 0.371 \$ 0.165 Certrifugal Certrifugal \$ 3720.150868 10705.92152 0.0536 \$ 0.4 \$ 0.4 \$ 0.4 \$ 0.4 \$ 0.4 \$ 3.892 \$ 3.892 \$ 3.892 \$ 3.892 \$ 1.5 \$ 3.892 \$ 1.5 \$ 3.892	Set by Design Group Set by Design Group Set by Design Group
If ees, Clee If ees, Clee If ees, Clee If ees, Clee If easily and	\$ 3,673 \$ 775 \$ 28,892 \$ 28,892 ash to Storage Tank 0.0165 8776 0.0351 0.0351 0.0540 0.0540 0.0540 0.0541 0.0542 0.0351 0.0351 0.0351 0.0351 0.0351 0.0351 0.037 0.165 Centrifugal Carbon Steel 0705.92152 0.03536 0.1538 0.03536 0.1538 0.03536 0.1538 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 <td>Set by Design Group Set by Design Group Set by Design Group</td>	Set by Design Group Set by Design Group Set by Design Group
al Fees, Cfee al Module Capital, CTM Pump 3: Fl ign Specs Pressure Change, (barg) wrate, (lb/day) Intel flowrate, (lb/hr) Intel flowrate, (lb/hr) Intel flowrate, (lb/hr) Intel flowrate, (lb/hr) Fump Efficiency Chased Power, hp Motor Efficiency Actual Purchase Power, hp Actual Purchase Power, hp Actual Purchase Power, kW mp pressure, barg mp Type Motor Efficiency Actual Purchase Power, KW Actual Purchase Power, KW Actual Purchase Power, KW Mp Actual Purchase Power, Power, Actual Purchase Mp Actual Purchase Power, Power, Purchase Power, Purchase Power, Power, Power, Power, Purchase Power, Power, Power, Power, Power, Power, Power, Purchase Power, Power, Power, Purchase Power, Power, Power, Purchase Power, Power, Power, Power, Power, Power, Power, Power, Power, Po	§ 3.673 § 735 § 28,892 s 28,892 sh to Storage Tank 0.165 0.766 385 0.0351 0.0351 0.0351 0.0540 0.056 0.0931 0.0580 0.0531 0.0581 0.0531 0.0165 0.77 0.165 0.7801 0.700 0.165 0.700 0.165 0.0591 0.0581 10705.92152 2480.100579 2480.100579 2.33892 0.0536 0.0536 0.0536 0.4 1.000 0.00000 0.00000 0.153 33 0.3382 1.05 332 1.15 1.85 1.15 1.85 1.15 1.15 1.15 1.15 1.15 1.15 1.15 1.15 1.15 321.1776457	Set by Design Group Set by Design Group Set by Design Group

Design Specs	denser to Flash Tank	
Pressure Change, (barg)	0.20	
Flowrate, (lb/day)	33728.73	
Inlet flowrate, (lb/hr)	1405	
Hydraulic Power, hp	0.1639	
Shaft Power, Brake hp Pump Efficiency	0.2521	Sat hu Dasign Crown
Purchased Power, hp	0.3731	Set by Design Group
Motor Efficiency	0.6758	
Actual Purchase Power, hp	0.5	Set by Design Group
Actual Purchase Power, kW	0.37	
Pump pressure, barg	0.2	
Pump Type	Centrifugal	Set by Design Group
Pump Material Cost Correlation- Pump	Carbon Steel	Set by Design Group
Purchase Cost, Cp	3720.150868	
Installed Cost, CBM	10705.92152	
Equipment Purchase Cost, Cp0	2480.100579	
K1 from Table A.1	3.3892	
K2 from Table A.1	0.0536	
K3 from Table A.1	0.1538	
Shaft Power, KW Presure Factor, FP	0.4	
C1 from Table A.2	0.00000	
C2 from Table A.2	0.00000	Pressure >10
C3 from Table A.3	0.00000	
Material of Construction Factor, FM from Figure A.18	1.5	
Identification Number	38	
Bare Module Factor, FBM	4.32	
B1 from Table A.4 B2 from Table A.4	1.89	
Contingency, Ccont	1605.888228	
Fee, Cfee	321.1776457	
2016 Costs		
Chemical Engineering Plant Cost Index in 2016	547	
Chemical Engineering Plant Cost Index in 2012	397 \$ 5,126	
Purchase Cost, Cp Installed Cost, CBM	\$ 14,751	
Total Contingency, Ccont	\$ 2,213	
Total Fees, Cfee	\$ 443	
Total Module Capital, CTM	\$ 17,406	
Pump 4	CSTR2 to Extruder	
Design Specs		
		Based on Extruder Pressure
Pressure Change, (barg)	17.570 105631.1	Based on Extruder Pressure
Pressure Change, (barg) Flowrate, (lb/day) inlet flowrate, (lb/hr)	17.570 105631.1 4401	Based on Extruder Pressure
Pressure Change, (barg) Flowrate, (lb/day) Inlet flowrate, (lb/hr) Hydraulic Power, hp	17.570 105631.1 4401 45.0908	Based on Extruder Pressure
Pressure Change, (barg) Flowrate, (lb/day) Inlet flowrate, (lb/hr) Hydraulic Power, hp Shaft Power, Brake hp	17.570 105631.1 4401 45.0908 64.4155	
Pressure Change, (barg) Flowrate, (lb/day) Inlet flowrate, (lb/hr) Hydraulic Power, hp Shaft Power, Brake hp Pump Efficiency	17.570 105631.1 4401 45.0908 64.4155 0.7	Based on Extruder Pressure Set by Design Group
Pressure Change, (barg) Flowrate, (lb/day) Inlet flowrate, (lb/hr) Hydraulic Power, hp Shaft Power, Brake hp Purp Efficiency Purchased Power, hp	17.570 105631.1 4401 45.0908 64.4155 0.77 70.8682	
Pressure Change, (barg) Flowrate, (lb/day) Inlet flowrate, (lb/hr) Hydraulic Power, hp Shaft Power, Brake hp Pump Efficiency Purchased Power, hp Motor Efficiency	17.570 105631.1 4401 45.0908 64.4155 0.7 70.8682 0.9089	Set by Design Group
Pressure Change, (barg) Flowrate, (lb/day) Inlet flowrate, (lb/hr) Hydraulic Power, hp Shaft Power, Brake hp Purp Efficiency Purchased Power, hp	17.570 105631.1 4401 45.0908 64.4155 0.77 70.8682	
Pressure Change, (barg) Flowrate, (b/day) Iniet flowrate, (b/hr) Hydraulic Power, hp Shaft Power, Brake hp Pumpe Efficiency Purchased Power, hp Motor Efficiency Actual Purchase Power, hp	17.570 105631.1 4401 64.4155 0.7 70.8682 0.9089 75 55.3 17.570	Set by Design Group Set by Design Group
Pressure Change, (barg) Flowrate, (b/day) Initel flowrate, (b/day) Initel flowrate, (b/hr) Hydraulic Power, hp Shaft Power, farske hp Purchased Power, hp Actual Purchase Power, hp Actual Purchase Power, hp Actual Purchase Power, hp Actual Purchase Power, hp Pump Type	17.570 105631.1 4401 45.0908 64.4155 0.77 70.8682 0.9089 75 55.93 17.570 Centrifugal	Set by Design Group Set by Design Group Set by Design Group Set by Design Group
Pressure Change, (barg) Pressure Change, (barg) Flowrate, (lb/day) Inlet flowrate, (lb/hr) Hydraulic Power, hp Shaft Power, Brake hp Puruhased Power, hp Motor Efficiency Actual Purchase Power, hp Actual Purchase Power, kW Purup pressure, barg Pump Type Pump Material	17.570 105631.1 4401 64.4155 0.7 70.8682 0.9089 75 55.3 17.570	Set by Design Group Set by Design Group
Pressure Change, (barg) Flowrate, (b/day) Initet Rowrate, (b/day) Initet Rowrate, (b/hr) Hydraulic Power, hp Shaft Power, Brake hp Purpt Efficiency Purchase Power, hp Actual Purchase Power, hp Actual Purchase Power, kW Purp pressure, Barg Purp Type Purp Material Cost Correlation - Purp	17.570 105631.1 4401 45.0908 64.415 0.7 77.8682 0.9089 75 55.93 17.570 Centrifugal Carbon Steel	Set by Design Group Set by Design Group Set by Design Group Set by Design Group
Pressure Change, (barg) Pressure Change, (barg) Flowrate, (lb/day) Intel flowrate, (lb/day) Shaft Power, bp Shaft Power, Brake hp Purdhased Power, hp Motor Efficiency Actual Purchase Power, hp Actual Purchase Power, hp Purdhase International Purchase Power, kW Pump pressure, barg Pump Type Pump Material Cost Correlation-Pump Purchase Cost, Cp	17.570 105631.1 4401 45.0908 64.4155 0.77 70.8682 0.9089 75 55.93 17.570 Certifugal Carbon Steel 16759.20905	Set by Design Group Set by Design Group Set by Design Group Set by Design Group
Pressure Change, (barg) Pressure Change, (barg) Flowrate, (b/day) Intel flowrate, (b/day) Shaft Power, hp Shaft Power, hp Purchase Power, hp Motor Efficiency Purchase Power, hp Actual Purchase Power, hp Actual Purchase Power, hp Actual Purchase Power, hp Catual Purchase Power, hp Pump Type Pump Material Cost Correlation-Pump Purchase Cost, Cp Installed Cost, CBM Equipment Purchase Cost, CpO	17.570 105631.1 4401 45.9908 64.4155 0.77 70.8632 0.9089 75 55.93 17.570 Centrifugal Carbon Steel 16759.20905 48229.97325 88964.188094	Set by Design Group Set by Design Group Set by Design Group Set by Design Group
Pressure Change, (barg) Pressure Change, (barg) Flowrate, (lb/day) Intel flowrate, (lb/thr) Hydraulic Power, hp Shaft Power, Brake hp Purup Efficiency Purchase Power, hp Actual Purchase Power, hp Actual Purchase Power, kW Purup pressure, barg Pump Material Cost Correlation- Pump Purchase Cost, Cp Installed Cost, CpM Equipment Purchase Cost, Cp0 K1 from Table A.1	17.570 105631.1 4401 45.0908 64.4155 0.7 70.8682 0.9089 75 55.93 17.570 Centrifugal Carbon Steel 16759.20905 4829.97325 8966.188004 3.3892	Set by Design Group Set by Design Group Set by Design Group Set by Design Group
Pressure Change, (barg) Pressure Change, (barg) Flowrate, (lb/day) Initel flowrate, (lb/hr) Hydraulic Power, hp Shaft Power, for Power, hp Purchased Power, hp Motor Efficiency Actual Purchase Power, hp Actual Purchase Power, hp Actual Purchase Power, hp Catual Purchase Power, hp Dump Drge Purp Type Purp Material Cost Correlation-Purp Purchase Cost, Cp0 Installed Cost, Cp0 Kt from Table A.1 K2 from Table A.1	17.570 105631.1 4401 45.0908 64.4155 0.77 70.8682 0.9089 75 55.93 17.570 Centrifugal Carbon Steel 16759.20905 4822.97325 8966.188094 3.3892 0.0536	Set by Design Group Set by Design Group Set by Design Group Set by Design Group
Pressure Change, (barg) Flowrate, (b/day) Inlet flowrate, (b/ldy) Inlet flowrate, (b/ldy) Shaft Power, hp Shaft Power, Brake hp Purchasel Power, hp Motor Efficiency Purchasel Power, hp Actual Purchase Power, hp Actual Purchase Power, kW Pump pressure, barg Pump Type Pump Type Purchase Cost, Cp Installed Cost, CBM Equipment Purchase Cost, Cp0 K1 from Table A.1 K3 from Table A.1 K3 from Table A.1	17:570 10:6631.1 4401 45:0908 64:4155 0.770.8682 0.9089 75 55:93 17:570 Centriage Carbon Steel 16759.20905 48229.97325 8966.18804 3.3892 0.6358 0.1538	Set by Design Group Set by Design Group Set by Design Group Set by Design Group
Pressure Change, (barg) Flowrate, (b/day) Initet Rowate, (b/hr) Hydraulic Power, hp Shaft Power, Brake hp Purnaed Rower, hp Motor Efficiency Purnaed Rower, hp Actual Purchase Power, kny Actual Purchase Power, kny Actual Purchase Power, kny Pump efficiency Pump efficiency Cost Correlation - Pump Cost Correlation - Pump Purchase Cost, Cp Installed Cost, CBM Equipment Purchase Cost, Cp0 K1 from Table A.1 K3 from Table A.1 Shaft Power, KW	17,570 105631.1 4401 45,093 64,4155 0.7 70,8652 0.0089 75 55,93 17,570 Centrifugal Carbon Steel 16759,20905 48229,97325 8956,188004 3,3892 0.0538 0.1538 55,9	Set by Design Group Set by Design Group Set by Design Group Set by Design Group
Pressure Change, (barg) Flowrate, (b/day) Inlet flowrate, (b/ldy) Inlet flowrate, (b/ldy) Shaft Power, hp Shaft Power, Brake hp Purchasel Power, hp Motor Efficiency Purchasel Power, hp Actual Purchase Power, hp Actual Purchase Power, kW Pump pressure, barg Pump Type Pump Type Purchase Cost, Cp Installed Cost, CBM Equipment Purchase Cost, Cp0 K1 from Table A.1 K3 from Table A.1 K3 from Table A.1	17:570 10:6631.1 4401 45:0908 64:4155 0.770.8682 0.9089 75 55:93 17:570 Centriage Carbon Steel 16759.20905 48229.97325 8966.18804 3.3892 0.6358 0.1538	Set by Design Group Set by Design Group Set by Design Group Set by Design Group
Pressure Change, (barg) Pressure Change, (barg) Flowrate, (b/day) Initel flowrate, (b/day) Initel flowrate, (b/hr) Shaft Power, fp Pump Efficiency Purchase Power, hp Actual Purchase Power, hp Actual Purchase Power, hp Actual Purchase Power, hp Pump Type Pump Material Cost Correlation-Pump Purchase Cost, Cp Installed Cost, CBM Equipment Purchase Cost, CpO K1 from Table A.1 K3 from Table A.1 K3 from Table A.1 K3 from Table A.2 C1 from Table A.2	17.570 105631.1 4401 45.0908 64.415 0.77 77.8682 0.9089 75 55.93 17.570 Carbon Steel 16759.2005 48269.297325 48266.18804 3.3892 0.0536 0.1538 55.9 1.55.9 1.55.9 0.3892 0.0536 0.1382 0.55.9 0.3892 0.0536 0.1382 0.0536 0.1382 0.0536 0.1382 0.0536 0.1382 0.0536 0.1382 0.0536 0.1382 0.0536 0.0536 0.0536 0.0536 0.0536 0.0536 0.0536 0.0536 0.0536 0.0556 0.0559 0.0556 0.0566 0.0566 0.0566 0.0566 0.0566 0.0566 0.0566 0.0566 0.0566	Set by Design Group Set by Design Group Set by Design Group Set by Design Group
Pressure Change, (barg) Flowrate, (lb/day) Inlet flowrate, (lb/hr) Hydraulic Power, hp Shaft Power, Brake hp Purnp Efficiency Purchased Power, hp Motor Efficiency Actual Purchase Power, hp Actual Purchase Power, hp Pump Type Pump Type Purp Adterial Cost Correlation - Pump Purchase Cost, Cp Hit from Table A.1 K1 from Table A.1 K3 from Table A.1 Shaft Power, KP Presure Factor, FP C1 from Table A.2 C2 from Table A.2 C3 from Table A.3	17.570 1056311 445098 64.4155 0.77 70.8682 0.9389 755 17.570 Centrifugal Carbo Steel 16759.20905 48229.9735 8866.188094 3.3892 0.0556 0.0558 0.0058	Set by Design Group Set by Design Group Set by Design Group Set by Design Group
Pressure Change, (barg) Flowrate, (b/day) Initel flowrate, (b/day) Initel flowrate, (b/day) Shaft Power, Brake hp Purnage fficiency Purnage fficiency Purnage fficiency Motor Efficiency Purnage for purchase Power, hp Actual Purchase Power, hp Actual Purchase Power, kW Pump pressure, barg Pump Type Pump Atterial Cost Correlation- Pump Octor Cost, Cp0 K1 from Table A.1 K2 from Table A.1 K3 from Table A.1 K3 from Table A.1 Shaft Power, KW Pressure Factor, FP C1 from Table A.2 C2 from Table A.3 C3 from Table A.3 C3 from Table A.3 C3 from Table A.3 C4 from Table A.3 C3 from Table A.3 C3 from Table A.3 C4 from Table A.3 C3 from Table A.3	17,570 105631.1 44010 45,0908 64,4155 0.7 70,8682 0.0399 75 55,3 17,570 Centrifugal (Carbon Steel 16759,20905 48229,97325 8956,188004 0.0538 0.0538 0.0538 0.0538 0.03559 1.255 0.0.39350 0.039570 0.00576 0.0	Set by Design Group Set by Design Group Set by Design Group Set by Design Group
Pressure Change, (barg) Flowrate, (b/day) Intel flowrate, (b/day) Intel flowrate, (b/day) Shaft Power, bp Shaft Power, Brake hp Purchase Power, hp Motor Efficiency Actual Purchase Power, hp Actual Purchase Power, hp Actual Purchase Power, hp Actual Purchase Power, hp Cost Correlation-Pump Pump Type Pump Material Cost Correlation-Pump Purchae Cost, Cp Installed Cost, Cp Installed Cost, Cp Installed Cost, Cp Right For Table A.1 K3 from Table A.1 K3 from Table A.1 K3 from Table A.1 C3 from Table A.2 C3 from Table A.3 Material of Construction Factor, FM from Figure A.18	17:570 10:6631.1 4401 45:0908 64:4155 0.077 70:8682 0.0889 75 55:93 17:570 Centrifugal Carbon Steel 16759.20905 48229.97325 8966.18804 3.3892 0.0536 0.1538 55:93 0.0536 0.1538 55:93 0.0536 0.33570 0.33570 0.03570 0.03550 0.0350 0.0350 0.0350 0.0350 0.0350 0.0350 0.03550 0.0350 0.0350 0.03550 0.0350 0.03550 0.03550 0.03550 0.0350 0.03550 0.0350 0.03500 0.03500 0.05500 0.05500 0.05500 0.05500 0.05500	Set by Design Group Set by Design Group Set by Design Group Set by Design Group
Pressure Change, (barg) Flowrate, (b/day) Initel flowrate, (b/day) Initel flowrate, (b/day) Shaft Power, Brake hp Purnage fficiency Purnage fficiency Purnage fficiency Motor Efficiency Purnage for purchase Power, hp Actual Purchase Power, hp Actual Purchase Power, kW Pump pressure, barg Pump Type Pump Atterial Cost Correlation- Pump Octor Cost, Cp0 K1 from Table A.1 K2 from Table A.1 K3 from Table A.1 K3 from Table A.1 Shaft Power, KW Pressure Factor, FP C1 from Table A.2 C2 from Table A.3 C3 from Table A.3 C3 from Table A.3 C3 from Table A.3 C4 from Table A.3 C3 from Table A.3 C3 from Table A.3 C4 from Table A.3 C3 from Table A.3	17,570 105631.1 44010 45,0908 64,4155 0.7 70,8682 0.0399 75 55,3 17,570 Centrifugal (Carbon Steel 16759,20905 48229,97325 8956,188004 0.0538 0.0538 0.0538 0.0538 0.03559 1.255 0.0.39350 0.039570 0.00576 0.0	Set by Design Group Set by Design Group Set by Design Group Set by Design Group
Pressure Change, (barg) Flowrate, (b/day) Initet Rowrate, (b/day) Initet Rowrate, (b/day) Shaft Power, hp Shaft Power, Brake hp Purp Efficiency Purchase Power, hp Actual Purchase Power, hp Actual Purchase Power, hp Actual Purchase Power, kW Pump pressure, barg Pump Type Pump Type Pump Material Cost, Correlation - Pump Cost, Correlation - Pump Purchase Cost, Cp K1 from Table A.1 K3 from Table A.1 Shaft Power, KW Pressure Factor, FP C1 from Table A.2 C2 from Table A.2 C3 from Table A.3 Material of Construction Factor, FM from Figure A.18 Identification Number Barer Module Ractor, FEM	17,570 105631.1 4401 45,098 64,4155 0.0,7 70,8682 0.0989 755 55,93 17,570 Certrifugal Carbon Steel 16759,20905 48229,97355 8896,188094 0.0534 0.0535 0.0559 1.255 0.039570 0.03	Set by Design Group Set by Design Group Set by Design Group Set by Design Group
Pressure Change, (barg) Pressure Change, (barg) Flowrate, (b/day) Initel flowrate, (b/day) Initel flowrate, (b/day) Shaft Rower, fp Shaft Rower, Brake hp Purdhaed Power, hp Actual Purchase Power, hp Actual Purchase Power, hp Actual Purchase Power, hp Catual Purchase Power, hp Catual Purchase Dower, hp Purp Pye Pump Tyde Pump Tyde Equipment Purchase Cost, Cp0 K1 from Table A.1 K3 from Table A.3 Data Purchase Cost, FM Bal from Table A.4 Ba Z fr	17,570 105631.1 4401 45,093 64,4155 0.7 70,8682 0.0089 75 55,93 17,570 Centrifugal Carbon Steel 16759.2005 48265.188004 0.0536 0.0536 0.01338 0.55.9 1.25 0.03350 0.33852 0.03350 0.33852 0.03350 0.33852 0.03350 0.1338 55.9 1.25 3.892 1.25	Set by Design Group Set by Design Group Set by Design Group Set by Design Group
Pressure Change, (barg) Flowrate, (lb/day) Initet flowrate, (lb/day) Initet flowrate, (lb/hr) Hydraulic Power, hp Shaft Power, Brake hp Purnbatefliciency Purchased Power, hp Motor Efficiency Actual Purchase Power, hp Actual Purchase Power, hp Actual Purchase Power, hp Pump Type Pump Type Pump Material Cost Correlation-Pump Purchase Cost, Cp Installed Cost, CBM Equipment Purchase Cost, CpO K1 from Table A.1 K3 from Table A.1 K3 from Table A.1 K3 from Table A.1 Shaft Power, KP C 2 from Table A.2 C3 from Table A.3 Material of Construction Factor, FM from Figure A.18 Identification Number Bare Module Factor, FBM B1 from Table A.4 B2 from Table A.4 Contragency, Ccont Fee, Cfee	17,570 10,6631,1 445,0908 64,4155 0,0,7 70,8682 0,9389 755 17,570 Centrifugal Carbo Steel 16759,20905 48229,9735 8366,18804 3,3892 0,0536 0,01538 55,93 16,559,00 16,559,00 16,559,00 16,559,00 16,559,00 16,559,00 16,559,00 16,559,00 16,559,00 16,559,00 16,559,00 17,570 1,570 1,5	Set by Design Group Set by Design Group Set by Design Group Set by Design Group
Pressure Change, (barg) Flowrate, (lb/day) Initel flowrate, (lb/day) Initel flowrate, (lb/h) Hydraulic Power, hp Shaft Power, Brake hp Purup Efficiency Purup Efficiency Motor Efficiency Purup Efficiency Purup Efficiency Purup Efficiency Actual Purchase Power, hp Actual Purchase Power, kW Pump pressure, barg Pump Type Pump Type Purthase Cost, Cp Installed Cost, CBM Equipment Purchase Cost, CpO K1 from Table A.1 K2 from Table A.1 K3 from Table A.1 K3 from Table A.1 C3 from Table A.2 C2 from Table A.2 C3 from Table A.2 C3 from Table A.2 C2 from Table A.2 C3 from Table A.4 B1 from Table A.4 B2 from Table A.4	17,570 105631.1 4401 45,098 64,4155 0.7 70,8582 0.0389 755 553 17,570 Centriflugal (Carbon Steel 16759,20905 48259,97325 8956,188094 0.0535 0.0535 0.0535 0.03570 0.03570 0.039570 0.039570 0.039570 0.039570 0.039570 1.155 3.03 0.039570 1.155 3.03 0.1518 3.1555 3.1555 3.	Set by Design Group Set by Design Group Set by Design Group Set by Design Group
Pressure Change, (barg) Flowrate, (lb/day) Initel flowrate, (lb/hr) Hydraulic Power, hp Shaft Power, Brake hp Purnbateflictency Purchased Power, hp Actual Purchase Power, hp Cost Correlation-Pump Pump Type Pump Material Cost Correlation-Pump Equipment Purchase Cost, CpO K1 from Table A.1 K3 from Table A.1 K3 from Table A.1 K3 from Table A.2 C3 from Table A.2 C3 from Table A.3 Material of Construction Factor, FM from Figure A.18 Identification Number Bar Module Factor, FEM B1 from Table A.4 B2 from Table A.4 B2 from Table A.4 Contingency, Cont Fee, Clee Z016 Costs Chemical Engineering Plant Cost Index in 2016	17,570 105631.1 4401 45,093 64,4155 0.7 70,8682 0.0089 75 55,93 17,570 Centrifugal Carbon Steel 16759.2005 48265.188004 0.0536 0.0536 0.01338 0.55.9 1.25 0.03350 0.33852 0.03350 0.33852 0.03350 0.33852 0.03350 0.1338 55.9 1.25 3.892 1.25	Set by Design Group Set by Design Group Set by Design Group Set by Design Group
Pressure Change, (barg) Flowrate, (lb/day) Inlet flowrate, (lb/hr) Hydraille Yower, hp Shaft Power, Brake hp Pump Efficiency Purchased Power, hp Actual Purchase Power, hp Actual Purchase Power, hp Actual Purchase Power, hp Actual Purchase Power, hw Pump pressure, barg Pump Type Pump Material Cost Correlation-Pump Purchase Cost, Cp Installed Cost, CpM Equipment Purchase Cost, Cp0 K1 from Table A.1 K3 from Table A.1 K3 from Table A.1 K3 from Table A.1 K3 from Table A.2 C.2 from Table A.2 C.2 from Table A.3 Material Grostruction Factor, FM from Figure A.18 Identification Number Bare Module Factor, FBM B1 from Table A.4 B2 from Table A.4 Contingency, Cont Fee, Clee 2016 Costs	17:570 10:6631.1 44001 45:0908 64:4155 0.07 70:8682 0.0889 75 55:93 17:570 Centrifugal Carbon Steel 16759.20905 48229.97325 8966.18804 48229.97325 0.0536 0.1538 8966.18804 1.25 0.0536 0.1538 0.03350 0.33570 0.035570 0.035570 0.035570 0.035570 0.035570 0.035570 0.035570 0.035570 0.03570	Set by Design Group Set by Design Group Set by Design Group Set by Design Group
Pressure Change, (barg) Flowrate, (lb/day) Inlet flowrate, (lb/hr) Hydraulic Power, hp Shaft Power, Brake hp Pump Efficiency Purchased Power, hp Actual Purchase Cost, Cp Pump Type Pump Type Purthase Cost, Cp K1 from Table A.1 K3 from Table A.1 K3 from Table A.1 Shaft Power, FW Presure Factor, FP C1 from Table A.2 C2 from Table A.3 Material of Construction Factor, FM from Figure A.18 Identification Number Bare Module Factor, FP C1 from Table A.4 B2 from Table A.4 B2 from Table A.4 Contingency, Coont Fee, Cfee 2016 Coast	17.570 1066311 445098 64.4155 0.7 70.8682 0.9393 75 5533 17.570 Cartrifugal Carbon Steel 16759.20905 48229.97355 8866.188094 3.3892 0.0536 0.1538 55.93 142.93350 0.0536 0.33570 0.33570 -0.39350 0.03571 -0.39350 -0.39350 -1.55 38 4.32 1.35 7234.495987 1446.595197 547 5 5 397 5 397 5 547 5 397 5 5 397 5 5	Set by Design Group Set by Design Group Set by Design Group Set by Design Group
Pressure Change, (barg) Flowrate, (Ib/day) Inlet flowrate, (Ib/hr) Hydraile Power, hp Shaft Power, Brake hp Pump Efficiency Purchased Power, hp Actual Purchase Power, kW Pump Efficiency Installed Cost, CBM Equipment Purchase Cost, Cp0 K1 from Table A.1 K2 from Table A.1 K3 from Table A.1 K3 from Table A.1 K3 from Table A.1 K3 from Table A.2 C2 from Table A.3 Material Gostruction Factor, FM from Figure A.18 Identification Number Bare Modul Factor, FM B.1 from Table A.4 B.2 from	17.570 105631.1 4401 45.0908 64.4155 0.7 70.8582 0.3089 753 553 17.570 Carbon Steel 16759.20005 48229.97325 8966.188094 3.3892 0.0536 0.0536 0.0536 0.03570 -0.00226 1.5 38 7234.495387 1446.893197 5 23071 5 387 5 387	Set by Design Group Set by Design Group Set by Design Group Set by Design Group
Pressure Change, (barg) Flowrate, (lb/day) Inlet flowrate, (lb/hr) Hydraulic Power, hp Shaft Power, Brake hp Pump Efficiency Purchased Power, hp Actual Purchase Cost, Cp Pump Type Pump Type Purthase Cost, Cp K1 from Table A.1 K3 from Table A.1 K3 from Table A.1 Shaft Power, FW Presure Factor, FP C1 from Table A.2 C2 from Table A.3 Material of Construction Factor, FM from Figure A.18 Identification Number Bare Module Factor, FP C1 from Table A.4 B2 from Table A.4 B2 from Table A.4 Contingency, Coont Fee, Cfee 2016 Coast	17.570 1066311 445098 64.4155 0.7 70.8682 0.9393 75 5533 17.570 Cartrifugal Carbon Steel 16759.20905 48229.97355 8866.188094 3.3892 0.0536 0.1538 55.93 142.93350 0.0536 0.33570 0.33570 -0.39350 0.43570 -0.00226 1.5 7234.495987 1446.593197 547 \$ 2.0,091 5 397 \$ 2.2,091	Set by Design Group Set by Design Group Set by Design Group Set by Design Group

		Pumo 5:	Evaporator P	ump			
	Design Spe			unp			
				2.42			
	Press Flowrate, (ure Change, (barg) Ib/day)		2.43 139264.5	From HYSYS		
		flowrate, (lb/hr)		5803	From HYSYS		
	Hydraulic F			8.2			
	Shaft Powe	er, hp Efficiency		12.6 0.65	Set by Design Group		
		/Break Power, hp		14.7	Set by Design Group		
		r Efficiency		0.859			
		l Purchase Power, hp		15	Set by Design Group		
		I Purchase Power, kW		11.19 2.1			
	Pump pres Pump Type			2.1 Centrifugal	Set by Design Group		
	Pump Mat			arbon Steel	Set by Design Group		
		ation- Pump					
	Purchase C			174.896583			
	Installed Co Equipment	ost, CBM Purchase Cost, Cp0		7770.23583 116.597722			
		1 Table A.1		3.3892			
		n Table A.1		0.0536			
		n Table A.1 ower, KW		0.1538			
	Presure Fa			11.2 1.00			
		om Table A.2		0.00000			
	C2 fro	om Table A.2		0.00000	Pressure >10		
		om Table A.3	<u> </u>	0.00000			
		f Construction Factor, FM from Figure A.18 ification Number	<u> </u>	1.5			
		le Factor, FBM		4.32			
	B1 from	n Table A.4		1.89			
		n Table A.4		1.35			
	Contingend Fee, Cfee	:y, Ccont		665.535374 33.1070748			
	2016 Costs						
	Chemical E	ngineering Plant Cost Index in 2016		547			
		ngineering Plant Cost Index in 2012		397			
	Purchase C Installed Co		\$	8,508 24,484			
		ngency, Ccont	\$	3,673			
	Total Fees,	Cfee	\$	735			
		ule Capital, CTM	\$	28,892			
	Utilities (Pelletized)					Utilities (Spun)	
	Service Factor					Service Factor	-
Service Factor	0.95		S	ervice Fa	ctor	0.95	
Days/yr	365		[Days/yr		365	
Hours/ day	24		H	lours/ day	y	24	
Operation Hours/yr	8322		0	Operatio	n Hours/yr	8322	
	Pump Electricity					Pump Electricity	
Total kW	180.05		1	otal kW		180.05	
Total kW-hr	1498369.442			otal kW		1498369.442	
Pice per kW-hr	\$ 0.0545	Calvert City, KS		Pice per l		\$ 0.0545	Calvert City, K
Total Price/yr	\$ 81,661.13	Calvert City, KS		Total Pric		\$ 81,661.13	Calvert City, K.
Total Price/yi				Otal Plic			
	Reactor Electricity (stiring)					or Electricity (stiring)	
Total kW	63.64			otal kW		113.29	
Total kW-hr	529570.47			otal kW		942782.736	
Pice per kW-hr	\$ 0.0545	Calvert City, KS		Pice per k		\$ 0.0545	Calvert City, K
Total Price/yr	\$ 28,861.59		L L	otal Pric	e/yr	\$ 51,381.66	
	Reactor Heating (Steam Jacket)				Reactor	Heating (Steam Jacket)	
Duty (J/s)	1291116458			Outy (J/s)		1291116458	
(Btu/h)	4405289355			(Btu/h)		4405289355	
Flow Rate, (lb/h)	4738398.79		F	low Rate		4738398.79	
1000 lb	4738.39879			1000 lb	· · · · ·	4738.39879	
Cost/1000 lb	4.75			Cost/1000	lb	4.75	
						\$ 22,507.39	
LOST	\$ 22 507 39		l c	Cost			
Cost	\$ 22,507.39 Cooling Water		0	Cost			
	Cooling Water			Cost		Cooling Water	
	Cooling Water Condenser 1	DI-10				Cooling Water Condenser 1	nkillise
Price for annual gpm	Cooling Water	Phillips	F	Price/1000) gal	Cooling Water	Phillips
Price for annual gpm Inlet CW Flow,	Cooling Water Condenser 1 \$ 120.00	Phillips	F	Price/1000 nlet CW	D gal Flow,	Cooling Water Condenser 1 \$ 120.00	Phillips
Price for annual gpm Inlet CW Flow, Flow Rate, lb/hr	Cooling Water Condenser 1 \$ 120.00 1228099.042	Phillips	F	Price/1000 nlet CW Flow Rate	D gal Flow,	Cooling Water Condenser 1 \$ 120.00 1228099.042	Phillips
Price for annual gpm Inlet CW Flow, Flow Rate, lb/hr gpm	Cooling Water Condenser 1 \$ 120.00 1228099.042 2465.591757	Phillips	F I F	Price/1000 nlet CW Flow Rate gpm	D gal Flow, e, lb/hr	Cooling Water Condenser 1 \$ 120.00 1228099.042 2465.591757	Phillips
Price for annual gpm Inlet CW Flow, Flow Rate, Ib/hr gpm Total Price/yr	Cooling Water Condenser 1 \$ 120.00 1228099.042	Phillips	F I F	Price/1000 nlet CW Flow Rate gpm Fotal Pric	D gal Flow, e, lb/hr e/yr	Cooling Water Condenser 1 \$ 120.00 1228099.042	Phillips
Price for annual gpm Inlet CW Flow, Flow Rate, lb/hr gpm	Cooling Water Condenser 1 \$ 120.00 1228099.042 2465.591757	Phillips	F I F	Price/1000 nlet CW Flow Rate gpm	D gal Flow, e, lb/hr e/yr	Cooling Water Condenser 1 \$ 120.00 1228099.042 2465.591757 \$ 295,871.01 1	Phillips
Price for annual gpm Inlet CW Flow, Flow Rate, Ib/hr gpm Total Price/yr	Cooling Water Condenser 1 \$ 120.00 1228099.042 2465.591757 \$ 295,871.01	Phillips	F 1 7	Price/1000 nlet CW Flow Rate gpm Fotal Pric	Dgal Flow, e, lb/hr re/yr f Water,	Source Source 12000 \$ 12000 1228099.042 2465.591757 \$ 295,871.01	Phillips
Price for annual gpm Inlet CW Flow, Flow Rate, Ib/hr gpm Total Price/yr Density of Water,	Cooling Water Condenser 1 \$ 120.00 1228099.042 2465.591757 \$ 295,871.01 1	Phillips	F 1 7 7	Price/1000 nlet CW Flow Rate gpm Total Pric Density o Heat Flow	Dgal Flow, e, lb/hr re/yr f Water,	Cooling Water Condenser 1 \$ 1228099.042 1228099.042 2465.591757 \$ 295,871.01 1	Phillips
Price for annual gpm Inlet CW Flow, Flow Rate, Ib/hr gpm Total Price/yr Density of Water, Heat Flow, Btu/hr	Cooling Water Condenser 1 \$ 120.00 1228099.042 2465.591757 \$ 295,871.01 1 40527268	Philips	F 1 7 1 1 5	Price/1000 nlet CW Flow Rate gpm Total Pric Density o Heat Flow	0 gal Flow, e, lb/hr ie/yr f Water, etu/hr etat (Water), Btu/lbF	S 120.00 \$ 120.00 1228099.042 2465.591757 \$ 295,871.01 1 40527268	Phillips
Price for annual gpm Inlet CW Flow, Flow Rate, lb/hr gpm Total Price/yr Density of Water, Heat Flow, Btu/hr Specific Heat (Water), Btu/lbF CW out Temp, C	Cooling Water Condenser 1 \$ 120.00 1228099.042 2465.591757 \$ 295,871.01 1 40527268 1 1	Phillips	F 1 7 1 1 5 7 6 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7	Price/1000 nlet CW Flow Rate gpm Total Price Density o Jeas Flow Specific H CW out Te	2 gal Flow, e, lb/hr fe/yr f Water, , Btu/hr leat (Water), Btu/lbF mp, C	Source Source \$ 120.00 1228099.042 2465.591757 \$ 295,871.01 1 40527268 1 120.00	Phillips
Price for annual gpm Inlet CW Flow, Flow Rate, Ib/hr gpm Total Price/yr Density of Water, Heat Flow, Btu/hr Specific Heat (Water), Btu/IbF CW out Temp, C CW un Temp, C	Cooling Water Condenser 1 \$ 120.00 1228099.042 2465.591757 \$ 295,871.01 1 40527268 1 1 120.0	Phillips	Г Г Г Г С С С	Price/1000 nlet CW Flow Rate gpm Total Pric Density o Heat Flow Specific H	D gal Flow, e, b/hr e/yr f Water, , Btu/hr Heat (Water), Btu/lbF mp, C	Source Source 12000 12000 1228099.042 2465.591757 \$ 295,871.01 1 40527268 1	Phillips
Price for annual gpm Inlet CW Flow, Flow Rate, Ib/hr gpm Total Price/yr Density of Water, Heat Flow, Btu/hr Specific Heat (Water), Btu/IbF CW out Temp, C	Cooling Water Condenser 1 \$ 120.00 1228099.042 2465.591757 \$ 295,871.01 40527268 1 1 1200.0 87.00 33.0	Phillips	Г Г Г Г С С С	Price/1000 nlet CW Flow Rate gpm Fotal Pric Density o Heat Flow Specific H CW out Ten CW in Ten	D gal Flow, e, b/hr e/yr f Water, , Btu/hr Heat (Water), Btu/lbF mp, C	Cooling Water Condenser 1 \$ 120.00 1228099.042 2465.591757 \$ 295,871.01 1 40527268 1 12000 87.00 33.0	Phillips
Price for annual gpm Inlet CW Flow, Flow Rate, lb/hr gpm Total Price/yr Density of Water, Heat Flow, Btu/hr Specific Heat (Water), Btu/lbF CW out Temp, C CW in Temp, C Temp Difference	Cooling Water Condenser 1 \$ 120.00 1228099.042 2465.591757 \$ 295,871.01 40527268 1 120.0 87.00 33.0 Hot Oil	Philips	F I F F C C C C C C C C	Price/1000 nlet CW Flow Rate gpm Total Price Density o Heat Flow Specific H CW out Te CW out Te CW in Ten Temp Diffe	D gal Flow, e, lb/hr ie/yr f Water, btu/hr btu/tr eat (Water), Btu/lbF emp, C mp, C rp, C erence	Cooling Water Condenser 1 \$ 1228099.042 2465.591757 \$ 295,871.01 40527268 1 1 1 1 1 2 120.0 87.00 33.0 Hot Oil	Phillips
Price for annual gpm Inlet CW Flow, Flow Rate, lb/hr gpm Total Price/yr Density of Water, Heat Flow, Btu/hr Specific Heat (Water), Btu/lbF CW un Temp, C CW in Temp, C	Cooling Water Condenser 1 \$ 120.00 1228099.042 2465.591757 \$ 295,871.01 40527268 1 1 1200.0 87.00 33.0	Phillips	F I F F C C C C C	Price/1000 nlet CW Flow Rate gpm Fotal Pric Density o Heat Flow Specific H CW out Ten CW in Ten	D gal Flow, e, lb/hr ie/yr f Water, btu/hr btu/tr eat (Water), Btu/lbF emp, C mp, C rp, C erence	Cooling Water Condenser 1 \$ 120.00 1228099.042 2465.591757 \$ 295,871.01 1 40527268 1 12000 87.00 33.0	Phillips

Appendix D: Batch Production Process

	ting: Jacketed/Batch 1 (Ajit	ated)
	tions and Specifications	
	et Conditions	
1ass Flow HMDA, (kg/day)	54239.17058 68208.897	
1ass Flow Adipic Acid, (kg/day) 1ass Flow Water, (kg/day)	8408.234904	
lass Flow Nylon Salt, (kg/day)	0400.234304	
1ass Flow Nylon 6,6, (kg/day)		
emperature, C	25	
	let Conditions	
lass Flow HMDA, (kg/day)		
lass Flow Adipic Acid, (kg/day)	-	
lass Flow Water, (kg/day)	8408.234904	
1ass Flow Nylon Salt, (kg/day)	122447.614	
lass Flow Nylon 6,6, (kg/day)	-	
emperature, C	250	
Sizing	g of Equipment	
otal Mass Flow Out, (kg/day)	130855.8489	
IDA	0.52	Mass Balance
HMDA	0.41	Mass Balance
120	0.06	Mass Balance
ensity ADA, (kg/m ³)	1359.998997	Literature
ensity HMDA, (kg/m ³)	840052384	Literature
ensity Water, (kg/m ³)	999.997995	Literature
ensity, (kg/m ³)	344422245	Eiterature
······································	344422243	
tal Elou Pate (ka/kr)	E452 245022	
tal Flow Rate, (kg/hr)	5452.345937	Density (Manual)
(m³/day)	1.58304E-05	Density/Mass Flow Rate
me in Vessel, (hr)		Reaction Time
(day)	_ _	hr/24
eaction Rate, (lb/mol/s)	6.0475	From Literature 95% Confidence
olume, (m³)	27	Material Balance
ameter, (m)	2.3	· · · · · · · · · · · · · · · · · · ·
)	3	Heuristic
essure, (psia)	145	Pressure of Vessel-Literature
sign Pressure, (psia)	195	
(barg)	12.43	
ity, (kW)	57.34084483	Shaft Work
	eted/Batch Reactor (Ajitat	ted)
rchase Cost, Cp	763199.1005	Cpo*Fp*Fm
stalled Cost, CBM	1577055.05	Cpo*FBM
uipment Purchase Cost, Cp0	73394.09529	
K1 from Table A.1	4.1052	Volume Min: 0.1 m ³ Max: 35 m ³
K2 from Table A.1	0.5320	Volume Min: 0.1 m ³ Max: 35 m ³
K3 from Table A.1	-0.0005	Volume Min: 0.1 m ³ Max: 35 m ³
Volume,m3	27	
resure Factor, FP	3.35440143	
C1 from Table A.2	0	
C2 from Table A.2	0	
C3 from Table A.3	0	
laterial of Construction Factor, FM from Figure A.18	3.1	Vertical Process Vessel (SS clad)
Identification Number	20	Vertical Process Vessel (SS clad)
are Module Factor, FBM	21.4874922	B1(B2*Fm*Fp)
B1 from Table A.4	2.25	Vertical Process Vessel
B2 from Table A.4	1.85	Vertical Process Vessel
ntingency, Ccont	236558.2576	0.15*CBM
e, Cfee	47311.65151	0.03*CBM
	2016 Costs	
emical Engineering Plant Cost Index in 2017	547	
nemical Engineering Plant Cost Index in 2012	397	
urchase Cost, Cp	1051561.481	Cp*(CEPCI ₂₀₁₆ /CEPCI ₂₀₁₂)
nstalled Cost, CBM	2172919.679	CBM*(CEPCI ₂₀₁₆ /CEPCI ₂₀₁₂
otal Contengency	325937.9518	
otal Fees	65187.59037	
otal rees		

	g and Costing: Evaporator	
	litions and Specifications et Conditions	
Ini Mass Flow HMDA, (kg/day)	et Conditions	
Mass Flow Adipic Acid, (kg/day)		
Mass Flow Water, (kg/day)	16817	
Mass Flow Nylon Salt, (kg/day)	122447.614	
Mass Flow Nylon 6,6, (kg/day)	-	
Temperature, C	250	338.5C= BP at 1 atn
Pressure, (barg)	10.00	
Total Flow, (kg/day)	139264.614 tlet Conditions	
Mass Flow HMDA, (kg/day)		
Mass Flow Adipic Acid, (kg/day)		
Mass Flow Water, (kg/day)	24973	
Mass Flow Nylon Salt, (kg/day)	105884.23	
Mass Flow Diamine, (kg/day)	8756.22	
Mass Flow Nylon 6,6, (kg/day)		
Temperature, C	280	338.5C= BP at 1 atn
F	536	
Pressure, (barg)	10.000	
Temperature of Hot Oil, F	599.000	Low Pressure Steam
c	315.000	
Total Flow, (kg/day)	139613	
	g of Equipment	
Volume, (ft ³)	183.4796701	
m3	5.195560775	2013.56
Diameter, (ft)	4.270305425	
m	1.301589094	
Heat Flow (Qo), Btu/hr	497,240.43	m/latent heat
Uo. Btu/hrFft ²	400	Literature 400-2000
Delta T, F	54.000	changed to Fahrenheit
LMTD, CF, F	86.8	
LMTD, F	87.23	
Delta T (Hot in Cold Out), F	63.0	
Delta T (Hot Out Cold in), F	117.0	
Correction Factor	0.995	
Area, (ft ²)	14.3221348	
m2	1.3305693	
	relation- Evaporator	
Purchase Cost, Cp	362448.503	Cpo*Fp*Fn
Installed Cost, CBM	\$ 922,571.86	Cpo*FBN
Equipment Purchase Cost, Cp0	\$ 116,945.80	87891.54938
K1 from Table A.1	5.0238	
K2 from Table A.1 K3 from Table A.1	0.3475	
Area, (m2)	1.330569292	
Presure Factor, FP	1.00	
C1 from Table A.2	0.15780	
C2 from Table A.2	-0.29920	
C3 from Table A.3	0.14130	
Material of Construction Factor, FM from Figure A.18	3.1	Vertical Process Vessel (SS
Identification Number	20	Vertical Process Vessel (SS
Bare Module Factor, FBM	7.890701031	B1(B2*Fm*Fp
B1 from Table A.4	2.25	Vertical Process Vessel
B2 from Table A.4 Contingency, Ccont	1.82 138385.7795	Vertical Process Vessel 0.15*CBN
Fee, Cfee	27677.1559	0.03*CBN
	2016 Costs	3.05 CBW
Chemical Engineering Plant Cost Index in 2016	547	
Chemical Engineering Plant Cost Index in 2012	397	
Purchase Cost, Cp	\$ 499,393.78	Cp*(CEPCI ₂₀₁₆ /CEPCI ₂₀₁₂
Installed Cost, CBM	\$ 1,271,150.65	CBM*(CEPCI ₂₀₁₆ /CEPCI ₂₀₁₂
Total Contengency	\$ 190,672.60	
Total Fees	\$ 38,134.52	
СТМ	\$ 1,499,957.77	CBM+Confengency+Fee

Reactor Sizing and Cost	ting: Flash Drum		Storage	Tank (Diamine)	
Process Conditions and				ions and Specifications	
Inlet Condit				t Conditions	
Mass Flow HMDA, (kg/day)	-		Mass Flow HMDA, (kg/day)	-	
Mass Flow Adipic Acid, (kg/day)	-		Mass Flow Adipic Acid, (kg/day)	-	
Mass Flow Water, (kg/day)	24973		Mass Flow Water, (kg/day)	-	
Mass Flow Nylon Salt, (kg/day)	-		Mass Flow Nylon Salt, (kg/day)	-	
Mass Flow Nylon 6,6, (kg/day)	-		Mass Flow Nylon 6,6, (kg/day)		
Mas Flow Diamine, (kg/day)	8756.22	342C= BP at 20 psia	Mas Flow Diamine, (kg/day)	8756.22	
Temperature, C Pressure, (barg)	3.812	55.3	Temperature, C Pressure, (barg)	3.80	338.5C= BP at 1 atr
Total Flow, (kg/day)	33728.72756	55.5	Total Flow, (kg/day)	8756.22	
Outlet Condi				of Equipment	
Mass Flow HMDA, (kg/day)	-		X _{Diamine}	0.23	Mass Balance
Mass Flow Adipic Acid, (kg/day)			Density Diamine, (kg/m ³)	839.599	Literatur
Mass Flow Water, (kg/day)	24972.50756		Total Flow Rate, (kg/day)	8756.22	
Mass Flow Nylon Salt, (kg/day)	-		(m ³ /day)	10.42905264	Density/Mass Flow Rat
Mass Flow Nylon 6,6, (kg/day)	-		(m ³ /week)	73.00336849	
Mas Flow Diamine, (kg/day)	8756.22	342C= BP at 20 psia	Time in Vessel, (hr)	168	Store for a Wee
Temperature, C	110	109.32C= BP at 20 psia	(day)	7	hr/2
Pressure, (barg)	0.084		Reaction Rate, ()		,
Total Flow, (kg/day)	33728.72756		Volume, (m ³)	73.00336849	
Sizing of Equi			Diameter, (m)	3.1	
Overall Temp, C	109		L/D	3	Heurist
Overall Pressure, (barg)	0.084		Orientation	5	Vertica
	0.23	Mass Balance	Pressure, (psia)	145	Pressure of Vessel-Literatur
X _{Diamine} X _{H2O}	0.23	Mass Balance	Design Pressure, (psia)	195	Fressure of Vessel-Elteratur
AH20 Density Diamine, (kg/m ³)	0.116	Literature		193	
			(barg)	12.43 eted/Batch Reactor (Ajitate	0
Density Water, (kg/m ³)	0.018	Literature			
Density, (kg/m ³)	0.0407		Purchase Cost, Cp	227484.6077	Cpo*Fp*Fr
(ft ³ /day)	2.257028728	Density/Mass Flow Rate	Installed Cost, CBM	535184.2713	Cpo*FBN
(m ³ /day)	79.70634847	Conversion	Equipment Purchase Cost, Cp0	50816.7765	2
Volume, (m ³)	4.27		K1 from Table A.1	3.4974	Volume Min: 0.1 m ³ Max: 35 m
Diameter, (m)	1.219192399		K2 from Table A.1	0.4485	Volume Min: 0.1 m ³ Max: 35 m
Pressure, (psia)	20	Pressure of Vessel-	K3 from Table A.1	0.1074	Volume Min: 0.1 m ³ Max: 35 m
Design Pressure, (psia)	70		Volume,m3	73.00336849	
(barg)	3.81280228		Presure Factor, FP	4.47656509	
Cost Correlation-	89708.39275	Cpo*Fp*Fm	C1 from Table A.2 C2 from Table A.2	0	
Purchase Cost, Cp Installed Cost, CBM	227986.1914	Cpo*FBM	C3 from Table A.3	0	
Equipment Purchase Cost, Cp0	27566.96214	сро гым	Material of Construction Factor, FM from Figure A.18	1	Vertical Process Vessel (SS clac
K1 from Table A.1	27566.96214	Min: 0.1 m ³ Max: 35 m ³	Identification Number	1	
K1 from Table A.1 K2 from Table A.1	4.1052	Min: 0.1 m Max: 35 m Min: 0.1 m ³ Max: 35 m ³	Bare Module Factor, FBM	10.53164542	Vertical Process Vessel (SS clac B1(B2*Fm*Fg
K3 from Table A.1	-0.0005	Min: 0.1 m Max: 35 m Min: 0.1 m ³ Max: 35 m ³	B1 from Table A.4	10.53104542	Vertical Process Vesse
Volume,m3	4.27	Min: 0.1 m Max: 35 m	B2 from Table A.4	1.85	Vertical Process Vesse Vertical Process Vesse
Presure Factor, FP	4.27			80277.6407	
C1 from Table A.2	1.049741755		Contingency, Ccont Fee, Cfee	16055.52814	0.15*CBP 0.03*CBP
C2 from Table A.2	0			016 Costs	0.05 (6)
C3 from Table A.3	0		Chemical Engineering Plant Cost Index in 2016	547	
Material of Construction Factor, FM from Figure A.18	3.1	Vertical Process Vessel (SS)	Chemical Engineering Plant Cost Index in 2012	397	
Identification Number	20	Vertical Process Vessel (SS)	Purchase Cost, Cp	313435.9708	Cp*(CEPCI ₂₀₁₆ /CEPCI ₂₀₁
Bare Module Factor, FBM	8.270268963	B1(B2*Fm*Fp)	Installed Cost, CBM	737394.9532	CBM*(CEPCI ₂₀₁₆ /CEPCI ₂₀₁
B1 from Table A.4	2.25	Vertical Process Vessel	Total Contengency	110609.243	
B2 from Table A.4	1.85	Vertical Process Vessel	Total Fees	22121.8486	
Contingency, Ccont	34197.92871	0.15*CBM	СТМ	\$ 870,126.04	CBM+Confengency+Fee
Fee, Cfee	6839.585743	0.03*CBM			
2016 Cos					
Chemical Engineering Plant Cost Index in 2016	547				
Chemical Engineering Plant Cost Index in 2012	397	0.00000 (0000)			
Purchase Cost, Cp	123603.2515	Cp*(CEPCI ₂₀₁₆ /CEPCI ₂₀₁₂)			
Installed Cost, CBM	314127.0698	CBM*(CEPCI ₂₀₁₆ /CEPCI ₂₀₁₂)			
Total Contengency	47119.06047				
Total Fees	9423.812094				
CTM	\$ 370,669.94	CBM+Confengency+Fees			

Reactor Sizing and Costir	a. Condoncor from Ever	and a second		Deaster Since and Casti	an Inchested (Datch 2 (Alit	atod)
Reactor Sizing and Costin Process Conditio	ons and Specifications	orator			ng: Jacketed/Batch 2 (Ajit ons and Specifications	ated)
	le Information				Conditions	
	Conditions			Mass Flow HMDA, (kg/day)	-	
Inlet Process Temp, C	280	536		Mass Flow Adipic Acid, (kg/day)	-	
Pressure, psia Pressure, (barg)	159.7 10.00			Mass Flow Water, (kg/day) Mass Flow Nylon Salt, (kg/day)	105884.23	
Outle	t Conditions			Mass Flow Nylon 6,6, (kg/day)		
Outlet Process Temp, C	109	228.2		Temperature, C	280	
Pressure, psia	70.0			Outle	t Conditions	
Shell Side Design Pressure, barg	3.8 le Information			Mass Flow HMDA, (kg/day)	0	
	Conditions			Mass Flow Adipic Acid, (kg/day) Mass Flow Water, (kg/day)	252.25	
Inlet Cooling WaterTemp, F	87			Mass Flow Nylon Salt, (kg/day)	-	
Inlet Cooling WaterTemp, C	30.56			Mass Flow Nylon 6,6, (kg/day)	105631.1	
Outle	t Conditions			Temperature, C	280	
Outlet Steam Temp, F	120.0			Sizing c	of Equipment	
Outlet Steam Temp, C	48.9			Total Mass Flow Out, (kg/hr)	4411.80625	
	ign Specs			X _{Nylon 66}	0.99762	Mass Balance
	nt Description HEX			X _{H20}	0.00238	Mass Balance Literature
Equipment Type	Tubular			Density Nylon 66, (kg/m3)		
Equipment Description Tube Material	Stainless		1	Density Water, (kg/m3)	999.997995 1140	Literature
Shell Material	Stainless		1	Density, (kg/m3) Total Flow Rate, (kg/hr)	4411.842917	
Tube Side	Cooling Water		1	(m ³ /day)	3.871171957	Density/Mass Flow Rate
Shell Side	Process		1	Time in Vessel, (hr)	-	Reaction Time
HEX TEMA Type	AES		1	(day)		hr/24
Equipment Description	Floating Head		1	Reaction Rate Constant, (kg/mol/s)		From Literature 95% Confidence
	alculations			Volume, (m ³)	24	Levenspiel Plot
Density of Cooling Water, (lb/m ³)	2195.1	.652/.688btu/lbF		Diameter, (m)	2.2	
Mass Flow Input Process Stream, (lb/day)	307794.1356			L/D	3	Heuristic
Cp Steam, (btu/lbF)	1	Engineering Toolbox	c	Pressure, (psia)	145	Pressure of Vessel-Literature
Cp Diamine, (btu/lbF)	1.20237E-06	JCT Document		Design Pressure, (psia)	195	
X _{Diamine}	0.23	Mass Balance Entering		(barg)	12.43	
X _{H2O}	0.77	Mass Balance Entering		Duty, (J/s)	0	Adiabatic
Total Cp, (btu/lbF)	0.770000277	Calculated	1		ted/Batch Reactor (Ajitat	
Heat Flow (Qo), Btu/day Area of Heat Transfer (A0), m2	53.13726	m*Cp*LMTD 1.20237E-06		Purchase Cost, Cp Installed Cost, CBM	693474.0042 1438059.271	Cpo*Fp*Fm Cpo*FBM
Alea of fleat fraisier (A0), fliz	55.15720	1.20237E-06	2	Equipment Purchase Cost, Cp0	68947.71679	сротным
Overall Heat Transfer Coefficient (U0), Btu/hrft ² F	1200.0			K1 from Table A.1	4.1052	Volume Min: 0.1 m ³ Max: 35 m ³
Btu/dayft ² F	28800.0			K2 from Table A.1	0.5320	Volume Min: 0.1 m ³ Max: 35 m ³
Btu/daym ² F	2675.6			K3 from Table A.1	-0.0005	Volume Min: 0.1 m ³ Max: 35 m ³
Velocity 30-50, (ft/s)	50.0			Volume,m3	24	
ft/hr	180000.0			Presure Factor, FP	3.244506158	
m/hr	54864.0			C1 from Table A.2	0	
LMTD, CF, (F) LMTD, CF, C	285.1 140.6			C2 from Table A.2	0	
LMTD, C	140.8			C3 from Table A.3 Material of Construction Factor, FM from Figure A.18	3.1	Vertical Process Vessel (SS clad)
Delta T (Hot in Cold Out)	231.1			Identification Number	20	Vertical Process Vessel (SS clad)
Delta T (Hot Out Cold in)	78.4			Bare Module Factor, FBM	20.85724281	B1(B2*Fm*Fp)
Correction Factor	0.995			B1 from Table A.4	2.25	Vertical Process Vessel
	rrelation- HEX			B2 from Table A.4	1.85	Vertical Process Vessel
Purchase Cost, Cp Installed Cost, CBM	55405.91226 \$ 148,570		1	Contingency, Ccont Fee, Cfee	215708.8906 43141.77812	0.15*CBM 0.03*CBM
Equipment Purchase Cost, Cp0	\$ 20,475		1		43141.77812 16 Costs	0.03*CBM
K1 from Table A.1	4.8306		1	Chemical Engineering Plant Cost Index in 2016	547	
K2 from Table A.1	-0.8509			Chemical Engineering Plant Cost Index in 2012	397	
K3 from Table A.1	0.3187		1	Purchase Cost, Cp	955491.89	Cp*(CEPCI ₂₀₁₆ /CEPCI ₂₀₁₂)
Area,m2	53		<u> </u>	Installed Cost, CBM	1981406.602	CBM*(CEPCI ₂₀₁₆ /CEPCI ₂₀₁₂)
Presure Factor, FP	1.00 0.03881		+	Total Contengency	297210.9903	
C1 from Table A.2 C2 from Table A.2	-0.11272		1	Total Fees CTM	59442.19806 \$ 2,338,059.79	CBM+Confengency+Fees
C2 from Table A.2 C3 from Table A.3	-0.11272 0.08183		1	C I WI	× 2,538,059.79	CDIVI+CONTENGENCY+Fees
Material of Construction Factor, FM from Figure A.18	2.7		1			
Identification Number	5		1			
Bare Module Factor, FBM	7.26					
B1 from Table A.4	2.25	Vertical Process Vessel	1			
B2 from Table A.4	1.85	Vertical Process Vessel				
Contingency, Ccont Fee, Cfee	22285.52584 4457.105167	0.15*CBM 0.03*CBM				
	4437.105187 16 Costs	0.05 °CBW				
Chemical Engineering Plant Cost Index in 2016	547					
Chemical Engineering Plant Cost Index in 2012	397					
Purchase Cost, Cp	\$ 76,340.14	Cp*(CEPCI ₂₀₁₆ /CEPCI ₂₀₁₂)	4			
Installed Cost, CBM	204704.998	CBM*(CEPCI ₂₀₁₆ /CEPCI ₂₀₁₂)	4			
Total Contengency Total Fees	30705.7497 6141.149941		1			
CTM	\$ 241,551.90	CBM+Confengency+Fees				
	÷ 241,551.90	Controllengelity+Fees	1			

	pinnerett	<u>s</u>			sting: Extruder	nd Cos	Reactor Sizing a	
		Pressure, (barg)					Process Conditio	
	49.653	kW			tions	Conditi	Inlet	
Quoted P	\$ 985,462.00	CBM			105,631		g/day)	on 6,6 Flow Rates, (kg
					1.223			kg/s
	\$ 1,357,802.81				280			nperature, C
	\$ 40,734.08 \$ 40,734.08		T	Peters and Ti	51.352 Twin Screw			e of Extruder
	\$ 40,734.08 \$ 1,439,270.97		Timmernause	Peters and 1	Twin Screw			ssure, (barg)
	\$ 1,459,270.97	CIM	Top Price		130,000.00	s		based on Flow
			TopTrice		532303.36	7		M
								N
	e Tank (Pellets)	Storage			15969.1008			!S
	ions and Specifications	Process Condit			79845.504			ntengency
	t Conditions	Inlet	djusted Price	2016 Ad	179,118.39	\$		based on Flow
		Mass Flow HMDA, (kg/day)	djusted Price	2016 Ad	733,425.54	\$		N
	-	Mass Flow Adipic Acid, (kg/day)	djusted Price		110,013.83	\$		usted Fees
	-	Mass Flow Water, (kg/day)	djusted Price	2016 Ad	106,460.67	\$		usted Contengency
	-	Mass Flow Nylon Salt, (kg/day)			949,900.04	\$		N
	105631.1	Mass Flow Nylon 6,6, (kg/day)						-
	0.00	Mas Flow Diamine, (kg/day)						
338.5C= BP at 1 a	290	Temperature, C			a Defension		Solids flo	
	43141.78	Pressure, (barg)		0 ² 10 ³		ow rate 0		
	105631.10	Total Flow, (kg/day)			·	йн —	TATING TATIN	106
	of Equipment	Sizing						
Mass Bala	0.23	X _{Diamine}						
Literat	1140.000	Density Nylon 6,6, (kg/m ³)						
	105631.10	Total Flow Rate, (kg/day)						
Density/Mass Flow R	92.65885965	(m³/day)						Stl, S
	92.65885965	(m ³ /week)		/	rew press	Sci		Purchased cost, \$
Store for a We	168	Time in Vessel, (hr)			X	1	Screw extruder	chas
hr	7	(day)		-type extruder	Rol			Pun
		Reaction Rate, ()						
	92.65885965	Volume, (m ³)				TI .		
	3.4	Diameter, (m)					Pug mill extruder	
Heuri	3	L/D		Jan. 2002	autor woods	+		
Verti		Orientation	6	1 10	1	10-1	10 ⁻²	104 10-3
Pressure of Vessel-Literat	145	Pressure, (psia)		and the second second			Solids f	
	195	Design Pressure, (psia)		A CONTRACTOR AND A CONTRACT	and the second second		and the second se	
	12.43	(barg)						
	eted/Batch Reactor (Ajitated)							
Cpo*Fp*	299763.7031	Purchase Cost, Cp			leater	l Oil H	Therma	
Cpo*F	694916.5006	Installed Cost, CBM			49.653			
	62379.39998	Equipment Purchase Cost, Cp0	Quoted Price	Alibaba C	20,000.00	\$		M
-	3.4974	K1 from Table A.1						
	0.4485	K2 from Table A.1			27,556.68	\$		M
	0.1074	K3 from Table A.1			826.70	\$		ntengency
	92.65885965 4.805491928	Volume,m3 Presure Factor, FP		-	826.70 29,210.08	\$ \$		is M
	4.805491928	C1 from Table A.2			29,210.08	Ş		VI
	0	C2 from Table A.2						
	0	C3 from Table A.3						
Vertical Process Vessel (SS c	1	Material of Construction Factor, FM from Figure A.18						
Vertical Process Vessel (33 c	18	Identification Number						
B1(B2*Fm*	11.14016007	Bare Module Factor, FBM						
Vertical Process Ves	2.25	B1 from Table A.4						
Vertical Process Ves	1.85	B2 from Table A.4						
0.15*C	104237.4751	Contingency, Ccont						
0.03*C	20847.49502	Fee, Cfee						
	016 Costs							
	547	Chemical Engineering Plant Cost Index in 2016						
	397	Chemical Engineering Plant Cost Index in 2012						
Cp*(CEPCI ₂₀₁₆ /CEPCI ₂	413024.548	Purchase Cost, Cp						
CBM*(CEPCI ₂₀₁₆ /CEPCI ₂	\$ 957,479.41	Installed Cost, CBM						
	\$ 143,621.91							
	\$ 28,724.38							
CBM+Confengency+F	\$ 1,129,825.70	CTM						

Pressure Change, [ang]1Pressure Change, [ang]2.4.33Iwarte (Uylaw)10.884Iwarte (Uylaw)0.451Pung Efficancy0.65Vershard Newer, Irab A2.4Musc Efficiency0.65Actual Purchase Newer, Iw18.64Iwarp Pressure, Bargerow2.4Iwarp Pressure, Bargerow3.4Iwarp Pressu		Evaporator to CSTR 2	
lowards. (bi/wi)1958awited toward. (bi/wi)9726yrdaule Power, ha138AltPower, fask hap132Pump Efficiency0.65Actual Porthes Power, No2.22Motor efficiency0.876Actual Porthes Power, No12.54ump Pressure. Power, No12.64ump TypesCentrifiqueoutp MaterialCentro Steveset by Design Gro.2.764.44ump Attactial Control2.764.45varbase Cost, CDM2.714.45outp Material0.505.62.7000000000000000000000000000000000000	Design Specs		1
lowards. (bi/wi)1958awited toward. (bi/wi)9726yrdaule Power, ha138AltPower, fask hap132Pump Efficiency0.65Actual Porthes Power, No2.22Motor efficiency0.876Actual Porthes Power, No12.54ump Pressure. Power, No12.64ump TypesCentrifiqueoutp MaterialCentro Steveset by Design Gro.2.764.44ump Attactial Control2.764.45varbase Cost, CDM2.714.45outp Material0.505.62.7000000000000000000000000000000000000	Pressure Change, (barg)	2.43	
nike (horvate, (ip/h)9726half Novrate, (ip/h)13.8half Novrate, Brake hp21.2Pung Efficiency0.65Set by Design Gros3.75Actual Parbase Power, hp2.82Actual Parbase Power, hp2.84ump TypeCentrifuguSet by Design Gros3.84ump TypeCentrifuguSet by Design Gros3.84ump TypeCentrifuguump AttrialCentrifuguSet by Design Gros3.845stalled Cott, GD5.954 A490324Li Tom Table A.10.6556Shaft Power, RW13.6Shaft Power, RW13.6C G from Table A.10.0556Shaft Power, RW13.6C G from Table A.20.00000C G from Table A.30.00000C G from Table A.31.000000C G from Table A.41.100D from Table A.5			
pydraule Rower, hp138 121Pung BfGiency0.65Workhad Rower, hp0.22Motor Ellicency0.876Actual Purbase Power, NW18.64ump Pressure, Bower, NW18.64ump Typesare, Dewy, NW18.64ump Attactial Control54.04gegment Purchase Cost, CpO76.14.67336urchase Cost, CpQ76.14.6734621 Corratale A.13.382221 Corratale A.10.651621 Corratale A.10.651621 Corratale A.10.651621 Corratale A.20.6000021 Corratale A.20.6000021 Corratale A.20.6000021 Corratale A.30.6000021 Corratale A.30.6000022 Corratale A.30.6000021 Corratale A.30.6000022 Corratale A.30.6000022 Corratale A.30.6000022 Corratale A.30.6000022 Corratale A.30.6000023 Corratale A.30.6000024 Corratale A.30.6000025 Corratale A.30.6000026 Corratale A.30.6000027 Corratale A.30.60000 <td></td> <td></td> <td></td>			
Pump Efficiency0.65Set by Design GrouActual Packase Power, hp2.82Motor efficiency0.876Actual Packase Power, NW13.84ump Taysar, Days2.84ump Taysar, Days0.815set by Design GrouSet by Design Grouump MaterialCacheo Steeset Stee Group Group Material0.815ump Taysar, Days0.815set Stee Group Group Material0.815set Module Factor, FM from Figure A.181.5set Module Factor, FM3.03,13set Module Factor, FM from Figure A.181.5set Module Factor, FM3.03,13set Module Fa	Hydraulic Power, hp	13.8	
urchase Bower, hp Motor Efficiency 0.0275 Artual Purchase Power, Np Artual Purchase Power, Np Artual Purchase Power, NU map Fope Controlled The Controlled The Controlled The Controlled The Controlled	Shaft Power, Brake hp	21.2	
Motor efficiency0.876Artual Purbase Power, NW13.64ymp presure, Dway2.4ymp presure, Dway2.4ymp presure, Dway2.4ymp presure, Dway2.4ymp haterialCarbon Steelopt Gorrelation-PumpCarbon SteelymthaterialCarbon Steelopt Steel21913.65336ymthaterial0.8763ymthaterial0.8763ymthaterial0.8763ymthaterial0.8763ymthaterial0.8763ymthaterial0.8763ymthaterial0.8763ymthaterial0.8763ymthaterial0.8763ymthaterial0.8763ymthaterial0.8763ymthaterial0.8763ymthaterial0.8763ymthaterial0.8763ymthaterial0.8763ymthaterial0.8774 <td></td> <td></td> <td>Set by Design Grou</td>			Set by Design Grou
Artual Purbase Power, Np25Set by pregin GroArtual Purbase Power, NV13.64ump PyerCentrifulgiSet by Design Groump Artual Purbase Cost, Cp7614.67335outsace Cost, Cp7614.67335ump Artual Cost, Cp7614.67335ump Artual Purbase Cost, CpO3076.446021Li Tom Table A18.1562Li Tom Table A10.0156Li Tom Table A10.0156Suff Power, RV13.6Ca Tom Table A20.00000Ca Tom Table A20.00000Ca Tom Table A20.00000Ca Tom Table A20.00000Ca Tom Table A31.5deortfiction Number35are Module Factor, FM4.32B1 Tom Table A41.35Ca Tom Table A41.35Ca Tom Table A41.35B1 Tom Table A41.35B2 from Table A41.35B2 from Table A41.35B2 from Table A41.35B2 from Table A43.35,28TomTable A43.35,28Direst Factor, FM3.35,28Direst Factor, FM3.35,28Direst Factor, FD3.35,28Direst Factor, FD			
Actual Purchase Paver, NV18.64ump Tayesur, Nump2.24set by Design Group MaterialSet by Design Group Materialund MaterialCentrolitagiund Stardeloto, Fung7514.67335und Stardeloto, Cgo3076.446028All Stardeloto, Cgo20193.63356guinnet Turchase Cost, Cgo3076.446028La from Table A.10.0535Shaft Power, RW11.86C I from Table A.10.0536Shaft Power, RW11.86C I from Table A.20.00000Attarial C Cost.Crotic Patter Stard, P.P1.00C I from Table A.30.00000Attarial C Cost.Crotic Patter Stard, P.M.1.35Element Exc.P.R.M. Figure A.181.35Start Power, RW4.322 Tom Table A.30.00000Attarial C Cost.Crotic Patter Stard, PM from Figure A.181.36Start Power, Cost.3.270,2080342 Tom Table A.41.382 Tom Table A.41.392 from Table A.55.30,20Cost.Crotic A.53.30,13Cost.Crotic A.53.30,13Cost.Crotic A.53.30,13Cost.Crotic A.53.30,13Cost.C			
ump presum, barg2.4ump NptCentrifueSet by Design Groof Correlation-Pump21211 457338urchase Cost, Cp25714 47338gagment Purchase Cost, Cg0S076 44802411 Forn Table A.10.053812 Forn Table A.10.053813 Forn Table A.10.053814 Forn Table A.10.053815 Forn Table A.10.053815 Forn Table A.10.053816 Forn Table A.10.053817 Forn Table A.10.053818 Forn Table A.10.053818 Forn Table A.20.0000012 Forn Table A.20.0000012 Forn Table A.20.0000013 Forn Table A.20.0000014 Forn Table A.20.0000014 Forn Table A.20.0000014 Forn Table A.41.3915 forn Table A.41.3816 forn Table A.41.3816 forn Table A.41.3816 forn Table A.41.3916 forn Table A.41.3016 forn Table A.13.0116 forn Table A.13.0217 forn Table A.13.0218 forn Table A.1<			
ump TypeCentribugiSet by Design Consour Auron Material Consource Set by Design Consource Auron Set Set by Design Consource Auron Set			
ump MaterialCrebo SeeSet by Design Grou dot Correlation-Purpurchase Cost, C.p.76744.67333gaipment Purchase Cost, C.p.20213.653511 Forn Table A.120213.653512 Af Son Table A.10.053313 Forn Table A.10.053314 Forn Table A.10.053415 Forn Table A.10.053416 Forn Table A.20.0000011 Forn Table A.20.0000012 Forn Table A.20.0000012 Forn Table A.20.0000012 Forn Table A.20.0000012 Forn Table A.20.0000013 Forn Table A.30.0000014 factal Construction Factor, FM Forn Figure A.181.515 forn Table A.41.3515 forn Table A.41.3516 forn Table A.41.3510 forn Table A.51.3510 forn Tabl			Sat hu Dacian Crau
Data Core Control 7614.477338 varbase Cost, Cp 7614.477338 varbase Cost, CpO 7614.477338 varbase Cost, CpO 7614.477338 La Tom Table A.1 0.0514 S from Table A.1 0.0514 S from Table A.1 0.0514 S from Table A.1 0.0514 C from Table A.2 0.00000 C from Table A.2 0.00000 C from Table A.3 0.00000 C from Table A.3 0.00000 C from Table A.4 0.00000 C from Table A.4 0.00000 C from Table A.4 1.35 S from Table A.4 1.35 D from Table A.4 3.30 D from Table A.4 3.30 D from Table A.4			
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quipment Purchase Cost, Cp0 2480.100579 K1 from Table A.1 3.389; K2 from Table A.1 0.0536 K3 from Table A.1 0.0536 K3 from Table A.1 0.1538 Shaft Power, WW 0.4 resure Factor, FP 1.00 C1 from Table A.2 0.00000 C3 from Table A.2 0.00000 C4 from Table A.2 0.00000 C3 from Table A.3 0.00000 Aterial of Construction Factor, FM from Figure A.18 1.5 Identification Number 38 are Module Factor, FBM 4.32 B1 from Table A.4 1.89 B2 from Table A.5 1.60 Cfee 321.1776457 D16 Costs 547 Themical Engineering Plant Cost Index in 2012 3			
K1 from Table A.1 3.3892 K2 from Table A.1 0.0536 K3 from Table A.1 0.1538 Shaft Power, KW 0.4 Come Table A.1 0.0536 Come Table A.1 0.1538 Shaft Power, KW 0.4 Come Table A.2 0.00000 C1 from Table A.2 0.00000 C3 from Table A.3 0.00000 C3 from Table A.3 0.00000 C4 from Table A.3 0.00000 C3 from Table A.3 0.00000 C4 from Table A.3 0.00000 C1 from Table A.3 0.00000 C3 from Table A.3 0.00000 D1 form Table A.4 1.80 B1 from Table A.4 1.89 B2 from Table A.4 1.80 B2 from Table A.4 1.81 B2 from Table A.4			
R2 from Table A.1 0.0336 K3 from Table A.1 0.1538 Shaft Power, KW 0.4 resure Factor, FP 1.00 C1 from Table A.2 0.00000 C2 from Table A.2 0.00000 C3 from Table A.3 0.00000 Metrial of Construction Factor, FM from Figure A.18 1.5 Identification Number 38 are Module Factor, FBM 4.32 B1 from Table A.4 1.89 B2 from Table A.4 1.89 B2 from Table A.4 1.89 Doningency, Cont 1605.888228 e.e, Cfe 321.1776457 O16 Costs 547 hemical Engineering Plant Cost Index in 2016 547 hemical Engineering Plant Cost Index in 2012 397 urchase Cost, CpD \$ 5.1,26 stalled Costingency, Coont \$ 2,213 dat Costingency, Cont \$ 2,213 dat Costingency, Cont \$ 2,213 dat Costingency, Cont \$ 2,213 dat Al Costi Fees \$ 443	quinment Purchase Cost, Cn0		
K3 from Table A.1 0.358 Shaft Power, KW 0.4 Start Factor, FP 1.00 C1 from Table A.2 0.00000 C3 from Table A.2 0.00000 C3 from Table A.3 0.00000 C4 from Table A.3 0.00000 C3 from Table A.3 0.00000 C4 from Table A.4 1.5 Identification Number 38 are Module Factor, FBM from Figure A.18 1.5 S1 from Table A.4 1.85 B1 from Table A.4 1.85 B2 from Table A.4 1.85 D1 from Table A.4 1.85 B2 from Table A.4 1.85 D1 from Table A.4 38 D1 from Table C.4 1.85 D1 for Table A.4 1.85 D1 for Table A.4 1.85 D1 for Table C.4 33 Outsgraphy 1507 U16 Cost 1.905 Works Cost, fop \$51,126 Virshare Cost, fop \$51,226 Virshare Cost, fop \$2,213 Otal Foest, Cree			
Shaft Power, KW 0.4 Shaft Power, KW 0.4 resure Factor, FP 1.00 C1 from Table A.2 0.00000 C3 from Table A.2 0.00000 C3 from Table A.3 0.00000 Atterial of Construction Factor, FM from Figure A.18 1.5 Identification Number 38 are Module Factor, FBM 4.32 B1 from Table A.4 1.89 B2 from Table A.4 1.89 B2 from Table A.4 1.35 ontingency, Cont 1605.888228 ee, Cfe 321.1776457 016 6 oxts 547 hernical Engineering Plant Cost Index in 2012 397 urchase Cost, Cp \$ 5.126 stalled Cost, CM \$ 14,751 otal Fees, Cfee \$ 4.43	K1 from Table A.1	3.3892	
resure Factor, FP 1.00 C1 from Table A.2 0.00000 C3 from Table A.2 0.00000 C3 from Table A.3 0.00000 C4 from Table A.3 0.00000 C3 from Table A.3 0.00000 C4 from Table A.3 0.00000 C3 from Table A.3 0.00000 C4 from Table A.3 0.00000 S1 from Table A.4 1.35 Inform Table A.4 1.83 B2 from Table A.4 1.83 ontingency, Cont 1605 S88228 ee, Cfe 321.1776457 D16 Costs 547 hernical Engineering Plant Cost Index in 2012 397 urchase Cost, Cp \$ 5,126 stalled Cost, CBM \$ 14,751 Otal Fees, Cfee \$ 2,213 Otal Fees, Cfee \$ 443	K1 from Table A.1 K2 from Table A.1	3.3892 0.0536	
CL from Table A.2 0.00000 C2 from Table A.3 0.00000 C3 from Table A.3 0.00000 Atterial of Construction Factor, FM from Figure A.18 1.5 identification Number 38 are Module Factor, FBM 4.32 B1 from Table A.4 1.89 B2 from Table A.4 1.35 ontingency, Cont 1605 88828 ec, Ciee 321.1776457 Otto State in Cost Index in 2012 397 urchase Cost, CpM \$ 14,751 otal Fees, Ciee \$ 14,751 otal Fees, Ciee \$ 2,213	K1 from Table A.1 K2 from Table A.1 K3 from Table A.1	3.3892 0.0536 0.1538	
C2 from Table A.2 0.00000 C3 from Table A.3 0.00000 Material of Construction Factor, FM from Figure A.18 1.5 Identification Number 38 are Module Factor, FBM 4.32 B1 from Table A.4 1.80 B2 from Table A.4 1.83 ontingency, Cont 1605.88228 e.e., Cfe 321.1776457 OG 6 costs 547 hernical Engineering Plant Cost Index in 2012 397 urchase Cost, Cp \$ 5,126 statiled Cost, CGM \$ 14,751 otal Fees, Cfee \$ 443	K1 from Table A.1 K2 from Table A.1 K3 from Table A.1 Shaft Power, KW	3.3892 0.0536 0.1538 0.4	
C3 from Table A.3 0.0000 laterial of Construction Factor, FM from Figure A.18 1.5 identification Number 38 dentification Number 38 are Module Factor, FBM 4.32 B1 from Table A.4 1.85 B2 from Table A.4 1.85 noinegency, Ccont 1605 88228 ec, Cree 321 1776457 D16 Costs 547 mencial Engineering Plant Cost Index in 2012 397 urchase Cost, CDM \$ 5,126 stalled Cost, CBM \$ 14,751 Dtal Fees, Cree \$ 4.3	K1 from Table A.1 K2 from Table A.1 K3 from Table A.1 Shaft Power, KW resure Factor, FP	3.3892 0.0536 0.1538 0.4 1.00	
Atterial of Construction Factor, FM from Figure A.18 1.5 Identification Number 38 are Module Factor, FBM 4.32 B1 from Table A.4 1.89 B2 from Table A.4 1.35 ontingency, Cont 1605.888228 ec, Cfe 321.1776457 OBG costs 547 hemical Engineering Plant Cost Index in 2016 547 hemical Engineering Plant Cost Index in 2012 397 urchase Cost, Cp \$ 5,1,26 stalled Cost, CBM \$ 14,751 otal Contingency, Ccont \$ 2,213 otal Fees, Cfee \$ 443	K1 from Table A.1 K2 from Table A.1 K3 from Table A.1 Shaft Power, KW resure Factor, FP C1 from Table A.2	3.3892 0.0536 0.1538 0.4 1.00 0.00000	Presure >10
Identification Number 38 are Module Factor, FBM 4.32 B1 from Table A.4 1.89 B2 from Table A.4 1.83 ontingency, Cont 1605 S88228 ee, Cfee 321.1776457 016 Costs 547 hemical Engineering Plant Cost Index in 2016 547 hemical Engineering Plant Cost Index in 2012 397 urchase Cost, Cp \$ 5,126 stalled Cost, CBM \$ 14,751 otal Fees, Cfee \$ 443	K1 from Table A.1 K2 from Table A.1 K3 from Table A.1 Shaft Power, KW resure Factor, FP CL from Table A.2 Q from Table A.2	3.3892 0.0536 0.1538 0.4 1.00 0.00000 0.00000	Pressure >10
are Module Factor, FBM 4.32 B1 from Table A.4 1.85 D2 from Table A.4 1.35 ontingency, Ccont 1605.888228 e, Cfee 321.177657 D1G Costs 1005.888278 hemical Engineering Plant Cost Index in 2016 5.47 hemical Engineering Plant Cost Index in 2012 397 urchase Cost, Cp \$ 5.126 stalled Cost, CSM \$ 14,751 otal Contingency, Ccont \$ 2,213 utal Fees, Cfee \$ 443	K1 from Table A.1 K2 from Table A.1 K3 from Table A.1 Shaft Power, KW Sesure Factor, FP C1 from Table A.2 C2 from Table A.2 C3 from Table A.3	3.3892 0.0536 0.1538 0.4 1.00 0.00000 0.00000 0.00000	Pressure >10
B1 from Table A.4 1.89 B2 from Table A.4 1.83 B2 from Table A.4 1.655.88228 ee, Cfe 321.1776457 OI6 Gosts 321.1776457 OI6 Gosts 547 hemical Engineering Plant Cost Index in 2012 397 urchase Cost, Cp \$ 5,126 stalled Cost, GM \$ 14,751 otal Contingency, Cont \$ 2,213 otal Fees, Cfee \$ 443	K1 from Table A.1 K2 from Table A.1 K3 from Table A.1 Shaft Power, KW resure Factor, FP C1 from Table A.2 C2 from Table A.2 C3 from Table A.3 Table A.3 Tabl	3.3892 0.0536 0.1538 0.4 1.00 0.00000 0.00000 0.00000	Pressure >10
B2 from Table A.4 1.35 ontingency, Ccont 1605.88228 e, Cfee 321.1776457 OIG Costs 547 hemical Engineering Plant Cost Index in 2012 397 urchase Cost, Cost, CBM \$ 14,751 otal Cost, CBM \$ 14,751 otal Contingency, Ccont \$ 2,213 otal Fees, Cfee \$ 443	K1 from Table A.1 K2 from Table A.1 K3 from Table A.1 Shaft Power, KW Tesure Factor, FP C1 from Table A.2 C2 from Table A.2 C3 from Table A.3 C3 from Table A.3 Haterial of Construction Factor, FM from Figure A.18 Identification Number	3.3892 0.0536 0.1538 0.44 1.00 0.00000 0.00000 0.00000 1.5 38	Pressure >10
ontingency, Ccont 1605.888228 ee, Cfe 321.1776457 OIG Costs 321.1776457 bemical Engineering Plant Cost Index in 2016 547 hemical Engineering Plant Cost Index in 2012 397 urchase Cost, Cp \$ 5,126 stalled Cost, CBM \$ 14,751 otal Contingency, Ccont \$ 2,213 otal Fees, Cfee \$ 443	K1 from Table A.1 K2 from Table A.1 K3 from Table A.1 Shaft Power, KW resure Factor, FP C1 from Table A.2 C2 from Table A.2 C3 from Table A.3 C3 from Table A.3 Aterial of Construction Factor, FM from Figure A.18 Identification Number are Module Factor, FBM	3.3892 0.0536 0.1538 0.4 1.00 0.00000 0.00000 0.00000 1.15 3.38 4.32	Pressure >10
ee, Cfe 321.1776457 OBG costs	K1 from Table A.1 K2 from Table A.1 K3 from Table A.1 Shaft Power, KW resure Factor, FP C1 from Table A.2 C2 from Table A.2 C3 from Table A.3 Idential of Construction Factor, FM from Figure A.18 Identification Number are Module Factor, FBM B1 from Table A.4	3.3892 0.0536 0.1538 0.4 1.00 0.00000 0.00000 1.5 38 4.32 1.89	Pressure >10
hemical Engineering Plant Cost Index in 2016 547 hemical Engineering Plant Cost Index in 2012 397 urchase Cost, Cp \$ 5,126 stalled Cost, CBM \$ 14,751 otal Contingency, Ccont \$ 2,213 otal Fees, Cfee \$ 443	K1 from Table A.1 K2 from Table A.1 K3 from Table A.1 Shaft Power, KW Tesure Factor, FP C1 from Table A.2 C2 from Table A.2 C3 from Table A.3 Ataterial of Construction Factor, FM from Figure A.18 Identification Number Identification Number Identification Number Bat from Table A.4 B.1 from Table A.4 B.2 from Table A.4	3.3892 0.0536 0.1538 0.04 0.00000 0.00000 0.00000 0.00000 0.00000 1.15 38 4.32 1.89 1.135	Pressure >10
Benicial Engineering Plant Cost Index in 2012 397 urchase Cost, Cp \$ 5,126 nstalled Cost, CBM \$ 14,751 otal Configency, Ccont \$ 2,213 otal Fees, CFee \$ 443	K1 from Table A.1 K2 from Table A.1 K3 from Table A.1 Shaft Power, KW Presure Factor, FP C1 from Table A.2 C2 from Table A.2 C3 from Table A.3 Identification Number Jare Module Factor, FBM B1 from Table A.4 B2 from Table A.4 Ontingency, Cont	3.3892 0.0536 0.1538 0.4 1.00 0.00000 0.00000 1.5 38 4.32 1.89 1.35 1605.888228	Pressure >10
urchase Cost, Cp \$ \$,126 stalled Cost, CBM \$ 14,751 otal Contingenzy, Cont \$ 2,213 otal Fees, Cfee \$ 443	K1 from Table A.1 K2 from Table A.1 K3 from Table A.1 Shaft Power, KW Tesure Factor, FP C1 from Table A.2 C2 from Table A.2 C3 from Table A.3 Material of Construction Factor, FM from Figure A.18 Identification Number Module Factor, FBM B1 from Table A.4 B2 from Table A.4 B2 from Table A.4 C3 from Table A.4 C3 from Table A.4 C3 from Table A.4 C4 from Table A.4 C5 from Table	3.3892 0.0536 0.1538 0.04 0.00000 0.00000 0.00000 0.00000 0.00000 1.15 38 4.32 1.89 1.35 1.605.888228 321.1776457	Pressure >10
stalled Cost, CBM \$ 14,751 Otal Contingency, Ccont \$ 2,213 Otal Fees, Cfee \$ 443	K1 from Table A.1 K2 from Table A.1 K3 from Table A.1 K3 from Table A.1 K3 from Table A.1 C1 from Table A.2 C2 from Table A.2 C3 from Table A.3 Katerial of Construction Factor, FM from Figure A.18 identification Number identification Number Ist from Table A.4 D.1 from Table A.4 D.2 from Table A.4 Contingency, Ccont iee, Clee R016 Costs Costs Index Factor A.2 R016 Costs Index In 2016	3.3892 0.0536 0.1538 0.1538 0.04 0.00000 0.00000 1.5 3.38 4.32 1.89 1.89 3.21.1776457	Pressure >10
otal Contingency, Ccont \$ 2,213 otal Fees, Cfee \$ 443	K1 from Table A.1 K2 from Table A.1 K3 from Table A.1 Shaft Power, KW Presure Factor, FP C1 from Table A.2 C2 from Table A.2 C3 from Table A.3 Material of Construction Factor, FM from Figure A.18 Identification Number Sare Module Factor, FBM B1 from Table A.4 B2 from Table A.4 B2 from Table A.4 Contingency, Ccont Ge, Cfee	3.3892 0.0536 0.1538 0.04 0.00000 0.00000 0.00000 0.00000 0.00000 1.15 38 4.32 1.89 1.35 1005.888228 321.176457 547 397	Pressure >10
otal Fees, Cfee \$ 443	K1 from Table A.1 K2 from Table A.1 K3 from Table A.1 Shaft Power, KW Yresure Factor, FP C1 from Table A.2 C3 from Table A.2 C3 from Table A.3 Katerial of Construction FACtor, FM from Figure A.18 Identification Number Jare Module Factor, FBM B1 from Table A.4 B2 from Table A.4 B2 from Table A.4 Contingency, Cont Tee, Cfee D16 Costs Cost for Cost Index in 2016 Chemical Engineering Plant Cost Index in 2012 Vershase Cost, Cp	3.3892 0.0536 0.1538 0.0536 0.1538 0.01538 0.01538 0.01538 0.01538 0.00000 0.00000 0.00000 0.00000 1.00 1.5 38 1.35 1.005.88228 321.1776457 5 5.126	Pressure >10
	K1 from Table A.1 K2 from Table A.1 K3 from Table A.1 K3 from Table A.1 Shaft Power, KW Presure Factor, FP C1 from Table A.2 C3 from Table A.2 C3 from Table A.3 C4 from Table A.3 C4 from Table A.4 D4 from Table A.4 D4 from Table A.4 D5 from Table A.4 D5 from Table A.4 D5 from Table A.4 D6 from Table A.4 D7 from Table A.4 D6 from Table A.4 D6 from Table A.4 D6 from Table A.4 D7 from Table	3.3892 0.0536 0.1538 0.0536 0.0536 0.0536 0.0536 0.0536 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 1.15 3.38 1.89 1.35 1.605.88228 321.176457 547 55,5.126 54,751	Pressure >10
otal Module Capital, CTM \$ 17,406	K 1 from Table A.1 K2 from Table A.1 K3 from Table A.1 Shaft Power, KW Tesure Factor, FP C1 from Table A.2 C2 from Table A.2 C3 from Table A.3 Material of Construction Factor, FM from Figure A.18 Identification Number Internation Number B.1 from Table A.4 B.1 from Table A.4 B.2 from Table A.4 Contingency, Ccont tee, Cfee Old Costs Did Costs Did Costs Did Costs Did Costs Did Costs Cost Index in 2012 Participation Plant Cost Index in 2016 Did Costs Did Costs Cost, CpD mstalled Cost, CBM	3.3892 0.0536 0.1538 0.04 1.00 0.00000 0.00000 0.00000 0.00000 0.00000 1.05 38 4.32 1.89 1.135 1605.888228 321.1776457 97 \$ 5.126 \$ 14,751 \$ 2,213	Pressure >10
	K1 from Table A.1 K2 from Table A.1 K3 from Table A.1 K3 from Table A.1 K3 from Table A.1 C1 from Table A.2 C2 from Table A.2 C3 from Table A.2 C3 from Table A.3 Katerial of Construction Factor, FM from Figure A.18 Identification Number Identification Number B1 from Table A.4 B2 from Table A.4 B2 from Table A.4 Contingency, Ccont Costs Emerical Engineering Plant Cost Index in 2016 Chemical Engineering Plant Cost Index in 2016 Commission Cost, CDM coal Cost, CDM Cost Fees, Cfee	3.3892 0.0536 0.1538 0.1538 0.01 0.00000 0.00000 0.00000 0.00000 1.00 0.00000 1.01 0.00000 1.00 0.00000 1.00 1.00 1.01 1.02 1.03 1.03 1.05	Pressure >10

	denser to Flash Tank	
Design Specs	1	
Pressure Change, (barg)	0.20	
Flowrate, (lb/day)	33729	
Inlet flowrate, (lb/hr)	1405	
Hydraulic Power, hp	0.1639	
Shaft Power, Brake hp	0.2521	
Pump Efficiency	0.65	Set by Design Group
Purchased Power, hp	0.3731	
Motor Efficiency	0.6758	Cat ha Davies Cours
Actual Purchase Power, hp Actual Purchase Power, kW	0.5	Set by Design Group
Pump pressure, barg	0.37	
Pump Type	Centrifugal	Set by Design Group
Pump Material	Carbon Steel	Set by Design Group
Cost Correlation- Pump		
Purchase Cost, Cp	3720.150868	
Installed Cost, CBM	10705.92152	
Equipment Purchase Cost, Cp0	2480.100579	
K1 from Table A.1 K2 from Table A.1	3.3892 0.0536	
K3 from Table A.1	0.1538	
Shaft Power, KW	0.4	
Presure Factor, FP	1.00	
C1 from Table A.2	0.00000	
C2 from Table A.2	0.00000	Pressure >10
C3 from Table A.3	0.00000	
Material of Construction Factor, FM from Figure A.18	1.5	
Identification Number Bare Module Factor, FBM	4.32	
B1 from Table A.4	4.32	
D3 from Table 4.4	1.35	
Contingency, Ccont	1605.888228	
Fee, Cfee	321.1776457	
2016 Costs	· · · · · ·	
De litoli I due A-4 Contingency, Cont Fee, Cfee 2016 Costs Chemical Engineering Plant Cost Index in 2016 Chemical Engineering Plant Cost Index in 2012 Purchase Cost	547	
Chemical Engineering Plant Cost Index in 2012	397 \$ 5,126	
Purchase Cost, Cp Installed Cost, CBM	\$ 5,126	
Total Contingency, Ccont	\$ 2,213	
Total Fees, Cfee	\$ 443	
Total Module Capital, CTM	\$ 17,406	
Pump 4	: CSTR2 to Extruder	
	CSTR2 to Extruder	
Design Specs	: CSTR2 to Extruder	
Design Specs		
Design Specs Pressure Change, (barg)	17.570	Based on Extruder Pressure
Design Specs Pressure Change, (barg) Flowrate, (lb/day)	17.570 105631	Based on Extruder Pressure
Design Specs Pressure Change, (barg) Flowrate, (lb/day) Inlet flowrate, (lb/hr)	17.570 105631 4401	Based on Extruder Pressure
Design Specs Pressure Change, (barg) Flowrate, (Ib/day) Inlet flowrate, (Ib/hr) Hydraulic Power, hp	17.570 105631	Based on Extruder Pressure
Design Specs Pressure Change, (barg) Flowrate, (lb/day) Inlet flowrate, (lb/hr)	17.570 105631 4401 45.0908	Based on Extruder Pressure Set by Design Group
Design Specs Pressure Change, (barg) Flowrate, (lb/day) Inlet flowrate, (lb/hr) Hydraulic Power, Irake Shaft Power, Brake hp	17.570 105631 4401 45.0908 69.3705	
Design Specs Pressure Change, (barg) Flowrate, (lb/day) Inlet flowrate, (lb/hr) Hydraulic Power, Ipp Shaft Power, Brake hp Pump Efficiency Purchased Power, hp Motor Efficiency	17.570 105631 4401 45.0908 69.3705 0.65 76.1572 0.9109	Set by Design Group
Design Specs Pressure Change, (barg) Flowrate, (lb/day) Inlet flowrate, (lb/hr) Hydraulic Power, hp Shaft Power, Brake hp Pump Efficiency Purchased Power, hp Motor Efficiency Actual Purchase Power, hp	17.570 105631 4401 69.3705 0.65 76.1572 0.9109 15	
Design Specs Pressure Change, (barg) Flowrate, (lbj/day) Initet Riowrate, (lb/hr) Hydraulic Power, hp Shaft Power, Brake hp Pump Efficiency Purchased Power, hp Motor Efficiency Actual Purchase Power, hp Actual Purchase Power, hp	17.570 106611 4401 45.0908 69.3705 0.65 76.1572 0.9109 1.157 1.139	Set by Design Group
Design Specs Pressure Change, (barg) Flowrate, (lb/dav) inlet flowrate, (lb/hr) Hydraulic Power, hp Shaft Power, Srake hp Pump Efficiency Purthased Power, hp Actual Purchase Power, hp Actual Purchase Power, kW Pump pressure, barg	17.570 105631 4401 69.3705 76.1572 0.9109 15 11.19 17.570	Set by Design Group Set by Design Group
Design Specs Pressure Change, (barg) Flowrate, (lb/day) Inlet flowrate, (lb/hr) Hydraulic Power, hp Shaft Power, Brake hp Purchased Power, hp Motor Efficiency Purchased Power, hp Actual Purchase Power, kW Pump pressure, barg Pump Pressure, barg	17.570 109631 4401 45.0908 69.3705 0.65 76.1572 0.9109 11.19 17.570 Centrifugal	Set by Design Group Set by Design Group Set by Design Group Set by Design Group
Design Specs Pressure Change, (barg) Flowrate, (lb/day) Intel Rowrate, (lb/hr) Hydraulic Power, hp Shaft Power, Brake hp Pump Efficiency Purchased Power, hp Actual Purchase Power, hp Actual Purchase Power, kW Pump pressure, barg Pump Type Pump Meterial	17.570 105631 4401 69.3705 76.1572 0.9109 15 11.19 17.570	Set by Design Group Set by Design Group
Design Specs Pressure Change, (barg) Flowrate, (Ib/day) Inlet flowrate, (Ib/hr) Hydraulic Power, hp Shaft Power, Strake hp Purp Efficiency Purchased Power, hp Motor Efficiency Actual Purchase Power, hp Actual Purchase Power, kW Pump Type Pump Type Pump Material Cost Correlation-Pump Purchase Cost, Cp	17.570 106531 4401 45.0908 69.3705 0.65 76.1572 0.9109 11.19 17.570 Certrifugal Carbon Steel 7694.565523	Set by Design Group Set by Design Group Set by Design Group Set by Design Group
Design Specs Pressure Change, (barg) Flowrate, (lb/day) Inlet Rowrate, (lb/hr) Hydraulic Power, hp Shaft Power, Strake hp Pump Efficiency Purthased Power, hp Actual Purchase Power, hp Actual Purchase Power, kW Pump pressure, barg Pump Type Pump Meterial Cost Correlation- Pump Pursteid Cost, Cp Installed Cost, CBM	17.570 105631 4401 45.0908 69.3705 0.65 76.1572 0.3109 11.59 11.59 17.570 Centrifugal Carbon Steel 7694.565523 22143.56825	Set by Design Group Set by Design Group Set by Design Group Set by Design Group
Design Specs Pressure Change, (barg) Flowrate, (lb/day) Inlet flowrate, (lb/hr) Hydraulic Power, hp Shaft Power, Srake hp Purp Efficiency Purchased Power, hp Motor Efficiency Purchase Power, kp Actual Purchase Power, kW Pump Type Pump Type Pump Material Cost Correlation. Pump Purchase Cost, Cp Installed Cost, CBM Equipment Purchase Cost, Cp0	17.570 105631 4401 45.0908 69.3705 0.655 76.1572 0.3109 11.19 12.570 Centrifugal Carbon Steel 7694.56523 22143.56825 4116.597722	Set by Design Group Set by Design Group Set by Design Group Set by Design Group
Design Specs Pressure Change, (barg) Flowrate, (lb/dsv) Intell Gowrate, (lb/hr) Hydraulic Power, hp Shaft Power, Brake hp Pump Efficiency Purchased Power, hp Motor Efficiency Actual Purchase Power, hp Actual Purchase Power, kW Pump pressure, barg Pump Type Pump Meterial Cost Correlation: Pump Purchase Cost, CpO Installed Cost, CBM Equipment: Purchase Cost, CpO K1 from Table A.1	17.570 105631 4401 45.0908 69.3705 0.65 76.1572 0.9109 11.19 17.570 Centrifugal Carbon Steel 7694.565523 22143.56825 4116.597722 3.3892 3.8922 3.892 3.8922 3.9922 3.9922 3.9922 3.9922 3.9922 3.9922 3.9922 3.9922 3.9922	Set by Design Group Set by Design Group Set by Design Group Set by Design Group
Design Specs Pressure Change, (barg) Flowrate, (lb/day) Inlet Rowret, (lb/hr) Hydraulic Power, hp Shaft Power, Brake hp Pump Efficiency Purchased Power, hp Actual Purchase Power, hp Actual Purchase Power, kW Pump pressure, barg Pump Type Pump Material Cost Correlation Pump Purchase Cost, Cp Installed Cost, CBM Equipment Purchase Cost, CpO K1 from Table A.1 K2 from Table A.1	17.570 105631 4401 45.0908 69.3705 0.655 76.1572 0.3109 11.19 12.570 Centrifugal Carbon Steel 7694.56523 22143.56825 4116.597722	Set by Design Group Set by Design Group Set by Design Group Set by Design Group
Design Specs Pressure Change, (barg) Flowrate, (lb/dsv) Intell Gowrate, (lb/hr) Hydraulic Power, hp Shaft Power, Brake hp Pump Efficiency Purchased Power, hp Motor Efficiency Actual Purchase Power, hp Actual Purchase Power, kW Pump pressure, barg Pump Type Pump Meterial Cost Correlation: Pump Purchase Cost, CpO Installed Cost, CBM Equipment: Purchase Cost, CpO K1 from Table A.1	17.570 105631 4401 45.0908 69.3705 0.655 776.1572 0.9109 11.19 17.570 Centrifugal Carbon Steel 7694.56522 22143.56825 22143.56825 4116.59772 0.0536	Set by Design Group Set by Design Group Set by Design Group Set by Design Group
Design Specs Pressure Change, (barg) Flowrate, (lb/day) Intel Rowrate, (lb/hr) Hydraulic Power, hp Shaft Power, Brake hp Pump Efficiency Purchased Power, hp Actual Purchase Power, hp Actual Purchase Power, hp Actual Purchase Power, hp Pump Material Cost Correlation: Pump Purchase Cost, Cp Installed Cost, CBM Equipment Purchase Cost, Cp0 K1 from Table A.1 K3 from Table A.1	17.570 105631 4401 45.0908 69.3705 0.65 76.1572 0.9109 11.19 17.570 Centrifugal Carbon Steel 7694.56523 22143.56825 4116.997722 3.3892 0.6536 0.1538	Set by Design Group Set by Design Group Set by Design Group Set by Design Group
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67% Capacity Production Process

Purchase Cost, Cp \$ 11,403 Installed Cost, GM \$ 32,814 Total Cost, CGM \$ 984 Total Fees, Clee \$ 984 Total Cost, GM \$ 38,721 Utilities (Pelletized) Service Factor \$ 984 Service Factor Service Factor Service Factor 0.95 Service Factor 0.95 Days/yr 365 Days/yr 365 Days/yr 365 Days/yr 365 Purce Factor 0.95 Service Factor 0.95 Service Factor Service Factor Service Factor 0.95 Service Factor 0.95 Service Factor 0.95 Service Factor Service Factor Service Factor Service Factor Service Factor Service Factor Service Factor <th></th> <th>Chemical Engineering P</th> <th></th> <th> 547</th> <th></th> <th></th> <th></th> <th></th>		Chemical Engineering P		 547						
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Hours/ day 24 Hours/ day 24 Operation Hours/yr 832 Operation Hours/yr 832 Operation Hours/yr 832 Operation Hours/yr 832 Total KW-hr 153.95 Total KW-hr 128169.403 Pice per KW-hr \$ 0.0045 Calvet City, KS Reactor Electricity (String) Total KW-hr 1281169.403 Total KW 106.69 Total KW-hr 5 Total KW 108.69 Total KW-hr 5 Total KW-hr 9.00451.85x1 Total KW-hr 1317754.123 Pice per KW-hr \$ 0.055 Calver City, KS Total KW-hr 9.00451.85x1 Total KW-hr 1317754.123 Pice per KW-hr \$ 0.055 Calver City, KS Total Price/yr \$ 71,817.60 Calver City, KS Total KW-hr 1317754.123 Pice per KW-hr \$ 0.055 Total KW-hr 1317754.123 Pice per KW-hr \$ 0.0545 Calver City, KS Total KW-hr 1201116458	Service Factor			Service Factor						
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Pump Electricity Pump Electricity Total KW 153.95 Total KW-hr 153.95 Total KW-hr 1281169.403 Total KW-hr 1381169.403 Pice per KW-hr \$ 0.0545 Calvert City, KS Pice per KW-hr \$ 0.0545 Calvert City, KS Total KW-hr \$ 0.0545 Calvert City, KS Pice per KW-hr \$ 0.0545 Calvert City, KS Total KW 108.69 Total KW-hr \$ 0.0545 Calvert City, KS Total KW 108.69 Total KW-hr 131775.121 Total KW-hr 90541.8347 Total KW-hr 131775.4321 Total KW-hr 90545 Calvert City, KS Pice per kW-hr \$ 1.0545 Total KW-hr 90545 Calvert City, KS Pice per kW-hr \$ 1.0545 Total KW-hr 131775.4321 Memp Electricity City City, KS Pice per kW-hr \$ 1.13776.4321 Total KW-hr 1281169.403 Calvert City, KS Pice per kW-hr \$ 1.13776.4321 Total KW-hr 1281169.403 Calvert City, KS Pice per kW-hr \$ 1.13776.4321	Hours/ day			Hours/ day						
Total kW 153.95 Total kW 153.95 Total kW-hr 1281169.403 Total kW-hr 1281169.403 Total kW-hr \$0.0545 Calvert City, KS Pice per kW-hr \$0.0545 Calvert City, KS Total kW-hr \$0.0545 Calvert City, KS Total kW-hr \$0.0545 Calvert City, KS Total kW-hr \$0.0545 Calvert City, KS Total kW-hr \$0.983.27.3 Total kW-hr \$0.0545 Calvert City, KS Total kW-hr \$131754.21 Total kW-hr \$0.0545 Calvert City, KS Total kW-hr \$131754.21 Total kW-hr \$0.0545 Calvert City, KS Total kW-hr \$131754.21 Total kW-hr \$0.0545 Calvert City, KS Total kW-hr \$131754.21 Duty (J/S) 1291116458 Total kW-hr \$131754.21 Total kW-hr Duty (J/S) 1291116458 Duty (J/S) 1291116458 Calvert City, KS Stow aste, (Ib/h 4438398.79 Fole per kW-hr \$2.0.031 Calvert City, KS Total kRW-hr 1291116458 <t< td=""><td>Operation Hours/yr</td><td>8322</td><td></td><td>Operation Hour</td><td>rs/yr</td><td></td><td>8322</td><td></td></t<>	Operation Hours/yr	8322		Operation Hour	rs/yr		8322			
Total kW-hr 1281169.403 Total kW-hr 1281169.403 Calvert City, KS Pice per kW-hr \$ 0.0345 Calvert City, KS Pice per kW-hr \$ 0.0345 Calvert City, KS Total Price/yr \$ 6.9,823.73 Total Price/yr \$ 0.9,823.73 Total KW-hr 1.0,1177.61 Total KW-hr 1.0,1177.61 Total KW-hr \$ 0.0,545 Calvert City, KS Total KW-hr \$		Pump Electricity			Pu	ump Elec	tricity			
Pice per kW-hr \$ 0.0545 Calvert City, KS Total Price/yr \$ 6.9,823.73 Total Price/yr \$ 6.9,823.73 Total KW 108.69 Total KW 108.69 Total KW 1137754.121 Total KW-hr 904541.8547 Total KW-hr \$ 0.0545 Calvert City, KS Total KW-hr \$ 0.0545 Calvert City, KS Total KW-hr \$ 0.0545 Calvert City, KS Total KW-hr \$ 0.0545 Calvert City, KS Total KW-hr \$ 0.0545 Calvert City, KS Total Price/yr \$ 4.9297.53 Total KW-hr \$ 0.0545 Calvert City, KS Total Price/yr \$ 4.9297.53 Total Price/yr \$ 7.1817.60 Calvert City, KS Total Price/yr \$ 4.9297.53 Total KW-hr 1.29111.6458 Calvert City, KS Total Price/yr \$ 4.93398.79 Duty (J/S) 1.2911.6458 Calvert City, KS Gast Obol 4.738.398.79 Cost1000 lb 4.738.398.79	Total kW	153.95		Total kW			153.95			
Total Price/yr \$ 69,823.73 Total Price/yr \$ 69,823.73 Rector Electricity (string) Cotal kW Reactor Electricity (string) Total kW 108.69 Total kW 1317754.121 Total kW-hr \$ 0.0545 Calvert City, KS Pice per KW-hr \$ 0.0545 Calvert City, KS Pice per kW-hr \$ 0.0545 Calvert City, KS Total kW-hr \$ 0.0545 Calvert City, KS Reactor Harring Steam Jacket) Reactor Harring Steam Jacket) Duty (J/s) 1291116458 Calvert City, KS Glow h//s 4405289355 Glow h//s 4405289355 Glow h//s 4738398.79 Gost /1000 lb 4738398.79 Cost/1000 lb 4738398.79 Cost/1000 lb 4738398.79 Coding Water Coding Water Codeser 1 Price/loo gal \$ 120.00 Phice/loo gal \$ 120.00 Phillips Price/loo gal \$ 2120.00 Phillips Price/loo gal \$ 2120.00 Phillips Gost Calver (Bur <th co<="" td=""><td>Total kW-hr</td><td>1281169.403</td><td></td><td>Total kW-hr</td><td></td><td></td><td>1281169.403</td><td></td></th>	<td>Total kW-hr</td> <td>1281169.403</td> <td></td> <td>Total kW-hr</td> <td></td> <td></td> <td>1281169.403</td> <td></td>	Total kW-hr	1281169.403		Total kW-hr			1281169.403		
Reactor Electricity (stiring) Reactor Electricity (stiring) Total kW 108.69 Total kW-hr 138.35 Total kW-hr 904541.8547 Total kW-hr 131754.121 Pice per kW-hr \$ 0.0545 Calvert City, KS Pice per kW-hr \$ 0.0545 Calvert City, KS Total kW-hr \$ 0.0545 Calvert City, KS Pice per kW-hr \$ 0.0545 Calvert City, KS Total kW-hr \$ 0.0545 Calvert City, KS Pice per kW-hr \$ 0.0545 Calvert City, KS Total kW-hr \$ 0.0545 Calvert City, KS Pice per kW-hr \$ 0.0545 Calvert City, KS Duty (J/s) 1291116458 Duty (J/s) 1291116458 Calvert City, KS Som Rate, (lp/h) 4438.398.79 Elow Rate, (lp/h) 4438.398.79 Cool ing Water Cost \$ 22.507.39 Cool ing Water Cooling Water Cooling Water Cooling Water Frice/1000 gal \$ 120.00 Phillips Inlet CW Flow, S 120.00 Phillips Flow Rate, (lp/hr 1228099.042 gpm 22809.90.42 gpm	Pice per kW-hr	\$ 0.0545	Calvert City, KS	Pice per kW-hr		\$	0.0545	Calvert City, KS		
Total kW 108.69 Total kW 1158.35 Total kW-hr 904541.8547 Total kW-hr 3137754.121 Pice per kW-hr \$ 0.0545 Calvert City, KS Total Price/yr \$ 49,29753 Total RW-hr \$ 0.0545 Calvert City, KS Total Price/yr \$ 49,29753 Total Price/yr \$ 71,817.60 Calvert City, KS Reactor Heating (Steam Jacket) Calvert City, KS Duty (J/s) 1291116458 Duty (J/s) 1291116458 Calvert City, KS Glow Atae, (Ib/h) 44738398.79 Glow 14738398.79 Calvert City, MS Calvert City, MS 1000 Ib 4.75 Cost/1000 Ib 4.75	Total Price/yr	\$ 69,823.73		Total Price/yr		\$	69,823.73			
Total kW-hr 904541.8547 Total kW-hr 1317754.121 Pice per kW-hr \$ 0.0545 Calvert City, KS Pice per kW-hr \$ 0.0545 Calvert City, KS Total Price/yr \$ 49,297.53 Total Price/yr \$ 0.0545 Calvert City, KS React	Reac	tor Electricity (stiring)			Reactor	Electric	city (stiring)			
Pice per kW-hr \$ 0.0545 Calvert City, KS Pice per kW-hr \$ 0.0545 Calvert City, KS Total Price/yr \$ 49,297,53 Total Price/yr \$ 71,817,60 Reactor Heating (Steam Jacket) Total Price/yr \$ 71,817,60 Calvert City, KS Duty (J/s) 129116458 Duty (J/s) 129116458 Calvert City, KS (Btu/h) 4405289355 Duty (J/s) 129116458 Calvert City, KS Oto Is 129116458 Duty (J/s) 129116458 Calvert City, KS (Btu/h) 4405289355 Duty (J/s) 129116458 Calvert City, KS Oto Is 44738398.79 Duty (J/s) 129116458 Calvert City, KS Cost \$ 22,507.39 Cost \$ 22,507.39 Cost Cost \$ 22,507.39 Cost \$ 22,507.39 Price/100 gal \$ 1200 Prilips Price/100 gal \$ 120.00 Price/100 gal \$ 120.00 Price/100 gal \$	Total kW	108.69		Total kW			158.35			
Total Price/yr \$ 49,297.53 Total Price/yr \$ 71,817.60 Reactor Heating (Steam Jacket) Duty (J/s) 1291116458 Duty (J/s) 1291116458 (Btu/h) 4405289355 (Btu/h) 4405289355 (Btu/h) 44738398.79 1000 lb 4738.39879 1000 lb 4738.39879 1000 lb 4738.39879 Cost/1000 lb 4.75 Cost/1000 lb 4.75 Cost/1000 lb 4.75 Coto \$ 22,507.39 Cost/1000 lb 9.75,20.00 Price/1000 gal \$ 120.00	Total kW-hr	904541.8547		Total kW-hr			1317754.121			
Reactor Heating (Steam Jacket) Reactor Heating (Steam Jacket) Duty (I/s) 1291116458 Duty (I/s) 1291116458 (Btu/h) 4405289355 (Btu/h) 4405289355 Flow Rate, (Ib/h) 44738.398.79 Flow Rate, (Ib/h) 44738.398.79 1000 Ib 4738.398.79 Flow Rate, (Ib/h) 4738.398.79 Cost/1000 Ib 4.75 Cost/1000 Ib 4.75 Cooling Water Cooling Water Cooling Water Cooling Water Cooling Water Cooling Water Cooling Water Cooling Water Flow Rate, Ib/hr 1228099.042 Flow Rate, Ib/hr 1228099.042 gpm 2465.591757 gpm 2465.591757 Total Price/rvr \$ 295.871.01 Density of Water, 1 Density of Water, 1 Density of Water, 1 Gerific Heat (Water), Btu/hr 40527268 Heat Flow, Btu/hr 40527268 Specific Heat (Water), Btu/hr 3.0 CW Temp, C 3.0 CW Temp, C CW out Temp, C 87.00 CW Temp, C 87.00 CW Temp,	Pice per kW-hr	\$ 0.0545	Calvert City, KS	Pice per kW-hr		\$	0.0545	Calvert City, KS		
Duty (I/s) 1291116458 Duty (I/s) 1291116458 (Btu/h) 4405289355 (Btu/h) 4405289355 Flow Rate, (Ib/h) 4738398.79 1000 lb 4738398.79 1000 lb 4738.398.79 1000 lb 4738.398.79 Cost/1000 lb 4738.398.79 Cost/1000 lb 4738.398.79 Cost \$ 22,507.39 Cost \$ 22,507.39 Cooling Water Cooling Water Cooling Water Cooling Water Cooling Water Cooling Water Price/1000 gal \$ 120.00 Phillips Price/1000 gal \$ 120.00 Phillips Price/1000 gal \$ 120.00 Phillips Price/1000 gal \$ 120.00 Phillips Inlet CW Flow,	Total Price/yr	\$ 49,297.53		Total Price/yr		\$	71,817.60			
(Btu/h) 4405289355 (Btu/h) 4405289355 Flow Rate, (lb/h) 4738398.79 Flow Rate, (lb/h) 4738398.79 1000 lb 4738.398.79 1000 lb 4738.398.79 Cost/1000 lb 4738.398.79 Cost/1000 lb 4738.398.79 Cost/1000 lb 4.75 Cost/1000 lb 4.75 Cost \$ 22,507.39 Cost \$ 22,507.39 Cooling Water Cost \$ 22,507.39 Condenser 1 Condenser 1 Price/1000 gal \$ 120.00 Phillips Inlet CW Flow, Inlet CW Flow, Inlet CW Flow, Price/1000 gal \$ 120.00 gpm 2465.591757 Inlet CW Flow, Inlet CW Flow, Inlet CW Flow, gpm 2465.591757 Intel CW Flow, Bu/hr 2465.591757 Intel CW Flow, Bu/hr Density of Water, 1 Intel CW Flow, Bu/hr 40527268 Intel CW Flow, Bu/hr 40527268 Specific Heat (Water), Btu/hE 1 Specific Heat (Water), Btu/hE 1 Intel CW Interp, C 120.00	Reacto	or Heating (Steam Jacket)			Reactor H	leating (Steam Jacket)			
Flow Rate, (lb/h) 4738398.79 Flow Rate, (lb/h) 4738398.79 1000 lb 4738.39879 1000 lb 4738.39879 Cost/1000 lb 4.75 Cost/1000 lb 4.75 Cost \$ 22,507.39 Cost \$ 22,507.39 Cooling Water Condenser 1 Condenser 1 Condenser 1 Condenser 1 Price/1000 gal \$ 120.00 Phillips Inlet CW Flow, Inlet CW Flow, \$ 122809.042 Price/1000 gal \$ 122809.042 gpm 2465.591757 gpm 2465.591757 Inlet CW Flow, Total Price/yr \$ 295,871.01 Total Price/yr \$ 295,871.01 Density of Water, 1 Density of Water, 1 Heat Flow, Btu/hr 40527268 Heat Flow, Btu/hr 40527268 Specific Heat (Water), Btu/lbF 1 Specific Heat (Water), Btu/lbF 1 CW out Temp, C 3.0 CW out Temp, C 37.00 CW out Temp, C 33.0 CW out Temp, C	Duty (J/s)	1291116458		Duty (J/s)			1291116458			
1000 lb 4738.39879 1000 lb 4738.39879 Cost/1000 lb -4.75 Cost/1000 lb -4.75 Cost \$ 22,507.39 Cost \$ 22,507.39 Cost \$ 22,507.39 Cost \$ 22,507.39 Coling Water Cost \$ 22,507.39 Cost Coling Water Condenser 1 Price/1000 gal \$ 120.00 Phillips Inlet CW Flow, S 120.00 Phillips Inlet CW Flow, Inlet CW Flow, 1228099.042 Pice/1000 gal \$ 122.009.042 gpm 2465.591757 gpm 2465.591757 Inder Cw Flow, 1 Total Price/yr \$ 295,871.01 gpm 2465.591757 Inder Cw/rec/yr \$ 295,871.01 Density of Water, Inder Cw Flow, Btu/hr Inder Cw Flow, Btu/hr Inder Cw Flow, Btu/hr Inder Cw Flow, Btu/hr Keat Flow, Btu/hr 40527268 Cw Temp, C Inder Cw Flow, Btu/hr Inder Cw Flow, Btu/hr Cw out Temp, C Inder Cw Flow, Btu/hr Specific Heat (Water), Btu/hF	(Btu/h)	4405289355		(Btu/h)			4405289355			
Cost/1000 lb 4.75 Cost/1000 lb 4.75 Cost \$ 22,507.39 Cost \$ 22,507.39 Cooling Water Cost \$ 22,507.39 Cooling Water Courdenser 1 Price/1000 gal \$ 120.00 Phillips Price/1000 gal \$ 120.00 Phillips Inlet CW Flow, Inlet CW Flow, Inlet CW Flow, 1228099.042 Price/1000 gal \$ 120.00 Phillips gpm 2465.591757 gpm 2465.591757 gpm 2465.591757 Total Price/yr \$ 295,871.01 Total Price/yr \$ 295,871.01 Total Price/yr \$ 295,871.01 Density of Water, 1 Density of Water, 1 40527268 End Water, 1 Specific Heat (Water), Btu/lbF 1 Specific Heat (Water), Btu/lbF 1 40527268 Gw out Temp, C 87.00 CW out Temp, C 87.00 87.00 87.00 Wolume, gal 110.00 Wolume, gal 110.00 Wolume, gal 110.00	Flow Rate, (lb/h)	4738398.79		Flow Rate, (lb/h)			4738398.79			
Cost \$ 22,507.39 Cost \$ 22,507.39 Cooling Water Cooling Water Condenser 1 Condenser 1 Price/1000 gal \$ 120.00 Phillips Inlet CW Flow, Inlet CW Flow, Inlet CW Flow, Price/1000 gal \$ 1228099.042 Price/1000 gal \$ 1228099.042 Price/1000 gal \$ 1228099.042 Price/1000 gal S 295,871.01 Price/1000 gal S 295,871.01 Gonsity of Water, \$ 295,871.01 Total Price/yr \$ 295,871.01 Density of Water, 1 Density of Water, 1 Density of Water, 1 Density of Water, 1 Specific Heat (Water), Btu/lbF 1 CW out Temp, C 120.00 CW out Temp, C 120.00 CW out Temp, C 120.00 Hot Oil Wolume, gal 10.00	1000 lb	4738.39879		1000 lb			4738.39879			
Cooling Water Cooling Water Cooling Water Price/100 gal \$ 120.00 Phillips Inlet CW Flow, Price/1000 gal \$ 120.00 Phillips Inlet CW Flow, Inlet CW Flow, Inlet CW Flow, Price/1000 gal \$ 1228099.042 gpm 2465.591757 gpm 2465.591757 gpm 2465.591757 Total Price/yr \$ 295,871.01 Total Price/yr \$ 295,871.01 Price/1000 gal 40527268 Beat Flow, Btu/hr 40527268 Heat Flow, Btu/hr 40527268 Price/IOU CW out Temp, C 120.0 CW out Temp, C 87.00 CW out Temp, C 120.0 CW in Temp, C 87.00 CW in Temp, C 87.00 Total Price/ 33.0 Hot Oil Volume, gal 110.00 Volume, gal 110.00	Cost/1000 lb	4.75		Cost/1000 lb			4.75			
Condenser 1 Condenser 1 Price/1000 gal \$ 120.00 Phillips Inlet CW Flow, S 120.00 Phillips Inlet CW Flow, Inlet CW Flow, Inlet CW Flow, Flow Rate, lb/hr 1228099.042 Flow Rate, lb/hr 1228099.042 gpm 2465.591757 gpm 2465.591757 Total Price/yr \$ 295,871.01 Total Price/yr \$ 295,871.01 Density of Water, 1 Density of Water, 1 Specific Heat (Water), Btu/lbF 1 Specific Heat (Water), Btu/lbF 1 CW out Temp, C 1280.0 CW out Temp, C 87.00 1 Temp Difference 3.0 CW in Temp, C 3.0 0 1 Volume, gal 110.00 Volume, gal 110.00 1 0	Cost	\$ 22,507.39		Cost		\$	22,507.39			
Price/1000 gal \$ 120.00 Phillips Inlet CW Flow, Inlet CW Flow, Inlet CW Flow, Inlet CW Flow, Flow Rate, lb/hr 1228099.042 Flow Rate, lb/hr 1228099.042 gpm 2465.591757 gpm 2465.591757 Total Price/yr \$ 295,871.01 Total Price/yr \$ 295,871.01 Density of Water, 1 Density of Water, 1 Heat Flow, Btu/hr 40527268 Heat Flow, Btu/hr 40527268 Specific Heat (Water), Btu/lbF 1 Specific Heat (Water), Btu/lbF 1 CW out Temp, C 87.00 CW out Temp, C 87.00 Temp Difference 33.0 Temp Difference 33.0 Volume, gal 110.00		Cooling Water			C	ooling V	Vater			
Inlet CW Flow, Inlet CW Flow, Inlet CW Flow, Flow Rate, lb/hr 1228099.042 Flow Rate, lb/hr 1228099.042 gpm 2465.591757 gpm 2465.591757 Total Price/yr \$ 295,871.01 Total Price/yr \$ 295,871.01 Density of Water, 1 Density of Water, 1 Heat Flow, Btu/hr 40527268 Heat Flow, Btu/hr 40527268 Specific Heat (Water), Btu/lbF 1 Specific Heat (Water), Btu/lbF 1 CW out Temp, C 120.0 CW out Temp, C 120.0 CW in Temp, C 33.0 Temp Difference 33.0 Temp Difference 33.0 Temp Difference 33.0 Volume, gal 110.00 Volume, gal 110.00		Condenser 1			(Condens	ser 1			
Flow Rate, lb/hr 1228099.042 Flow Rate, lb/hr 1228099.042 gpm 2465.591757 gpm 2465.591757 Total Price/yr \$ 295,871.01 Total Price/yr \$ 295,871.01 Density of Water, 1 Density of Water, 1 Heat Flow, Btu/hr 40527268 Heat Flow, Btu/hr 40527268 Specific Heat (Water), Btu/lbF 1 Specific Heat (Water), Btu/lbF 1 CW out Temp, C 120.0 CW out Temp, C 120.0 Temp Difference 33.0 CW in Temp, D 33.0 Hot Oil Volume, gal 110.00 Volume, gal 110.00	Price/1000 gal	\$ 120.00	Phillips	Price/1000 gal		\$	120.00	Phillips		
gpm 2465.591757 gpm 2465.591757 Total Price/yr \$ 295,871.01 Total Price/yr \$ 295,871.01 Density of Water, 1 Density of Water, 1 Heat Flow, Btu/hr 40527268 Heat Flow, Btu/hr 40527268 Specific Heat (Water), Btu/lbF 1 Specific Heat (Water), Btu/lbF 1 CW out Temp, C 2 CW out Temp, C 120.0 1 CW out Temp, C 3.0 CW out Temp, C 3.0 1 Temp Difference 33.0 Tom Difference 3.0 1 Volume, gal 110.00 Volume, gal 110.00 1	Inlet CW Flow,			Inlet CW Flow,						
Total Price/yr \$ 295,871.01 Total Price/yr \$ 295,871.01 Density of Water, 1 Density of Water, 1 Heat Flow, Btu/hr 40527268 Heat Flow, Btu/hr 40527268 Specific Heat (Water), Btu/lbF 1 Specific Heat (Water), Btu/lbF 1 CW out Temp, C 120.0 CW out Temp, C 120.0 CW in Temp, C 87.00 CW in Temp, C 87.00 Temp Difference 33.0 Temp Difference 33.0 Volume, gal 110.00	Flow Rate, lb/hr	1228099.042		Flow Rate, lb/h	r		1228099.042			
Density of Water, 1 Heat Flow, Btu/hr 40527268 Heat Flow, Btu/hr 40527268 Specific Heat (Water), Btu/lbF 1 Specific Heat (Water), Btu/lbF 1 CW out Temp, C 120.0 CW out Temp, C 120.0 CW in Temp, C 87.00 CW in Temp, C 87.00 Temp Difference 33.0 Temp Difference 33.0 Volume, gal 110.00	gpm	2465.591757		gpm			2465.591757			
Heat Flow, Btu/hr 40527268 Heat Flow, Btu/hr 40527268 Specific Heat (Water), Btu/lbF 1 Specific Heat (Water), Btu/lbF 1 CW out Temp, C 120.0 CW out Temp, C 120.0 CW in Temp, C 33.0 CW in Temp, C 87.00 Temp Difference 33.0 Temp Difference 33.0 Volume, gal 110.00 Volume, gal 110.00	Total Price/yr	\$ 295,871.01		Total Price/yr		\$	295,871.01			
Specific Heat (Water), Btu/lbF 1 CW out Temp, C 120.0 CW out Temp, C 120.0 CW in Temp, C 87.00 CW in Temp, C 87.00 Temp Difference 33.0 Temp Difference 33.0 Hot Oil Volume, gal 110.00	Density of Water,	1		Density of Wate	er,		1			
CW out Temp, C 120.0 CW out Temp, C 120.0 CW in Temp, C 87.00 CW in Temp, C 87.00 Temp Difference 33.0 Temp Difference 33.0 Hot Oil Volume, gal 110.00	Heat Flow, Btu/hr	40527268		Heat Flow, Btu/h	r		40527268			
CW in Temp, C 87.00 CW in Temp, C 87.00 Temp Difference 33.0 Temp Difference 33.0 Hot Oil Hot Oil Hot Oil Hot Oil	Specific Heat (Water), Btu/lbF	1		Specific Heat (V	Vater), Btu/lbF		1			
Temp Difference 33.0 Temp Difference 33.0 Hot Oil Volume, gal 110.00 Volume, gal 110.00										
Hot Oil Hot Oil Volume, gal 110.00 Volume, gal 110.00										
Volume, gal 110.00 Volume, gal 110.00	Temp Difference			Temp Difference						
		1 1				Hot O	1			
Cost \$ 4,079.90 DME Cost \$ 4,079.90 DME	Volume, gal			Volume, gal						
	Cost	\$ 4,079.90	DME	Cost		\$	4,079.90	DME		

Pump	5: Evaporator Pump	
Design Specs		
Pressure Change, (barg)	2.43	
Flowrate, (lb/day)	139265	From HYSY
Inlet flowrate, (lb/hr)	5803	From HYSY
Hydraulic Power, hp	8.2	
Shaft Power, hp	12.6	
Pump Efficiency	0.65	Set by Design Grou
Purchased/Break Power, hp	14.7	
Motor Efficiency	0.859	
Actual Purchase Power, hp	30	Set by Design Grou
Actual Purchase Power, kW	22.37	
Pump pressure, barg	2.1	
Pump Type	Centrifugal	Set by Design Grou
Pump Material	Carbon Steel	Set by Design Grou
Cost Correlation- Pump		
Purchase Cost, Cp	8275.691065	
Installed Cost, CBM	23815.94248	
Equipment Purchase Cost, Cp0	5517.127377	
K1 from Table A.1	3.3892	
K2 from Table A.1	0.0536	
K3 from Table A.1	0.1538	
Shaft Power, KW	22.4	
Presure Factor, FP	1.00	
C1 from Table A.2	0.00000	
C2 from Table A.2	0.00000	Pressure >10
C3 from Table A.3	0.00000	
Material of Construction Factor, FM from Figure A.18	1.5	
Identification Number	38	
Bare Module Factor, FBM	4.32	
B1 from Table A.4	1.89	
B2 from Table A.4	1.35	
Contingency, Ccont	3572.391372	
Fee, Cfee	714.4782744	
2016 Costs	•	
Chemical Engineering Plant Cost Index in 2016	547	
Chemical Engineering Plant Cost Index in 2012	397	
Purchase Cost, Cp	\$ 11,403	
Installed Cost, CBM	\$ 32,814	
Total Contingency, Ccont	\$ 4,922	
Total Fees, Cfee	\$ 984	
Total Module Capital CTM	\$ 38.721	

Reactor Sizing and Costing		ed)
	s and Specifications	
Mass Flow HMDA, (kg/day)	36340.19	
Mass Flow Adipic Acid, (kg/day)	45700.01	
Mass Flow Water, (kg/day)	5633.58	
Mass Flow Nylon Salt, (kg/day)	-	
Mass Flow Nylon 6,6, (kg/day)	-	
Temperature, C	250	
	Conditions	
Mass Flow HMDA, (kg/day) Mass Flow Adipic Acid, (kg/day)	-	
Mass Flow Water, (kg/day)	5633.58	
Mass Flow Water, (kg/day) Mass Flow Nylon Salt, (kg/day)	82039.83	
Mass Flow Nylon 6,6, (kg/day)		
Temperature, C	255	
	Equipment	
Fotal Mass Flow Out, (kg/day)	87673.41	
X _{ADA}	0.52	Mass Balance
X _{HMDA}	0.41	Mass Balance
X _{H20}	0.06	Mass Balance
Density ADA, (kg/m³)	1359.998997	Literature
Density HMDA, (kg/m ³)	840052384	Literature
Density Water, (kg/m ³)	999.997995	Literature
Density, (kg/m³)	344422245	
Total Flow Rate, (kg/hr)	3653.074167	
(m³/day)	1.06064E-05	Density/Mass Flow Rate
Time in Vessel, (hr)	-	Reaction Time
(day)		hr/24
Reaction Rate, (lb/mol/s)	6.0475	From Literature 95% Confidence
Volume, (m ³)	4.18	Material Balance
Diameter, (m)	1.2	
L/D	3	Heuristic
Pressure, (psia)	145	Pressure of Vessel-Literature
Design Pressure, (psia)	195	
(barg)	12.43	
Duty, (kW)	12.283	Shaft Work
Cost Correlation- Jacketer		
Purchase Cost, Cp	171753.0126	Cpo*Fp*Fm
Installed Cost, CBM	379070.5887	Cpo*FBN
Equipment Purchase Cost, Cp0	27256.6735	VI 10 04 3 ··· ·
K1 from Table A.1	4.1052	Volume Min: 0.1 m ³ Max: 35 m
K2 from Table A.1	0.5320	Volume Min: 0.1 m ³ Max: 35 m ³
K3 from Table A.1 Volume,m3	-0.0005	Volume Min: 0.1 m ³ Max: 35 m ³
Presure Factor, FP	2.032683762	
C1 from Table A.2	0	
C2 from Table A.2	0	
C3 from Table A.3	0	
Material of Construction Factor, FM from Figure A.18	3.1	Vertical Process Vessel (SS clad
Identification Number	20	Vertical Process Vessel (SS clad
Bare Module Factor, FBM	13.90744137	B1(B2*Fm*Fp
B1 from Table A.4	2.25	Vertical Process Vessel
B2 from Table A.4	1.85	Vertical Process Vessel
Contingency, Ccont	56860.58831	0.15*CBN
Cf	11372.11766	0.03*CBN
	5 Costs	
2016	5 Costs	
2016 Chemical Engineering Plant Cost Index in 2017	547	
2016 Chemical Engineering Plant Cost Index in 2017 Chemical Engineering Plant Cost Index in 2012	547 397	
2016 Chemical Engineering Plant Cost Index in 2017 Chemical Engineering Plant Cost Index in 2012 Purchase Cost, Cp	547 397 236647.098	Cp*(CEPCI ₂₀₁₆ /CEPCI ₂₀₁₂
2016 Chemical Engineering Plant Cost Index in 2017 Chemical Engineering Plant Cost Index in 2012 Purchase Cost, Cp Installed Cost, CBM	547 397 236647.098 522296.252	Cp*(CEPCI ₂₀₁₆ /CEPCI ₂₀₁₂ CBM*(CEPCI ₂₀₁₆ /CEPCI ₂₀₁₂
Fee, Cfee 2016 Chemical Engineering Plant Cost Index in 2017 Chemical Engineering Plant Cost Index in 2012 Purchase Cost, Cp Installed Cost, CBM Total Cost CBM Total Const Total Fees	547 397 236647.098	

	Reactor Sizing and Cos Process Conditions an			
	Inlet Condit		emedicins	
Ma	iss Flow HMDA, (kg/day)		-	
	iss Flow Adipic Acid, (kg/day)		-	
	iss Flow Water, (kg/day)		5633.58	
	iss Flow Nylon Salt, (kg/day)		82039.83	
Ma	iss Flow Nylon 6,6, (kg/day)		-	
	nperature, C		250	338.5C= BP at 1 atr
Pre	essure, (barg)		10.00	
Tot	al Flow, (kg/day)		87673.41	
	Outlet Cond	litions		
	iss Flow HMDA, (kg/day)		-	
-	iss Flow Adipic Acid, (kg/day)		-	
	iss Flow Water, (kg/day)		16732	
	iss Flow Nylon Salt, (kg/day)		70942.43	
Ma	iss Flow Diamine, (kg/day)		5866.67	
	nperature, C		280	338.5C= BP at 1 atr
	F		536	
Pre	ssure, (barg)		10.000	
Ten	nperature of Hot Oil, F		599.000	Low Pressure Stean
	c		315.000	
Tot	al Flow, (kg/day)		93541	
	Sizing of Equi	pmen	t	
Vol	lume, (ft ³)		859.402225	
1	m3		24.33553803	2013.5
Dia	imeter, (ft)		7.144882854	
	m		2.177760294	
-	at Flow (Qo), Btu/hr		1,391,998.55	m/latent hea
	. Btu/hrFft ²		400	Literature 400-200
-	Ita T, F		54.000	changed to Fahrenhei
		-	54.000	changed to Fahrenner
	TD, CF, F TD, F		87.23	
-				
-	Ita T (Hot in Cold Out), F		63.0	
	Ita T (Hot Out Cold in), F		117.0	
	rrection Factor		0.995	
	2a, (ft ²)		40.0940665	
	m2		3.7248591	
0	Cost Correlation- rchase Cost, Cp	Evapo		o *r *r
-			255855.7939	Cpo*Fp*Fr
-	talled Cost, CBM	\$	651,252.12	Cpo*FBN
Equ	uipment Purchase Cost, Cp0	\$	82,553.13	22162.7535
	K1 from Table A.1		5.0238	
	K2 from Table A.1		0.3475	
	K3 from Table A.1		0.0703	
	Area, (m2)		0.467566668	
Pre	sure Factor, FP		1.00	
_	C1 from Table A.2 C2 from Table A.2		0.15780	
-	C3 from Table A.3		0.14130	
	Iterial of Construction Factor, FM from Figure A.18		3.1	Vertical Process Vessel (S
0.4-2	iterial of construction ractor, rivi from rigure A.16			
Ma	Islandification Number	1	20	Vertical Process Vessel (St
	Identification Number		7 200701034	
	re Module Factor, FBM		7.890701031	B1(B2*Fm*F
	re Module Factor, FBM B1 from Table A.4		2.25	B1(B2*Fm*F Vertical Process Vesse
Bar	re Module Factor, FBM B1 from Table A.4 B2 from Table A.4		2.25 1.82	B1(B2*Fm*F Vertical Process Vesse Vertical Process Vesse
Bar Cor	re Module Factor, FBM B1 from Table A.4 B2 from Table A.4 ntingency, Ccont		2.25 1.82 97687.81823	B1(B2*Fm*Fp Vertical Process Vesse Vertical Process Vesse 0.15*CBP
Bar Cor	re Module Factor, FBM B1 from Table A.4 B2 from Table A.4 hingency, Ccont c, Cfee	sts	2.25 1.82	B1(B2*Fm*Fp Vertical Process Vesse Vertical Process Vesse 0.15*CBP
Bar Cor Fee	re Module Factor, FBM B1 from Table A.4 B2 from Table A.4 titingency, Ccont c, Cfee 2016 Co	sts	2.25 1.82 97687.81823 19537.56365	B1(B2*Fm*Fp Vertical Process Vesse Vertical Process Vesse 0.15*CBP
Bar Cor Fee Che	re Module Factor, FBM B1 from Table A.4 B2 from Table A.4 B2 from Table A.4 ntingency, Ccont ;, Cfee 2016 Co emical Engineering Plant Cost Index in 2016	sts	2.25 1.82 97687.81823 19537.56365 547	B1(B2*Fm*Fp Vertical Process Vesse Vertical Process Vesse 0.15*CBP
Bar Cor Fee Che	re Module Factor, FBM B1 from Table A.4 B2 from Table A.4 tingency, Ccont c, Cfee 2016 Co emical Engineering Plant Cost Index in 2016 emical Engineering Plant Cost Index in 2012	sts	2.25 1.82 97687.81823 19537.56365 547 397	B1(B2*Fm*Fr Vertical Process Vesse Vertical Process Vesse 0.15*CB/ 0.03*CB/
Bar Cor Fee Che Pur	re Module Factor, FBM B1 from Table A.4 B2 from Table A.4 titingency, Ccont c, Cfee 2016 Co emical Engineering Plant Cost Index in 2016 emical Engineering Plant Cost Index in 2012 chase Cost, Cp		2.25 1.82 97687.81823 19537.56365 547 397 410961.6392	B1(B2*Fm*Fj Vertical Process Vesse Vertical Process Vesse 0.15*CBI 0.03*CBI
Bar Cor Fee Che Che Pur Inst	re Module Factor, FBM B1 from Table A.4 B2 from Table A.4 titingency, Ccont , Cfee 2016 Co emical Engineering Plant Cost Index in 2016 emical Engineering Plant Cost Index in 2012 chase Cost, Cp talled Cost, CBM	\$	2.25 1.82 97687.81823 19537.56365 547 397 410961.6392 1,046,056.59	B1(B2*Fm*Fj Vertical Process Vesse Vertical Process Vesse 0.15*CBI 0.03*CBI
Bar Cor Fee Che Pur Inst	re Module Factor, FBM B1 from Table A.4 B2 from Table A.4 titingency, Ccont c, Cfee 2016 Co emical Engineering Plant Cost Index in 2016 emical Engineering Plant Cost Index in 2012 chase Cost, Cp		2.25 1.82 97687.81823 19537.56365 547 397 410961.6392	B1(B2*Fm*F Vertical Process Vesse Vertical Process Vesse

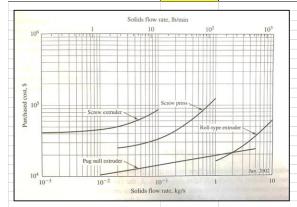
Reactor Sizing and C	osting: Flash Drum		
Process Conditions a			
Inlet Con			
Mass Flow HMDA, (kg/day)	-		
Mass Flow Adipic Acid, (kg/day)	-		
Mass Flow Water, (kg/day)	16732		
Mass Flow Nylon Salt, (kg/day)	-		
Mass Flow Nylon 6,6, (kg/day)	-		
Mas Flow Diamine, (kg/day)	5866.67	342C= BP at 20 psia	
Temperature, C	109		
Pressure, (barg)	3.812	55.3	
Total Flow, (kg/day)	22598.41		
Outlet Co	nditions		
Mass Flow HMDA, (kg/day)	-		
Mass Flow Adipic Acid, (kg/day)	-		
Mass Flow Water, (kg/day)	16731.74		
Mass Flow Nylon Salt, (kg/day)	-		
Mass Flow Nylon 6,6, (kg/day)	-		
Mas Flow Diamine, (kg/day)	5866.67	342C= BP at 20 psia	
Temperature, C	110	109.32C= BP at 20 psia	
Pressure, (barg)	0.084		
Total Flow, (kg/day)	22598.41		
Sizing of Eq			
Overall Temp, C	109		
Overall Pressure, (barg)	0.084		
X _{Diamine}	0.23	Mass Balance	
X _{H2O}	0.77	Mass Balance	
Density Diamine, (kg/m ³)	0.116	Literature	
Density Water, (kg/m ³)	0.018	Literature	
Density, (kg/m³)	0.0407		
(ft ³ /day)	2.257028728	Density/Mass Flow Rate	
(m³/day)	79.70634847	Conversion	
Volume, (m ³)	4.27		
Diameter, (m)	1.219192399		
Pressure, (psia)	20	Pressure of Vessel-	
Design Pressure, (psia)	70		
(barg)	3.81280228		
Cost Correlation			
Purchase Cost, Cp	89708.39275	Cpo*Fp*Fm	
Installed Cost, CBM	227986.1914	Cpo*FBM	
Equipment Purchase Cost, Cp0	27566.96214		
K1 from Table A.1	4.1052	Min: 0.1 m ³ Max: 35 m ³	
K1 from Table A.1 K2 from Table A.1	0.5320	Min: 0.1 m ³ Max: 35 m ³	
K3 from Table A.1	-0.0005		
Volume,m3		Min: 0.1 m ³ Max: 35 m ³	
Presure Factor, FP	4.27		
	1.049741755		
C1 from Table A.2 C2 from Table A.2	0		
C2 from Table A.2 C3 from Table A.3	0		
Material of Construction Factor, FM from Figure A.18	3.1	Vertical Process Vessel (SS)	
Identification Number	20	Vertical Process Vessel (SS)	
Bare Module Factor, FBM	8.270268963	B1(B2*Fm*Fp)	
B1 from Table A.4	2.25	Vertical Process Vessel	
B1 from Table A.4 B2 from Table A.4	2.25	Vertical Process Vessel	
Contingency, Ccont	34197.92871	0.15*CBM	
Fee, Cfee	6839.585743	0.03*CBM	
2016 0		0.00 0.01	
Chemical Engineering Plant Cost Index in 2016	547		
Chemical Engineering Plant Cost Index in 2010	397		
Purchase Cost, Cp	123603.2515	Cp*(CEPCI ₂₀₁₆ /CEPCI ₂₀₁₂)	
Installed Cost, CBM	314127.0698	CBM*(CEPCI ₂₀₁₆ /CEPCI ₂₀₁₂)	
Total Contengency	47119.06047		
Total Fees	9423.812094		
CTM	\$ 370,669.94	CBM+Confengency+Fees	

Storage T	ank (Diamine)	
	ns and Specifications	
	Conditions	
Mass Flow HMDA, (kg/day)	-	
Mass Flow Adipic Acid, (kg/day) Mass Flow Water, (kg/day)	-	
Mass Flow Nylon Salt, (kg/day)	-	
Mass Flow Nylon 6,6, (kg/day)	-	
Mas Flow Diamine, (kg/day)	5866.67	
Temperature, C	255	338.5C= BP at 1 atn
Pressure, (barg)	3.80	
Total Flow, (kg/day)		
Sizing of	Equipment	
X _{Diamine}	0.23	Mass Balance
Density Diamine, (kg/m ³)	839.599	Literature
Total Flow Rate, (kg/day)	8756.22	
(m³/day)	10.42905264	Density/Mass Flow Rate
(m³/week)	73.00336849	
Time in Vessel, (hr)	168	Store for a Week
(day)	7	hr/2
Reaction Rate, ()		
Volume, (m³)	73.00336849	
Diameter, (m)	3.1	
L/D	3	Heuristi
Orientation		Vertical
Pressure, (psia)	145	Pressure of Vessel-Literature
Design Pressure, (psia)	195	
(barg)	12.43	
Cost Correlation- Jacket	ed/Batch Reactor (Ajit	ated)
Purchase Cost, Cp	227484.6077	Cpo*Fp*Fn
Installed Cost, CBM	535184.2713	Cpo*FBN
Equipment Purchase Cost, Cp0	50816.7765	
K1 from Table A.1	3.4974	Volume Min: 0.1 m ³ Max: 35 m
K2 from Table A.1	0.4485	Volume Min: 0.1 m ³ Max: 35 m
K3 from Table A.1	0.1074	Volume Min: 0.1 m ³ Max: 35 m
Volume,m3	73.00336849	
Presure Factor, FP	4.47656509	
C1 from Table A.2	0	
C2 from Table A.2	0	
C3 from Table A.3	0	
Material of Construction Factor, FM from Figure A.18	1	Vertical Process Vessel (SS clad
Identification Number	18	Vertical Process Vessel (SS clad
Bare Module Factor, FBM	10.53164542	B1(B2*Fm*Fp
B1 from Table A.4	2.25	Vertical Process Vessel
B2 from Table A.4	1.85	Vertical Process Vessel
Contingency, Ccont	80277.6407	0.15*CBN
Fee, Cfee	16055.52814	0.03*CBN
	.6 Costs	
Chemical Engineering Plant Cost Index in 2016	547	
Chemical Engineering Plant Cost Index in 2012	397	
Purchase Cost, Cp	313435.9708	Cp*(CEPCI ₂₀₁₆ /CEPCI ₂₀₁₂
Installed Cost, CBM	737394.9532	CBM*(CEPCI ₂₀₁₆ /CEPCI ₂₀₁₂
Total Contengency Total Fees	110609.243 22121.8486	
CTM	\$ 870,126.04	CBM+Confengency+Fee

Reactor Sizing and Costing: (Process Conditions		itor
Shell Side In		
Inlet Con	ditions	
Inlet Process Temp, C	280 159.7	536
Pressure, psia Pressure, (barg)	10.00	
Outlet Co		
Outlet Process Temp, C	109	228.2
Pressure, psia Shell Side Design Pressure, barg	70.0	
Tube Side In Tube Side In		
Inlet Con	ditions	
Inlet Cooling WaterTemp, F	87	
Inlet Cooling WaterTemp, C	30.56	
Outlet Co Outlet Steam Temp, F	120.0	
Outlet Steam Temp, C	48.9	
Design		
Equipment [Description	
Equipment Type	HEX	
Equipment Description	Tubular	
Tube Material	Stainless	
Shell Material Tube Side	Stainless Cooling Water	
Shell Side	Process	
HEX TEMA Type	AES	
Equipment Description	Floating Head	
HEX Calco		
Density of Cooling Water, (lb/m ³)	2195.1	.652/.688btu/lbF
Mass Flow Input Process Stream, (Ib/day)	206222.4201	
Cp Steam, (btu/lbF)	1	Engineering Toolbox
Cp Diamine, (btu/lbF)	1.20237E-06	JCT Document
XDiamine	0.23	Mass Balance Entering
X _{H2O} Total Cp, (btu/lbF)	0.77	Mass Balance Entering Calculated
Heat Flow (Qo), Btu/day	27153316	m*Cp*LMTD
Area of Heat Transfer (A0), m2	35.60203	1.20237E-06
Overall Heat Transfer Coefficient (U0), Btu/hrft ² F	1200.0	
Btu/dayft ² F	28800.0	
Btu/daym ² F	2675.6 50.0	
Velocity 30-50, (ft/s) ft/hr	180000.0	
m/hr	54864.0	
LMTD, CF, (F)	285.1	
LMTD, CF, C	140.6	
LMTD, C	141.29	
Delta T (Hot in Cold Out) Delta T (Hot Out Cold in)	231.1 78.4	
Correction Factor	0.995	
Cost Correla	ation- HEX	
Purchase Cost, Cp	51275.77263	
Installed Cost, CBM	\$ 137,495	
Equipment Purchase Cost, Cp0 K1 from Table A.1	\$ 18,949 4.8306	
K2 from Table A.1	-0.8509	
K3 from Table A.1	0.3187	
Area,m2	35.60	
Presure Factor, FP	1.00	
C1 from Table A.2 C2 from Table A.2	0.03881	
C2 from Table A.2 C3 from Table A.3	-0.11272	
Material of Construction Factor, FM from Figure A.18	2.7	
Identification Number	5	
Bare Module Factor, FBM	7.26	
B1 from Table A.4	2.25	Vertical Process Vessel
B2 from Table A.4 Contingency, Ccont	1.85 20624.28916	Vertical Process Vessel 0.15*CBM
ee, Cfee	4124.857833	0.03*CBM
2016 (
Chemical Engineering Plant Cost Index in 2016	547	
Chemical Engineering Plant Cost Index in 2012	397	
Purchase Cost, Cp	\$ 70,649.49 189445.6116	CP*(CEPCI ₂₀₁₆ /CEPCI ₂₀₁₂)
	103443.0110	CBM*(CEPCI ₂₀₁₆ /CEPCI ₂₀₁₂)
Installed Cost, CBM Total Contengency	28416.84174	
Total Contengency Total Fees	28416.84174 5683.368349	

Reactor Sizing and Costin		itated)
	ns and Specifications	
Inlet C Mass Flow HMDA, (kg/day)	Conditions	
Mass Flow Adipic Acid, (kg/day)	-	
Mass Flow Water, (kg/day)	-	
Mass Flow Nylon Salt, (kg/day)	70942.43	
Mass Flow Nylon 6,6, (kg/day)	-	
Temperature, C	280	
	Conditions	
Mass Flow HMDA, (kg/day)	0	
Mass Flow Adipic Acid, (kg/day)	0	
Mass Flow Water, (kg/day)	169.01	
Mass Flow Nylon Salt, (kg/day)	-	
Mass Flow Nylon 6,6, (kg/day)	70772.84	
Temperature, C		
Total Mass Flow Out, (kg/hr)	Equipment 2955.910417	
X _{Wylon 66}	0.99762	Mass Balance
		Mass Balance
X _{H20}	0.00238 1139.999166	
Density Nylon 66, (kg/m3)		Literature
Density Water, (kg/m3)	999.997995	Literature
Density, (kg/m3)	1140	
Total Flow Rate, (kg/hr)	2955.934583	
(m³/day)	2.593685061	Density/Mass Flow Rate
Time in Vessel, (hr)	-	Reaction Time
(day)	ļ	hr/24
Reaction Rate Constant, (kg/mol/s)		From Literature 95% Confidence
Volume, (m ³)	8.126	Levenspiel Plot
Diameter, (m)	1.5	
L/D	3	Heuristic
Pressure, (psia)	145	Pressure of Vessel-Literature
Design Pressure, (psia)	195	
(barg)	12.43	
Duty, (J/s)	0	Adiabatio
Cost Correlation- Jackete	ed/Batch Reactor (Ajit	tated)
Purchase Cost, Cp	290226.2111	Cpo*Fp*Fm
Installed Cost, CBM	624220.2602	Cpo*FBM
Equipment Purchase Cost, Cp0	38800.78653	
K1 from Table A.1	4.1052	Volume Min: 0.1 m3 Max: 35 m3
K2 from Table A.1	0.5320	Volume Min: 0.1 m3 Max: 35 m3
K3 from Table A.1	-0.0005	Volume Min: 0.1 m3 Max: 35 m3
Volume,m3	8.126	
Presure Factor, FP	2.412872697	
C1 from Table A.2	0	
C2 from Table A.2	0	
C3 from Table A.3	0	
Material of Construction Factor, FM from Figure A.18	3.1	Vertical Process Vessel (SS clad)
Identification Number	20	Vertical Process Vessel (SS clad)
Bare Module Factor, FBM	16.08782491	B1(B2*Fm*Fp
B1 from Table A.4	2.25	Vertical Process Vessel
B2 from Table A.4	1.85	Vertical Process Vessel
Contingency, Ccont	93633.03904	0.15*CBN
Fee, Cfee	18726.60781	0.03*CBN
	.6 Costs	
Chemical Engineering Plant Cost Index in 2016 Chemical Engineering Plant Cost Index in 2012	547	
Purchase Cost, Cp	399883.4697	
Installed Cost, CBM		Cp*(CEPCI ₂₀₁₆ /CEPCI ₂₀₁₂
	860071.744	CBM*(CEPCI ₂₀₁₆ /CEPCI ₂₀₁₂
Total Contengency	129010.7616	
Total Fees CTM	25802.15232	CDM-Cf
СТМ	\$ 1,014,884.66	CBM+Confengency+Fees

Reactor Sizing and Costing: Extruder					
Process Conditions and Specifications					
Inlet Cond	itions				
Nylon 6,6 Flow Rates, (kg/day)	70,77	3			
kg/s	0.81	9			
Temperature, C	28	0			
kW	51.35	2			
Type of Extruder	Twin Screv	 Peters and Timmerhause 			
Pressure, (barg)					
Cp based on Flow	\$ 130,000.00	Top Price			
CBM	532303.3	5			
CTM					
Fees	15969.100	3			
Contengency	79845.504	4			
Cp based on Flow	\$ 179,118.39	2016 Adjusted Price			
CBM	\$ 733,425.54	2016 Adjusted Price			
Adjusted Fees	\$ 110,013.83	2016 Adjusted Price			
Adjusted Contengency	\$ 106,460.67	2016 Adjusted Price			
СТМ	\$ 949,900.04				



Thermal Oil	Heater		
kW	49.653		
CBM	\$ 20,000.00	Alibaba Quoted Price	
CBM	\$ 27,556.68		
Contengency	\$ 826.70		
Fees	\$ 826.70		
СТМ	\$ 29,210.08		

Pressure, (barg	3)			
kW			49.653	
CBM		\$	985,462.00	Quoted Price
CBM		\$	1,357,802.81	
Contengency		\$	40,734.08	
Fees		\$	40,734.08	
CTM		\$	1,439,270.97	
	Storage Tar			
	Process Conditions			
	Inlet Cor	ditior	IS	
Mass Flow HM			-	
	pic Acid, (kg/day)		-	
Mass Flow Wa			-	
	on Salt, (kg/day)		-	
Mass Flow Nyl	on 6,6, (kg/day)		105631	
Mas Flow Dian	nine, (kg/day)		0.00	
Temperature,	c		290	338.5C= BP at 1 atm
Pressure, (barg	3)		18726.61	
Total Flow, (kg	/day)		105631.00	
	Sizing of E	quipm	ent	
X _{Diamine}			0.23	Mass Balance
Density Nylon	6,6, (kg/m ³)		1140.000	Literature
Total Flow Rat			105631.00	
(m ³ /day)			92.65877193	Density/Mass Flow Rate
(m ³ /week)			92.65877193	
Time in Vessel	(br)		168	Store for a Week
(day)	. ()		7	hr/24
Reaction Rate,	0		,	11/24
Volume, (m ³)	0		92.65877193	
Diameter, (m) L/D			3.4	Heuristic
			3	
Orientation Pressure, (psia)		145	Vertical Pressure of Vessel-Literature
Design Pressure			145	Flessure of Vessel-Literature
(barg)	e, (psia)		12.43	
(5015)	Cost Correlation- Jacketed	Batch		eq)
Purchase Cost,		Datei	299763.3711	Cpo*Fp*Fm
Installed Cost,			694915.7708	Cpo*FBM
	rchase Cost, Cp0			Сротным
			62379.34855	
K1 from			3.4974	
K2 from K3 from			0.4485	
Volume,r			92.65877193	
Presure Factor			4.805490569	
C1 from 1			0	
C2 from			0	
C3 from 1			0	
	nstruction Factor, FM from Figure A.18		1	Vertical Process Vessel (SS clad)
	tion Number		18	Vertical Process Vessel (SS clad)
Bare Module F			11.14015755	B1(B2*Fm*Fp)
B1 from	Table A.4		2.25	Vertical Process Vessel
B2 from	Table A.4		1.85	Vertical Process Vessel
Contingency, C	Cont		104237.3656	0.15*CBM
Fee, Cfee			20847.47312	0.03*CBM
	2016	Costs		
Chemical Engir	neering Plant Cost Index in 2016		547	
	neering Plant Cost Index in 2012		397	
Purchase Cost,			413024.0907	Cp*(CEPCI ₂₀₁₆ /CEPCI ₂₀₁₂)
Installed Cost,		\$	957,478.40	CBM*(CEPCI ₂₀₁₆ /CEPCI ₂₀₁₂)
Total Contenge		\$	143,621.76	1011,
Total Fees		\$	28,724.35	
CTM		\$	1,129,824.52	CBM+Confengency+Fees
			-	

	porator to CSTR 2	
esign Specs	1 1	
Pressure Change, (barg)	2.43	
owrate, (lb/day)	70942	
Inlet flowrate, (lb/hr)	9726	
ydraulic Power, hp	13.8	
naft Power, Brake hp	21.2	
Pump Efficiency	0.65	Set by Design Group
urchased Power, hp	24.2	
Motor Efficiency	0.876	
Actual Purchase Power, hp	25	Set by Design Group
Actual Purchase Power, kW	18.64	
imp pressure, barg	2.4 Centrifugal	Cat hu Davies Crows
mp Type mp Material	Carbon Steel	Set by Design Group Set by Design Group
st Correlation- Pump	Carbon Steel	Set by Design Group
rchase Cost, Cp	7614.673536	
stalled Cost, CBM	21913.65356	
uipment Purchase Cost, Cp0	5076.449024	
K1 from Table A.1	3.3892	
K2 from Table A.1	0.0536	
K3 from Table A.1	0.1538	
Shaft Power, KW	18.6	
esure Factor, FP	1.00	
C1 from Table A.2	0.00000	D
C2 from Table A.2	0.00000	Pressure >10
C3 from Table A.3 aterial of Construction Factor, FM from Figure A.18	1.5	
Identification Number	38	
re Module Factor, FBM	4.32	
B1 from Table A.4	1.89	
B2 from Table A.4	1.35	
ntingency, Ccont	3287.048034	
e, Cfee	657.4096067	
16 Costs		
emical Engineering Plant Cost Index in 2016	547	
emical Engineering Plant Cost Index in 2012	397	
rchase Cost, Cp	\$ 10,492	
talled Cost, CBM	\$ 30,193	
tal Contingency, Ccont	\$ 4,529	
tal Fees, Cfee	\$ 906	
tal Module Capital, CTM	\$ 35,628	
	h to Storage Tank	
sign Specs	0.165	
sign Specs Pressure Change, (barg)		
sign Specs Pressure Change, (barg)	0.165	
sign Specs Pressure Change, (barg) wrate, (lb/day) Inlet flowrate, (lb/hr)	0.165	
sign Specs Pressure Change, (barg) wrate, (lb/day) Inlet flowrate, (lb/hr) draulic Power, hp	0.165 8756 365	
sign Specs Pressure Change, (barg) wrate, (lb/day) Inlet flowrate, (lb/hr) draulic Power, hp	0.165 8756 365 0.0351	Set by Design Group
sign Specs Pressure Change, (barg) wrate, (lb/day) Inlet flowrate, (lb/hr) draulic Power, hp aft Power, Brake hp Pump Efficiency rchased Power, hp	0.165 8756 365 0.0351 0.055 0.0931	Set by Design Group
sign Specs Pressure Change, (barg) wrate, (lb/day) Inlet flowrate, (lb/hr) draulic Power, hp aft Power, Brake hp Pump Efficiency rchased Power, hp Motor Efficiency	0.165 3756 365 0.0351 0.0540 0.65 0.0931 0.5801	
sign Specs Pressure Change, (barg) wrate, (lb/day) Inlet flowrate, (lb/hr) draulic Power, hp Pump Efficiency Pump Efficiency Actual Purchase Power, hp	0.165 8756 365 0.0351 0.0540 0.65 0.0931 0.5801 0.5801	Set by Design Group Set by Design Group
sign Specs Pressure Change, (barg) wrate, (lb/day) Inlet flowrate, (lb/hr) draulic Power, hp Aft Power, Brake hp Pump Efficiency rchased Power, hp Motor Efficiency Actual Purchase Power, hp Actual Purchase Power, kW	0.165 8756 365 0.0351 0.0540 0.65 0.0931 0.5801 0.5 0.37	
sign Specs Pressure Change, (barg) wrate, (lb/day) Inlet flowrate, (lb/hr) faraulic Power, hp ft Power, Brake hp Pump Efficiency Chased Power, hp Motor Efficiency Actual Purchase Power, hp Actual Purchase Power, kW mp pressure, barg	0.165 8756 0.0351 0.0540 0.0540 0.0931 0.5801 0.5801 0.5801 0.5801 0.5801	Set by Design Group
sign Specs Pressure Change, (barg) wrate, (lb/day) Inlet flowrate, (lb/hr) draulic Power, hp Pump Efficiency rchased Power, hp Motor Efficiency Actual Purchase Power, hp Actual Purchase Power, kW mp pressure, barg	0.165 8756 0.0351 0.0540 0.655 0.0931 0.5801 0.5801 0.5801 0.5801 0.5801 0.5801 0.5801	Set by Design Group Set by Design Group
sign Specs Pressure Change, (barg) wrate, (lb/day) Inlet flowrate, (lb/hr) draulic Power, hp fficiency Pump Efficiency Actual Purchase Power, hp Actual Purchase Power, kW mp pressure, barg mp Type mp Material	0.165 8756 0.0351 0.0540 0.0540 0.0931 0.5801 0.5801 0.5801 0.5801 0.5801	Set by Design Group
sign Specs Pressure Change, (barg) wrate, (lb/day) inlet flowrate, (lb/hr) draulic Power, hp aft Power, Brake hp Pump Efficiency Actual Purchase Power, hp Actual Purchase Power, hp Actual Purchase Power, kW mp pressure, barg mp Type mp Material ts Correlation- Pump	0.165 8756 0.0351 0.0540 0.65 0.0331 0.5801 0.5801 0.5801 0.5801 0.165 Centrifugal Carbon Steel	Set by Design Group Set by Design Group
sign Specs Pressure Change, (barg) wrate, (lb/day) Inlet flowrate, (lb/hr) draulic Power, hp fforeure, Irske hp Pump Efficiency rchased Power, hp Motor Efficiency Actual Purchase Power, hp Actual Purchase Power, kW mp pressure, barg mp Type mp Material st Correlation-Pump Chase Cost, Cp	0.165 8756 0.0351 0.0540 0.0540 0.0580 0.5801 0.5801 0.5801 0.5801 0.5801 0.580 0.5801 0.580 0.580 0.580 0.580 0.580 0.580 0.580 0.585 0.555 0.0551 0.0551 0.0551 0.0551 0.0551 0.0551 0.0551 0.0551 0.0551 0.0551 0.0551 0.0551 0.0551 0.0551 0.555 0	Set by Design Group Set by Design Group
sign Specs Pressure Change, (barg) wrate, (lb/day) Inlet flowrate, (lb/hr) draulic Power, hp Pump Efficiency Actual Purchase Power, hp Actual Purchase Power, hp Actual Purchase Power, kW mp pressure, barg mp Type mp Material t Correlation- Pump chase Cost, Cp lailed Cost, CBM	0.165 8756 0.0351 0.0540 0.65 0.0331 0.5801 0.5801 0.5 0.165 Centriugal Carbon Steel 3720.150868 10705.92152	Set by Design Group Set by Design Group
sign Specs Pressure Change, (barg) wrate, (lb/day) Inlet flowrate, (lb/hr) faraulic Power, hp ff Power, Brake hp Pump Efficiency Actual Purchase Power, hp Actual Purchase Power, hp Actual Purchase Power, kW mp pressure, barg mp Type mp Material st Correlation- Pump tchase Cost, Cp Lalled Cost, CBM uipment Purchase Cost, Cp0	0.165 8756 0.0351 0.0540 0.65 0.0331 0.5801 0.5801 0.5801 0.5801 0.5801 0.5801 0.5801 0.5801 0.5801 0.5801 0.5801 0.7000 0.7000 0.7000 2480.100579	Set by Design Group Set by Design Group
sign Specs Pressure Change, (barg) wrate, (lb/day) Inlet flowrate, (lb/hr) draulic Power, hp sft Power, Brake hp Pump Efficiency Crchased Power, hp Motor Efficiency Actual Purchase Power, hp Actual Purchase Power, hp mp pressure, barg mp Type mp Material ts Correlation-Pump rchase Cost, Cp talled Cost, CBM ujpment Purchase Cost, Cp0 K1 from Table A.1	0.165 8756 0.0351 0.0540 0.0540 0.0580 0.5801 0.5801 0.5801 0.5801 0.5801 0.5801 0.5801 0.580 0.65 0.0579 3720.150868 10705.92152 2480.100579 3.3892	Set by Design Group Set by Design Group
sign Specs Pressure Change, (barg) wrate, (lb/day) Inlet flowrate, (lb/hr) draulic Power, hp Pump Efficiency Pump Efficiency Actual Purchase Power, hp Actual Purchase Power, kW mp pressure, barg mp Material tt Correlation- Pump chase Cost, Cp talled Cost, CBM Lift from Table A.1 Efform Table A.1	0.165 8756 0.0351 0.0540 0.65 0.0931 0.5801 0.5801 0.5801 0.5 0.37 0.165 Centrifugal Carbon Steel 3720.150868 10705.92152 2480.100579 2480.100579 2480.100579	Set by Design Group Set by Design Group
sign Specs Pressure Change, (barg) wrate, (lb/day) Inlet flowrate, (lb/hr) draulic Power, hp aft Power, Brake hp Pump Efficiency rchased Power, hp Motor Efficiency Actual Purchase Power, hp Actual Purchase Power, kW mp pressure, barg mp Type mp Material st Correlation-Pump rchase Cost, Cp talled Cost, CBM uipment Purchase Cost, Cp0 K1 from Table A.1	0.165 8756 0.0351 0.0540 0.0540 0.0580 0.5801 0.5801 0.5801 0.5801 0.5801 0.5801 0.5801 0.580 0.5801 0.580 0.580 0.580 0.580 0.580 0.057 0.0579 2.480.100579 3.3892	Set by Design Group Set by Design Group
sign Specs Pressure Change, (barg) wrate, (lb/day) Inlet flowrate, (lb/hr) traulie Power, hp ft Power, Brake hp Pump Efficiency cchased Power, hp Motor Efficiency Actual Purchase Power, hp Actual Purchase Power, kW mp pressure, barg mp Type mp Attail tt Correlation-Pump chase Cost, Cp k1 from Table A.1 K2 from Table A.1 Shaft Power, KW	0.165 8756 0.051 0.0540 0.65 0.0931 0.5801 0.5801 0.5801 0.5801 0.5801 0.65 0.37 0.165 Carbon Steel 3720.150868 10705.92152 2480.100579 3.3892 0.0536 0.1538	Set by Design Group Set by Design Group
sign Specs Pressure Change, (barg) wrate, (lb/day) Inlet flowrate, (lb/hr) draulie Power, hp ffloiency Pump Efficiency Actual Purchase Power, hp Actual Purchase Power, hp Actual Purchase Power, kW mp pressure, barg mp Type Type to are a to a t	0.165 8756 0.0351 0.0540 0.0540 0.0580 0.5801 0.5801 0.5801 0.5801 0.5801 0.5801 0.5801 0.5801 0.580 0.5801 0.580 0.580 0.580 0.1558 2480.100579 3.3892 0.0536 0.1538 0.01538	Set by Design Group Set by Design Group
sign Specs Pressure Change, (barg) wrate, (lb/day) Inlet flowrate, (lb/hr) draulic Power, hp Pump Efficiency Chased Power, hp Motor Efficiency Actual Purchase Power, hp Actual Purchase Power, kW mp pressure, barg mp Material tt Correlation- Pump chase Cost, Cp talled Cost, CBM Jipment Purchase Cost, Cp0 K1 from Table A.1 K2 from Table A.1 K3 from Table A.1 Shaft Power, KW sure Factor, FP	0.0165 8756 0.0351 0.0540 0.0540 0.0580 0.0931 0.5801 0.5801 0.5801 0.5801 0.5801 0.5801 0.655 Centrifugal Carbon Steel 3720.150868 10705.92152 2480.100579 3.3892 0.0536 0.1538 0.0536	Set by Design Group Set by Design Group
ign Spees Pressure Change, (barg) wrate, (lb/day) Inlet flowrate, (lb/hr) fraulic Power, hp Pump Efficiency chased Power, hp Motor Efficiency Actual Purchase Power, hp Actual Purchase Power, kW mp pressure, barg mp Material t Correlation- Pump chase Cost, Cp alled Cost, CBM alignment Purchase Cost, Cp0 alled Cost, CBM Staf Power, KW sure Factor, FP C1 from Table A.1 C2 from Table A.2 C2 from Table A.2 C3 from Table A.3	0.165 8756 0.051 0.0540 0.65 0.0931 0.5801 0.5801 0.165 Carbon Steel 3720.150868 10705.92152 2480.100579 3.3892 0.0536 0.1538 0.4 1.00	Set by Design Group Set by Design Group Set by Design Group
ign Spees Pressure Change, (barg) wrate, (lb/day) Inlet flowrate, (lb/hr) raulic Power, hp ft Power, Brake hp Pump Efficiency Actual Purchase Power, hp Actual Purchase Power, hp Actual Purchase Power, kW Actual Purchase Power, kW on p pressure, barg np Type Om Material Correlation-Pump Chase Cost, Cp alled Cost, CBM alled Cost, CBM alled Cost, CBM Shaft Power, KW Super Actual Purchase Cost, Cp0 K1 from Table A.1 K3 from Table A.1 K3 from Table A.2 C2 from Table A.2 C3 from Table A.3 Evaluation Species Cost, CPM Filter Cost, CP C3 from Table A.2 C3 from Table A.2 C3 from Table A.3 Evaluation Cost, CPM Filter Cost, CPM Filter Cost, CPM Filter Cost, CPM C4 from Table A.2 C3 from Table A.2 C3 from Table A.3 Evaluation Cost, CPM Filter Cost, CPM Fil	0.165 8756 0.051 0.0540 0.65 0.0931 0.5801 0.5801 0.165 Carbon Steel 3720.15086 10705.92152 2480.100579 3.3892 0.0536 0.1538 0.1538 0.4 1.00 0.00000 0.00000 0.00000 0.00000	Set by Design Group Set by Design Group Set by Design Group
ign Spees Pressure Change, (barg) wrate, (lb/day) Inlet flowrate, (lb/hr) Iraulic Power, hp Pump Efficiency Chased Power, hp Actual Purchase Power, hp Actual Purchase Power, kW np pressure, barg p Material t Correlation-Pump chase Cost, Cp alled Cost, CBM Jipment Purchase Cost, Cp0 Alt from Table A.1 K2 from Table A.1 K3 from Table A.1 Shaft Power, KW sure Factor, FP C1 from Table A.2 (2 from Table A.2 (2 from Table A.2 (2 from Table A.2 (2 from Table A.3	0.165 8756 365 0.0351 0.0540 0.65 0.0931 0.5801 0.5801 0.5801 0.5801 0.5801 0.5801 0.5801 0.5801 0.165 Centrifugal Carbon Steel 3720.150868 10705.92152 2480.100579 3.3892 0.0538 0.1538 0.4 1.00 0.00000 0.00000	Set by Design Group Set by Design Group Set by Design Group
sign Specs Pressure Change, (barg) wrate, (lb/day) Inlet flowrate, (lb/hr) fraulic Power, hp ff Power, fake hp Pump Efficiency chased Power, hp Motor Efficiency Actual Purchase Power, hp Actual Purchase Power, kW mp pressure, barg mp Material tt Correlation-Pump chase Cost, Cp talled Cost, CBM appent Purchase Cost, Cp0 K1 from Table A.1 K3 from Table A.1 K3 from Table A.1 K3 from Table A.1 C2 from Table A.2 C2 from Table A.2 C3 from Table A.2 C4 from Table A.2 C5 from Table A.2 C4 from Table A.2 C5 from Table A.2 C5 from Table A.2 C6 from Table A.2 C6 from Table A.2 C7 from Table A.2 C7 from Table A.2 C3 from Table A.2 C3 from Table A.2 C3 from Table A.2 C3 from Table A.2 C4 from Table A.2 C5 from Table A.2 C4 from Table A.2 C5 from Table A.2 C5 from Table A.2 C6 from Table A.2 C6 from Table A.2 C6 from Table A.2 C6 from Table A.2 C7 from Table	0.0165 0.0351 0.0540 0.0540 0.0540 0.05801 0.58000 0.58000 0.580000 0.580000 0.580000 0.580000 0.5800000 0.5800000 0.5800000 0.58000000 0.58000000 0.58000000 0.580000000 0.580000000 0.5800000000000000000000000000000000000	Set by Design Group Set by Design Group Set by Design Group
sign Specs Pressure Change, (barg) wrate, (lb/day) Inlet flowrate, (lb/hr) faraulic Power, hp ft Power, Brake hp Pump Efficiency Actual Purchase Power, hp Actual Purchase Power, hp Actual Purchase Power, kW mp pressure, barg mp Type mp Material tc Correlation- Pump Crhase Cost, Cp talled Cost, CBM alignment Purchase Cost, Cp0 K1 from Table A.1 K3 from Table A.1 K3 from Table A.1 K3 from Table A.2 C2 from Table A.2 C3 from Table A.3 terial of Construction Factor, FM from Figure A.18 Identification Number te Module Factor, FBM El from Table A.4 Is from Table A.4 Is from Table A.3 Is from Table A.4 Is	0.165 8756 0.0351 0.0540 0.65 0.0331 0.5801 0.5801 0.5801 0.5801 0.5801 0.5801 0.5801 0.5801 0.5801 0.5801 0.5801 0.705 20037 3.3892 0.0536 0.1538 0.4 1.00 0.00000 0.00000 0.00000 0.00000 0.00000 1.5 38 4.32 1.89	Set by Design Group Set by Design Group Set by Design Group
sign Specs Pressure Change, (barg) wrate, (lb/day) Inlet flowrate, (lb/hr) faraulic Power, hp th Power, Brake hp Pump Efficiency rchased Power, hp Motor Efficiency Actual Purchase Power, hy Actual Purchase Power, hy Actual Purchase Power, kW mp Type mp Material t Correlation - Pump Crdase Cost, Cp talled Cost, CBM taigenent Purchase Cost, Cp0 K1 from Table A.1 K2 from Table A.1 K3 from Table A.1 Shaft Power, KW Sure Factor, FP C1 from Table A.2 C2 from Table A.2 C3 from Table A.3 Identification Number re Module Factor, FBM B1 from Table A.4 B1 from Table A.4 B2 from Table A.4 B2 from Table A.4	0.165 8756 365 0.0351 0.0540 0.65 0.0931 0.5801 0.5801 0.5801 0.5801 0.65 Carbon Steel 3720.150868 10705.92152 2480.100579 3.3892 0.6358 0.1538 0.4 1.00 0.00000 0.00000 1.5 38 4.32 1.89 1.35	Set by Design Group Set by Design Group Set by Design Group
sign Specs Pressure Change, (barg) wrate, (lb/day) Inlet flowrate, (lb/hr) draulic Power, hp aft Power, Rrake hp Pump Efficiency rchased Power, hp Motor Efficiency Actual Purchase Power, hp Actual Purchase Power, hp Actual Purchase Power, WW mp pressure, barg mp Type mp Material st Correlation-Pump Chase Cost, Cp talled Cost, CBM uipment Purchase Cost, Cp0 K1 from Table A.1 K3 from Table A.1 K3 from Table A.2 C2 from Table A.2 C3 from Table A.2 C3 from Table A.3 Stelfald Construction Factor, FM from Figure A.18 Iteliad Factor, FBM B1 from Table A.4 B2 from Table A.4	0.165 0.0351 0.0351 0.0540 0.0540 0.0540 0.05801 0.5801 0.5801 0.5801 0.5801 0.5801 0.5801 0.5801 0.5801 0.5801 0.5802 0.155 2480.100579 2480.100579 2480.100579 3.3892 0.0538 0.0558	Set by Design Group Set by Design Group Set by Design Group
sign Specs Pressure Change, (barg) wrate, (lb/day) Inlet flowrate, (lb/hr) draulic Power, hp aft Power, Brake hp Pump Efficiency rchased Power, hp Motor Efficiency Actual Purchase Power, hp Actual Purchase Power, hp Actual Purchase Power, kW mp pressure, barg mp Type mp Material st Correlation- Pump rchase Cost, Cp talled Cost, CBM uigment Purchase Cost, Cp0 K1 from Table A.1 K3 from Table A.1 K3 from Table A.2 C2 from Table A.2 C3 from Table A.2 Safer A.3 aterial of Construction Factor, FBM B1 from Table A.4 B2 from Table A.4 B3 from Table A.4 B4 from Table A.4 B4 from Table A.4 B4 from Table A.4	0.165 8756 365 0.0351 0.0540 0.65 0.0931 0.5801 0.5801 0.5801 0.5801 0.65 Carbon Steel 3720.150868 10705.92152 2480.100579 3.3892 0.6358 0.1538 0.4 1.00 0.00000 0.00000 1.5 38 4.32 1.89 1.35	Set by Design Group Set by Design Group Set by Design Group
sign Specs Pressure Change, (barg) wrate, (lb/day) Inlet flowrate, (lb/hr) draulic Power, hp aft Power, Brake hp Pump Efficiency rchased Power, hp Motor Efficiency Actual Purchase Power, hp Actual Purchase Power, hp Actual Purchase Power, kW mp pressure, barg mp Type mp Material st Correlation -Pump rchase Cost, Cp talled Cost, CBM ujment Purchase Cost, Cp0 K1 from Table A.1 K2 from Table A.1 K3 from Table A.1 Shaft Power, KW ssure Factor, FP C1 from Table A.2 C2 from Table A.2 C3 from Table A.3 Identification Number re Module Factor, FBM B1 from Table A.4 B1 form Table A.4 B1 from Table A.4 B1 form T	0.165 8756 0.0351 0.0351 0.0540 0.0540 0.0591 0.0580 0.0580 0.0580 0.0580 0.0580 0.0580 0.0580 0.059 2480.100579 3.3892 0.0336 0.1538 0.0150 0.000000 0.000000 0.000000 0.000000 0.000000	Set by Design Group Set by Design Group Set by Design Group
sign Specs Pressure Change, (barg) wrate, (lb/day) Inlet flowrate, (lb/hr) draulic Power, hp aft Power, Brake hp Pump Efficiency Chased Power, hp Motor Efficiency Actual Purchase Power, hp Actual Purchase Power, hp Actual Purchase Power, kW mp pressure, barg mp Type mp Material st Correlation- Pump Orchase Cost, Cp Lalled Cost, CBM uipment Purchase Cost, CpO K1 from Table A.1 K3 from Table A.1 K3 from Table A.1 K3 from Table A.1 Shaft Power, KW sure Factor, FP C1 from Table A.2 C2 from Table A.2 C3 from Table A.4 B1 from Table A.4 B1 from Table A.4 B2 from Table A.4 B2 from Table A.4 B1 form Table A.4	0.165 8756 0.0351 0.0540 0.65 0.0331 0.5801 0.165 0.37 0.165 0.37 0.165 0.37 0.165 0.37 0.165 0.37 0.165 0.37 0.165 0.37 0.165 0.37 0.165 0.37 0.165 0.37 0.165 0.37 0.1058 0.037 0.038 0.138 0.04 1.00 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 1.5 38 4.32 1.89 1.35 1605.88228 321.176457 <td>Set by Design Group Set by Design Group Set by Design Group</td>	Set by Design Group Set by Design Group Set by Design Group
sign Specs Pressure Change, (barg) wrate, (lb/day) Inlet flowrate, (lb/hr) draulic Power, hp aft Power, Brake hp Pump Efficiency rchased Power, hp Actual Purchase Power, hp Actual Purchase Power, hp Actual Purchase Power, kW mp pressure, barg mp Type mp Material st Correlation-Pump rchase Cost, CpA uigment Purchase Cost, CpO K1 from Table A.1 K3 from Table A.1 K3 from Table A.1 K3 from Table A.2 C2 from Table A.2 C3 from Table A.2 C3 from Table A.2 Safted South Caster Cost, FBM B1 from Table A.4 B2 from Table A.4 B1 from Table A.4 B2 from Table A.4 B1 from Table A.4 B2 from Table	0.165 8756 0.051 0.0540 0.65 0.0531 0.0540 0.0551 0.0531 0.05801 0.5801 0.165 0.037 0.165 Carbon Steel 3720.15084 10705.92152 2480.100579 3.3892 0.0536 0.1538 0.1538 0.4 1.00 0.00000 0.00000 0.00000 0.00000 0.00000 1.5 38 4.32 1.89 1.35 1605.88228 321.1776457	Set by Design Group Set by Design Group Set by Design Group
sign Specs Pressure Change, (barg) Wrate, (lb/day) Inlet flowrate, (lb/hr) draulic Power, hp aft Power, Brake hp Pump Efficiency rchased Power, hp Actual Purchase Power, hp Actual Purchase Power, hp Actual Purchase Power, hw mp Trype mp Material st Correlation - Pump rchase Cost, Cp talled Cost, CBM Ugment Purchase Cost, Cp0 K1 from Table A.1 K3 from Table A.1 K3 from Table A.2 C2 from Table A.2 C2 from Table A.2 C3 from Table A.2 C4 from Table A.2 C5 from Table A.2 C6 from Table A.2 C7 from Table A.2 C7 from Table A.2 C8 from Table A.2 C9 from Table A.4 B1 from Table A.4 B1 from Table A.4 B2 from Table A.4 B3 from Table A.4 B4 from Table A.4 B5 from	0.165 8756 0.0351 0.0351 0.0540 0.65 0.0351 0.0540 0.65 0.0931 0.5801 0.37 0.165 Carbon Steel 3720.150868 10705.92152 2480.100579 3.3892 0.1538 0.1538 0.1538 0.1538 0.1538 0.1538 1.000 0.00000 0.1538 1.5 38 4.32 1.5 1.5 1.5 1.5 1.5 1.5 1.5 1.5 1.5 1.5 1.5 1.5 1.5 1.5 1.5 1.5 1.5 1.5 1.35	Set by Design Group Set by Design Group Set by Design Group
sign Specs Pressure Change, (barg) wrate, (lb/day) Inlet flowrate, (lb/hr) draulic Power, hp Aft Power, Brake hp Pump Efficiency Trhased Power, hp Motor Efficiency Actual Purchase Power, hp Actual Purchase Power, hp Actual Purchase Power, kW mp pressure, barg mp Type mp Material st Correlation- Pump Motherial st Correlation- Pump Trchase Cost, Cp K1 from Table A.1 K3 from Table A.1 K3 from Table A.1 K3 from Table A.1 Shaft Power, KW seure Factor, FP C1 from Table A.2 C2 from Table A.2 C3 from Table A.3 Identification Number re Module Factor, FBM B1 from Table A.4 B2 from Table A.4 B2 from Table A.4 B2 from Table A.4 B1 from Table A.4 B2 from Table A.4 B3 from Table A.4 B	0.165 8756 0.051 0.0540 0.65 0.0531 0.0540 0.0551 0.0531 0.05801 0.5801 0.165 0.037 0.165 Carbon Steel 3720.15084 10705.92152 2480.100579 3.3892 0.0536 0.1538 0.1538 0.4 1.00 0.00000 0.00000 0.00000 0.00000 0.00000 1.5 38 4.32 1.89 1.35 1605.88228 321.1776457	Set by Design Group Set by Design Group Set by Design Group

Pump 2: Condens	er to Flash Tank	
Design Specs		
Pressure Change, (barg) Flowrate, (lb/day)	0.20	
Inlet flowrate, (lb/hr)	942	
Hydraulic Power, hp	0.1098	
Shaft Power, Brake hp	0.1689	
Pump Efficiency	0.65	Set by Design Group
Purchased Power, hp	0.2590	
Motor Efficiency Actual Purchase Power, hp	0.6522	Set by Design Group
Actual Purchase Power, kW	0.37	Set by Design Group
Pump pressure, barg	0.2	
Pump Type	Centrifugal	Set by Design Group
Pump Material	Carbon Steel	Set by Design Group
Cost Correlation- Pump	· · · · · · · · · · · · · · · · · · ·	
Purchase Cost, Cp Installed Cost, CBM	3720.150868 10705.92152	
Equipment Purchase Cost, Cp0	2480.100579	
K1 from Table A.1	3.3892	
K2 from Table A.1	0.0536	
K3 from Table A.1	0.1538	
Shaft Power, KW	0.4	
Presure Factor, FP C1 from Table A.2	1.00 0.00000	
C2 from Table A.2	0.00000	Pressure >10
C3 from Table A.3	0.00000	
Material of Construction Factor, FM from Figure A.18	1.5	
Identification Number	38	
Bare Module Factor, FBM	4.32	
B1 from Table A.4	1.89	
B2 from Table A.4	1.35 1605.888228	
Contingency, Ccont Fee, Cfee	1605.888228 321.1776457	
2016 Costs	521.1770457	
Chemical Engineering Plant Cost Index in 2016	547	
Chemical Engineering Plant Cost Index in 2012	397	
Purchase Cost, Cp	\$ 5,126	
Installed Cost, CBM	\$ 14,751 \$ 2,213	
Total Contingency, Ccont		
Total Fees, Cfee	\$ 443	
Total Fees, Cfee Total Module Capital, CTM	\$ 443 \$ 17,406	
Total Fees, Cfee	\$ 443 \$ 17,406	
Total Fees, Cfee Total Module Capital, CTM Pump 4: CSTR Design Specs	\$ 443 \$ 17,406 2 to Extruder	
Total Fees, Cfee Total Module Capital, CTM Pump 4: CSTR Design Specs Pressure Change, (barg)	\$ 443 \$ 17,406 2 to Extruder 17.570	Based on Extruder Pressure
Total Fees, Cfee Total Module Capital, CTM Pump 4: CSTR Design Specs Pressure Change, (barg) Flowrate, (lb/day)	\$ 443 \$ 17,406 2 to Extruder 17.570 70773	Based on Extruder Pressure
Total Fees, Cfee Total Module Capital, CTM Pump 4: CSTR Design Specs Pressure Change, (barg) Flowrate, (lb/day) Inlet flowrate, (lb/hr)	\$ 443 \$ 17,406 2 to Extruder 17,570 17,570 2949	Based on Extruder Pressure
Total Fees, Cfee Total Module Capital, CTM Pump 4: CSTR Design Specs Pressure Change, (barg) Flowrate, (lb/day) Inlet flowrate, (lb/hr) Hydraulic Power, hp	\$ 443 \$ 17,406 2 to Extruder 17.570 70773 2949 30.2109	Based on Extruder Pressure
Total Fees, Gee Total Module Capital, CTM Pump 4: CSTR Design Specs Pressure Change, (barg) Flowrate, (lb/hr) Inlet flowrate, (lb/hr) Hydraulic Power, Ipn Shaft Power, Brake hp	\$ 443 \$ 17,406 2 to Extruder 17.570 70773 2299 30.2109 46.4782	
Total Fees, Cfee Total Module Capital, CTM Pump 4: CSTR Design Specs Pressure Change, (barg) Flowrate, (lb/day) Inlet flowrate, (lb/hr) Hydraulic Power, hp	\$ 443 \$ 17,406 2 to Extruder 17.570 70773 2949 30.2109	
Total Fees, Cfee Total Module Capital, CTM Pump 4: CSTR Design Specs Pressure Change, (barg) Flowrate, (lb/day) Inlet flowrate, (lb/hr) Hydraulic Power, hp Shaft Power, Brake hp Pump Efficiency	\$ 443 \$ 17,406 2 to Extruder 17,570 70773 2949 30.2109 46,4782 0.655	
Total Fees, Cfee Total Module Capital, CTM Pump 4: CSTR Design Specs Pressure Change, (barg) Flowrate, (lb/day) Inlet flowrate, (lb/hr) Hydraulic Power, hp Pump Efficiency Purchased Power, hp Motor Efficiency Actual Purchase Power, hp	\$ 443 \$ 17,406 2 to Extruder 17,570 70773 2949 30,2109 46,4782 0.655 51,6403 0,9000 55	Set by Design Group
Total Fees, Cfee Total Module Capital, CTM Pump 4: CSTR Design Specs Pressure Change, (barg) Flowrate, (lb/day) Inlet flowrate, (lb/hr) Hydraulic Power, hp Shaft Power, Brake hp Pump Efficiency Purchased Power, hp Motor Efficiency Actual Purchase Power, hp Actual Purchase Power, hp Actual Purchase Power, kW	\$ 443 \$ 17,406 2 to Extruder 17,570 70773 2949 30,2109 46,4782 0.55 51,6403 0,9000 55 41,01	Set by Design Group
Total Fees, Gee Total Module Capital, CTM Pump 4: CSTR Design Specs Pressure Change, (barg) Flowrate, (lb/day) Inlet flowrate, (lb/hr) Hydraulie Power, hp Shaft Power, Brake hp Purnp Efficiency Purchased Power, hp Motor Efficiency Actual Purchase Power, hp Actual Purchase Power, kW Pump pressure, barg	§ 443 \$ 17,406 2 to Extruder 17.570 70773 2949 30.2109 46.4782 0.655 51.6403 0.9000 55 41.01 17.570	Set by Design Group Set by Design Group
Total Fees, Cfee Total Module Capital, CTM Pump 4: CSTR Design Specs Pressure Change, (barg) Flowrate, (lb/day) Inlet flowrate, (lb/hr) Hydraulic Power, hp Shaft Power, Brake hp Pump Efficiency Purchased Power, hp Motor Efficiency Actual Purchase Power, hp Actual Purchase Power, hp Actual Purchase Power, kW Pump pressure, barg Pump Type	§ 443 \$ 17,406 2 to Extruder 17,570 70773 2949 30.2109 46.4782 0.655 51.6403 0.9000 55 41.01 17.570 Centrifugal	Set by Design Group Set by Design Group Set by Design Group Set by Design Group
Total Fees, Cfee Total Module Capital, CTM Pump 4: CSTR Design Specs Pressure Change, (barg) Flowrate, (lb/day) Inlet flowrate, (lb/hr) Hydraulic Power, hp Shaft Power, Bp Pump Efficiency Purchased Power, hp Actual Purchase Power, hp Actual Purchase Power, kW Pump pressure, barg Pump Type Pump Type Pump Material	§ 443 \$ 17,406 2 to Extruder 17.570 70773 2949 30.2109 46.4782 0.655 51.6403 0.9000 55 41.01 17.570	Set by Design Group Set by Design Group Set by Design Group Set by Design Group
Total Fees, Gree Total Module Capital, CTM Pump 4: CSTR Design Specs Pressure Change, (barg) Flowrate, (lb/day) Inlet flowrate, (lb/hr) Hydraulie Power, hp Shaft Power, Brake hp Pump Efficiency Purchased Power, hp Actual Purchase Power, hp Actual Purchase Power, kW Pump rype Pump Moterial Cost Correlation- Pump	§ 443 \$ 17,406 2 to Extruder 17,570 70773 2949 30.2109 46.4782 0.655 51.6403 0.9000 55 41.01 17.570 Centrifugal	Set by Design Group Set by Design Group Set by Design Group Set by Design Group
Total Fees, Cfee Total Module Capital, CTM Pump 4: CSTR Design Specs Pressure Change, (barg) Flowrate, (lb/day) Inlet flowrate, (lb/hr) Hydraulic Power, hp Shaft Power, Brake hp Pump Efficiency Purchased Power, hp Actual Purchase Power, hp Actual Purchase Power, hp Actual Purchase Power, kW Pump pressure, barg Pump Type Pump Material Cost Correlation- Pump Purchase Cost, Cp	§ 443 \$ 17,406 2 to Extruder 17,570 70773 2949 30.2109 46.4782 0.656 51.6403 0.9000 55 41.01 17.570 Carbon Steel	Set by Design Group Set by Design Group Set by Design Group Set by Design Group
Total Fees, Gree Total Module Capital, CTM Pump 4: CSTR Design Specs Pressure Change, (barg) Flowrate, (lb/day) Inlet flowrate, (lb/hr) Hydraulie Power, hp Shaft Power, Brake hp Pump Efficiency Purchased Power, hp Actual Purchase Power, hp Actual Purchase Power, kW Pump rype Pump Moterial Cost Correlation- Pump	§ 443 \$ 17,406 2 to Extruder 17,570 70773 2949 30,2109 46,4782 0.655 51.6403 0.9000 55 41.01 17,570 Centrifugal Carbon Steel 16759.20905	Set by Design Group Set by Design Group Set by Design Group Set by Design Group
Total Fees, Cfee Total Module Capital, CTM Pump 4: CSTR Design Specs Flowrate, (Ib/day) Inlet flowrate, (Ib/hn') Hydraulic Power, hp Shaft Power, Brake hp Pump Efficiency Purchased Power, hp Actual Purchase Power, hp Actual Purchase Power, kW Pump pressure, barg Pump Type Pump Material Cost Correlation-Pump Purchase Cost, Cp Installed Cost, CBM Equipment Purchase Cost, CpO K1 from Table A.1	§ 443 \$ 17,406 2 to Extruder 17,570 70773 2949 30,2109 46,4782 0.655 51.6403 0.9000 55 41.01 17,570 Centrifugal Carbon Steel 16759,20905 48229,97325 8966,188094 3.892	Set by Design Group Set by Design Group Set by Design Group Set by Design Group
Total Fees, Cfee Total Module Capital, CTM Pump 4: CSTR Design Specs Pressure Change, (barg) Flowrate, (lb/day) Inlet flowrate, (lb/hr) Hydraulic Power, hp Shaft Power, prache Power, hp Pump Efficiency Purchased Power, hp Actual Purchase Power, hp Actual Purchase Power, hp Pump Type Pump Type Pump Type Pump Material Cost Correlation- Pump Purchase Cost, Cp0 Installed Cost, CBM Equipment Purchase Cost, Cp0 K1 from Table A.1 K2 from Table A.1	\$ 443 \$ 17,406 2 to Extruder 17,570 70773 2949 30.2109 46.4782 0.655 51.6403 0.9000 555 41.01 17.570 Carbon Steel 16759.20905 48229.97325 8966.188094 3.3892 0.0536	Set by Design Group Set by Design Group Set by Design Group Set by Design Group
Total Fees, Gree Total Module Capital, CTM Pump 4: CSTR Design Specs Pressure Change, (barg) Flowrate, (lb/day) Inlet flowrate, (lb/hr) Hydraulic Power, Pp Shaft Power, Brake hp Pump Efficiency Purchased Power, hp Motor Efficiency Actual Purchase Power, hp Actual Purchase Power, hp Pump Asterial Cost Correlation- Pump Purchase Cost, Cp Installed Cost, CBM Equipment Purchase Cost, Cp0 K1 from Table A.1 K3 from Table A.1 K3 from Table A.1	§ 443 \$ 17,406 2 to Extruder 17,570 70773 2949 30,2109 46,4782 0.655 51,6403 0.9000 55 41,01 17,570 Carbon Steel 16759,20905 48229,97325 8966,188094 3.3892 0.0538 0.1538	Set by Design Group Set by Design Group Set by Design Group Set by Design Group
Total Fees, Cfee Total Module Capital, CTM Design Specs Pressure Change, (barg) Flowrate, (Ib/day) Inlet flowrate, (Ib/hr) Hydraulic Power, hp Shaft Power, Brake hp Pump Efficiency Purup Efficiency Actual Purchase Power, hp Actual Purchase Power, kW Pump resure, barg Pump Type Pump Material Cost Correlation-Pump Purchase Cost, Cp0 K1 from Table A.1 K3 from Table A.1 Shaft Power, KW	§ 443 \$ 17,406 2 17,570 70773 2949 30,2109 46,4782 0.65 51,6403 0.9000 55 41,01 17,570 250 41,01 17,570 255 41,01 17,570 16759,20905 48229,97325 48261,88094 3.3892 0.0538 0.0538 0.1538 55.9	Set by Design Group Set by Design Group Set by Design Group Set by Design Group
Total Fees, Cfee Total Module Capital, CTM Pump 4: CSTR Design Specs Fressure Change, (barg) Flowrate, (lb/day) Inlet flowrate, (lb/hr) Hydralite Power, hp Shaft Power, Srake hp Pump Efficiency Purchase Orewer, hp Actual Purchase Power, hp Actual Purchase Power, hp Pump Type Pump Material Cost Correlation-Pump Purchase Cost, Cp Installed Cost, CBM Equipment Purchase Cost, Cp0 Installed Cost, CBM Equipment Purchase Cost, Cp0 K1 from Table A.1 K2 from Table A.1 K3 from Table A.1 Shaft Power, KW Presure Factor, FP	\$ 443 \$ 17,406 2 17,406 2 17,570 70773 2949 30,2109 46,4782 0.655 51,6403 0.9000 555 41,010 17,570 Carthringal Carthon Steel 16759,20905 48229,97325 8956,188094 3.3892 0.0536 0.1538 0.0536 0.1538 0.1538 55,9 1.25 55,9	Set by Design Group Set by Design Group Set by Design Group Set by Design Group
Total Fees, Cfee Total Module Capital, CTM Design Specs Pressure Change, (barg) Flowrate, (Ib/day) Inlet flowrate, (Ib/hr) Hydraulic Power, hp Shaft Power, Brake hp Pump Efficiency Purmp Efficiency Actual Purchase Power, hp Actual Purchase Power, kW Pump pressure, barg Pump Type Purmp Aterial Cost Correlation-Pump Purchase Cost, Cp0 K1 from Table A.1 K3 from Table A.1 Shaft Power, KW	§ 443 \$ 17,406 2 17,570 70773 2949 30,2109 46,4782 0.65 51,6403 0.9000 55 41,01 17,570 250 41,01 17,570 255 41,01 17,570 16759,20905 48229,97325 48261,88094 3.3892 0.0538 0.0538 0.1538 55.9	Set by Design Group Set by Design Group Set by Design Group Set by Design Group
Total Fees, Gee Total Module Capital, CTM Pump 4: CSTR Design Specs Pressure Change, (barg) Flowrate, (lb/day) Inlet flowrate, (lb/hr) Hydraulie Power, hp Shaft Power, Brake hp Pump Efficiency Purchased Power, hp Actual Purchase Power, hp Actual Purchase Power, hp Actual Purchase Power, kW Pump pressure, barg Pump Type Pump Material Cost Correlation- Pump Purchase Cost, Cp Installed Cost, CBM Equipment Purchase Cost, Cp0 K1 from Table A.1 K3 from Table A.1 K3 from Table A.1 Shaft Power, KP Presure Factor, FP C1 from Table A.2	§ 443 \$ 17,406 2 to Extruder 17,570 70773 2949 30.2109 46.4782 0.65 51.6403 0.9000 55 41.01 17.570 Carbon Steel 16759.20905 48229.97325 88965.188094 3.3892 0.0536 0.1538 55.9 1.25 -0.39350	Set by Design Group Set by Design Group Set by Design Group Set by Design Group
Total Resc, Gree Total Module Capital, CTM Design Specs Pressure Change, (barg) Flowrate, (lb/day) Inlet flowrate, (lb/hr) Hydraulic Power, Brake hp Purmp Efficiency Purmp Efficiency Actual Purchase Power, hp Actual Purchase Power, kW Pump prope Pump Material Cost Correlation- Pump Purtable Cost, Cp0 K1 from Table A.1 K2 from Table A.1 K3 from Table A.1 Shaft Power, FP C1 from Table A.2 C2 from Table A.3 Material Cost, CFM Table A.3	§ 443 \$ 17,406 2 to Extruder 2 to Extruder 17,570 70773 2949 30.2109 46.4782 0.65 51.6403 0.9000 55 41.01 17.570 Carbon Steel 16759.20905 48229.97325 8896.188094 3.3892 0.0536 0.1538 55.9 1.25 -0.39350 0.35570 0.0526	Set by Design Group Set by Design Group Set by Design Group Set by Design Group
Total Fees, Cfee Total Module Capital, CTM Design Specs Pressure Change, (barg) Flowrate, (Ib/day) Inlet flowrate, (Ib/hr) Hydraulic Power, hp Shaft Power, Brake hp Pump Efficiency Pump Efficiency Pump Efficiency Pump Efficiency Pump resure, barg Pump resure, barg Pump Type Pump Material Cost Correlation-Pump Cost Correlation-Purchase Cost, Cp0 K1 from Table A.1 K3 from Table A.1 Shaft Power, KW Presure Factor, FP C.1 from Table A.2 C.2 form Table A.3 Material JCostruction Factor, FM from Figure A.18 Identification Number	§ 443 \$ 17,406 2 17,570 17,570 70773 2949 30,2109 46,4782 0.65 51,6403 0.9000 55 41,01 17,570 Centrifugal Carbon Steel 16759,20905 48229,97325 8966,18804 3.3892 0.0538 0.1538 0.33500 0.39570 0.39570 0.00226 1.5 3.8392 3.3892	Set by Design Group Set by Design Group Set by Design Group Set by Design Group
Total Fees, Cfee Total Module Capital, CTM Pesign Specs Pressure Change, (barg) Flowrate, (lb/day) Inlet flowrate, (lb/hr) Hydraulic Power, hp Shaft Power, Brake hp Pump Efficiency Purmp Efficiency Pump Efficiency Pump Efficiency Pump Efficiency Pump Type Pump Type Pump Material Cost Correlation- Pump P Purchase Cost, Cp Installed Cost, CBM Equipment Purchase Cost, CpO K1 from Table A.1 K3 from Table A.1 K3 from Table A.1 Shaft Power, KW Presure Factor, FP C1 from Table A.2 C2 from Table A.3 Material of Construction Factor, FM from Figure A.18 Identification Number Bare Module Factor, FPM	§ 443 \$ 17,406 2 17,570 70773 2949 30.2109 46.4782 0.655 51.6403 0.516403 0.9000 555 41.01 17.570 Centrifugal Carbon Steel 16759.20905 48229.97325 8966.188094 3.3892 0.0535 0.1538 55.9 1.255 -0.33500 0.33570 -0.00226 1.538 388 4.32 -0.00226 1.538 388 4.32 -0.0226	Set by Design Group Set by Design Group Set by Design Group Set by Design Group
Total Module Capital, CTM Pump 4: CSTR Design Specs Pressure Change, (barg) Flowrate, (lb/day) Inlet flowrate, (lb/hr) Hydraulic Power, hp Shaft Power, Brake hp Pump Efficiency Purchased Power, hp Actual Purchase Power, hp Actual Purchase Power, kW Pump Type Pump Material Cost Correlation- Pump Purchase Cost, Cp Installed Cost, CBM Equipment Purchase Cost, Cp0 K1 from Table A.1 K3 from Table A.1 K3 from Table A.1 Shaft Power, KP Presure Factor, FP C1 from Table A.2 C2 from Table A.3 Material IC Construction Factor, FM from Figure A.18 Identification Number Bare Module Factor, FBM B1 from Table A.4	§ 443 \$ 17,406 2 to Extruder 17,570 70773 2949 30.2109 46.4782 0.65 51.6403 0.9000 55 41.01 17,570 Carbon Steel 16759,20905 48229,97325 8866,188094 3.3892 0.0536 0.1538 55.9 1.25 -0.39350 0.33570 -0.39350 -0.39350 3.889 1.53 3.839 1.53 3.839 1.53 3.839 3.839 3.839 3.839 3.839 1.53 3.839 3.839 3.839 3.839 3.839 3.839 3.839 3.839 <td>Set by Design Group Set by Design Group Set by Design Group Set by Design Group</td>	Set by Design Group Set by Design Group Set by Design Group Set by Design Group
Total Fees, Gee Total Module Capital, CTM Design Specs Pressure Change, (barg) Flowrate, (Ib/day) Inlet flowrate, (Ib/hr) Hydraulic Power, hp Shaft Power, Brake hp Pump Efficiency Pintale Cost, Cop Installed Cost, CBM Equipment Purchase Cost, Cp0 K1 from Table A.1 K3 from Table A.1 Shaft Power, KW Presure Factor, FP C1 from Table A.2 C2 from Table A.3 Material Costruction Factor, FM from Figure A.18 Identification Number Bare Modul	§ 443 \$ 17,406 2 to Extruder 17,570 70773 2949 30,2109 46,4782 0.65 51,6403 0.9000 55 41,01 17,570 Centrifugal Carbon Steel 16759,20905 48229,97325 8966,188094 3.3892 0.0538 0.1538 0.39570 0.39570 0.00226 11,5 38 4.32 1.58 38 4.323 1.58 38 4.32 1.38 4.32 1.38 4.32 1.35	Set by Design Group Set by Design Group Set by Design Group Set by Design Group
Total Ress, Gree Total Module Capital, CTM Design Specs Pressure Change, (barg) Flowrate, (lb/day) Inlet flowrate, (lb/hr) Hydraulic Power, Brake hp Purmp Efficiency Purchased Power, hp Actual Purchase Power, hp Actual Purchase Power, kW Pump Efficiency Actual Purchase Power, kW Pump Type Pump Material Cost Correlation- Pump Purchase Cost, Cp Installed Cost, CBM Equipment Purchase Cost, Cp0 K1 from Table A.1 K2 from Table A.1 K3 from Table A.1 K3 from Table A.1 Shaft Power, KW Presure Factor, FP C1 from Table A.2 C2 from Table A.3 Material Of Construction Factor, FM from Figure A.18 Identification Number Bare Module Factor, FBM B1 from Table A.4	§ 443 \$ 17,406 2 to Extruder 17,570 70773 2949 30.2109 46.4782 0.65 51.6403 0.9000 55 41.01 17,570 Carbon Steel 16759,20905 48229,97325 8866,188094 3.3892 0.0536 0.1538 55.9 1.25 -0.39350 0.33570 -0.39350 -0.39350 3.889 1.53 3.839 1.53 3.839 1.53 3.839 3.839 3.839 3.839 3.839 1.53 3.839 3.839 3.839 3.839 3.839 3.839 3.839 3.839 <td>Set by Design Group Set by Design Group Set by Design Group Set by Design Group</td>	Set by Design Group Set by Design Group Set by Design Group Set by Design Group
Total Fees, Cfee Total Module Capital, CTM Design Specs Pressure Change, (barg) Flowrate, (lb/day) Inlet flowrate, (lb/hr) Hydraulic Power, hp Shaft Power, Brake hp Pump Efficiency Pump Efficiency Pump Efficiency Pump Efficiency Pump Efficiency Pump persoure, barg Pump pressure, barg Pump Type Purchase Cost, Cp Installed Cost, CBM Equipment Purchase Cost, Cp0 K1 from Table A.1 K3 from Table A.1 K3 from Table A.1 K3 from Table A.2 C1 from Table A.2 C2 from Table A.3 Material of Construction Factor, FM from Figure A.18 Identification Number Bare Module Factor, FBM B1 from Table A.4 B2 from Table A.4 B2 from Table A.4	§ 443 \$ 17,406 2 17,570 70773 2944 30.2109 46.4782 0.655 51.6403 0.055 41.01 17.570 70773 29244 30.2109 46.4782 0.655 51.6403 0.9000 555 41.01 16759.20905 48229.97325 8966.188094 3.3892 0.0555 48229.97325 8966.188094 3.3892 0.0555 4.229.97325 8966.188094 3.3892 0.0555 4.329 0.0556 0.33500 0.33570 0.33570 0.00226 1.155 3.88 4.32 1.89 1.35 7234.495987 7234.495987	Set by Design Group Set by Design Group Set by Design Group Set by Design Group
Total Fees, Cfee Total Module Capital, CTM Design Specs Pressure Change, (barg) Flowrate, (lb/day) Inlet flowrate, (lb/hr) Hydraulic Power, hp Shaft Power, Brake hp Pump Efficiency Purchased Power, hp Motor Efficiency Pump Efficiency Pump Efficiency Pump Efficiency Pump Purchase Power, hp Actual Purchase Power, kW Pump pressure, barg Pump Material Cost Correlation - Pump P Purchase Cost, Cp Installed Cost, CBM Equipment Purchase Cost, Cp0 K1 from Table A.1 K3 from Table A.1 K3 from Table A.1 K3 from Table A.1 Shaft Power, KW Presure Factor, FP C1 from Table A.2 C2 from Table A.3 Material of Construction Factor, FM from Figure A.18 Identification Number Bare Module Factor, FBM B1 from Table A.4 B2 from Table A.4 B2 from Table A.4 B2 from Table A.4	§ 443 \$ 17,406 2 17,570 70773 2949 30.2109 46.4782 0.655 51.6403 0.516403 0.9000 555 41.01 0.7579 Centrifugal Carbon Steel 16759.20905 48229.97325 8966.188094 3.3892 0.0536 0.1538 55.9 1.255 -0.3350 0.33570 0.0226 1.35 7234.495987 7234.495987 1446.89197	Set by Design Group Set by Design Group Set by Design Group Set by Design Group
Total Ress, Gree Total Module Capital, CTM Design Specs Pressure Change, (barg) Flowrate, (lb/day) Inlet flowrate, (lb/hr) Hydraulic Power, Brake hp Pump Efficiency Purchased Power, hp Actual Purchase Power, hp Actual Purchase Power, kW Pump Efficiency Actual Purchase Power, kW Pump Type Pump Material Cost Correlation- Pump Purchase Cost, Cp Installed Cost, CBM Equipment Purchase Cost, Cp0 K1 from Table A.1 K2 from Table A.1 K3 from Table A.1 K3 from Table A.1 Shaft Power, KW Presure Factor, FP C1 from Table A.2 C2 from Table A.3 Material Of Construction Factor, FM from Figure A.18 Identification Number Bare Module Factor, FBM B1 from Table A.4 Contingeny, Ccont Fee, Cfee 2016 Costs Chemical Engineering Plant Cost Index in 2016 Chemical Engineering Plant Cost Index in 2012	§ 443 \$ 17,406 2 to Extruder 17,570 70773 2949 30,2109 46,4782 0.65 51,6403 0.9000 55 41,01 17,570 Carbon Steel 16759,20905 48229,97325 8966,188094 3.3892 0.0538 0.1538 3.3892 0.0538 0.3350 0.3350 0.3352 -0.00226 1.5 38 7234,495987 1446,89197 547 397	Set by Design Group Set by Design Group Set by Design Group Set by Design Group
Total Fees, Cfee Total Module Capital, CTM Pump 4: CSTR Design Specs Pressure Change, (barg) Flowrate, (Ib/day) Inlet flowrate, (Ib/hr) Hydraulic Power, hp Shaft Power, Brake hp Pump Efficiency Purchased Power, hp Motor Efficiency Pump rescue, barg Pump ruppe Purchase Cost, Cp Installed Cost, CBM Equipment Purchase Cost, CpO K1 from Table A.1 K3 from Table A.1 Shaft Power, KW Presure Factor, FP C1 from Table A.2 C2 from Table A.3 Material Ocostruction Factor, FM from Figure A.18. Identification Number Bare Module Factor, FBM B1 from Table A.4 B2 from Table A.4 Contingency, Ccont Fee, Cfee 2016 Costs	\$ 443 \$ 17,406 2 17,570 70773 2949 30,2109 46,4782 0.65 51,6403 0.9000 55 41,01 17,570 17,570 70773 2949 30,2109 46,4782 0.65 51,6403 0.9000 55 41,01 17,570 Centrifugal Carbon Steel 3.3892 0.0536 0.01538 0.0555 -0.039350 0.39570 -0.00226 1.55 -0.039350 0.39570 -0.00226 1.55 -0.39350 0.39570 -0.00226 1.55 -0.39350 0.39570 -0.00226 1.58 38 4.323 1.38 7234,495987 1446,899197 5 23,091	Set by Design Group Set by Design Group Set by Design Group Set by Design Group
Total Fees, Cfee Total Module Capital, CTM Design Specs Pressure Change, (barg) Flowrate, (lb/day) Inlet flowrate, (lb/hr) Hydraulic Power, hp Shaft Power, Brake hp Pump Efficiency Pump Tyrchase Power, hp Actual Purchase Power, kW Pump Type Pump Type Purchase Cost, Cp Installed Cost, CBM Equipment Purchase Cost, CpO K1 from Table A.1 K2 from Table A.1 K3 from Table A.1 K3 from Table A.1 K3 from Table A.1 K3 from Table A.2 C1 from Table A.3 Material of Construction Factor, FM from Figure A.18 Identification Number Bare Module Factor, FBM B1 from Table A.4 B2 from Table A.4 Contingency, Ccont Fee, Cfee 2016 Costs Chemical Engineering Plant Cost Index in 2	§ 443 \$ 17,406 2 17,570 70773 2949 30,2109 46,4782 0.655 51,6403 0.51 51,6403 0.55 41,01 17,570 Centrifugal Carbon Steel 16759,20905 48229,97325 8966,188094 3.8892 0.0536 0.0538 0.555,9 1.125 8966,188094 3.8892 0.0536 0.0538 0.559,9 1.125 8966,188094 3.8892 0.0536 0.0538 55,9 1.0538 55,9 1.255 -0.039500 0.039500 0.039500 0.00226 1.53 1.33 7234,495987 1446,899197 547 3397 547 349 547 35 53,091 \$ 66,453	Set by Design Group Set by Design Group Set by Design Group Set by Design Group
Total Fees, Cfee Total Module Capital, CTM Pump 4: CSTR Design Specs Pressure Change, (barg) Flowrate, (Ib/day) Inlet flowrate, (Ib/hr) Hydraulic Power, hp Shaft Power, Brake hp Pump Efficiency Purchased Power, hp Motor Efficiency Pump rescue, barg Pump ruppe Purchase Cost, Cp Installed Cost, CBM Equipment Purchase Cost, CpO K1 from Table A.1 K3 from Table A.1 Shaft Power, KW Presure Factor, FP C1 from Table A.2 C2 from Table A.3 Material Ocostruction Factor, FM from Figure A.18. Identification Number Bare Module Factor, FBM B1 from Table A.4 B2 from Table A.4 Contingency, Ccont Fee, Cfee 2016 Costs	\$ 443 \$ 17,406 2 17,570 70773 2949 30,2109 46,4782 0.65 51,6403 0.9000 55 41,01 17,570 17,570 70773 2949 30,2109 46,4782 0.65 51,6403 0.9000 55 41,01 17,570 Centrifugal Carbon Steel 3.3892 0.0536 0.01538 0.0555 -0.039350 0.39570 -0.00226 1.55 -0.039350 0.39570 -0.00226 1.55 -0.39350 0.39570 -0.00226 1.55 -0.39350 0.39570 -0.00226 1.58 38 4.323 1.38 7234,495987 1446,899197 5 23,091	Set by Design Group Set by Design Group Set by Design Group Set by Design Group

Pump 5: Eva	porator Pump	
Design Specs		
Pressure Change, (barg)	2.43	
Flowrate, (lb/day)	87673	From HYSYS
Inlet flowrate, (lb/hr)	3653	From HYSYS
Hydraulic Power, hp	5.2	
Shaft Power, hp	8.0	
Pump Efficiency	0.65	Set by Design Group
Purchased/Break Power, hp	9.5	
Motor Efficiency	0.841	
Actual Purchase Power, hp	10	Set by Design Group
Actual Purchase Power, kW	7.46	, , ,
Pump pressure, barg	2.1	
Pump Type	Centrifugal	Set by Design Group
Pump Material	Carbon Steel	Set by Design Group
Cost Correlation- Pump		,
Purchase Cost, Cp	6174.896583	
Installed Cost, CBM	17770.23583	
Equipment Purchase Cost, Cp0	4116.597722	
K1 from Table A.1	3.3892	
K2 from Table A.1	0.0536	
K3 from Table A.1	0.1538	
Shaft Power, KW	11.2	
Presure Factor, FP	1.00	
C1 from Table A.2	0.00000	
C2 from Table A.2	0.00000	Pressure >10
C3 from Table A.3	0.00000	
Material of Construction Factor, FM from Figure A.18	1.5	
Identification Number	38	
Bare Module Factor, FBM	4.32	
B1 from Table A.4	1.89	
B2 from Table A.4	1.35	
Contingency, Ccont	2665.535374	
Fee, Cfee	533.1070748	
2016 Costs		
Chemical Engineering Plant Cost Index in 2016	547	
Chemical Engineering Plant Cost Index in 2012	397	
Purchase Cost, Cp	\$ 8,508	
Installed Cost, CBM	\$ 24,484	
Total Contingency, Ccont	\$ 3,673	
Total Fees, Cfee	\$ 735	
Total Module Capital, CTM	\$ 28,892	

Utilitie	es (Pelletized)		Utiliti	ies (Spun)	
Ser	vice Factor		Servi	ice Factor	
Service Factor	0.95		Service Factor	0.95	
Days/yr	365		Days/yr	365	
Hours/ day	24		Hours/ day	24	
Operation Hours/yr	8322		Operation Hours/yr	8322	
Pun	np Electricity		Pump	Electricity	
Total kW	168.86		Total kW	168.86	
Total kW-hr	1405283.711		Total kW-hr	1405283.711	
Pice per kW-hr	\$ 0.0545	Calvert City, KS	Pice per kW-hr	\$ 0.0545	Calvert City, KS
Total Price/yr	\$ 76,587.96		Total Price/yr	\$ 76,587.96	
Reactor E	lectricity (stiring)		Reactor Ele	ectricity (stiring)	
Total kW	63.64		Total kW	113.29	
Total kW-hr	529570.47		Total kW-hr	942782.736	
Pice per kW-hr	\$ 0.0545	Calvert City, KS	Pice per kW-hr	\$ 0.0545	Calvert City, KS
Total Price/yr	\$ 28,861.59		Total Price/yr	\$ 51,381.66	
Reactor He	ating (Steam Jacket)		Reactor Heat	ing (Steam Jacket)	
Duty (J/s)	1291116458		Duty (J/s)	1291116458	
(Btu/h)	4405289355		(Btu/h)	4405289355	
Flow Rate, (lb/h)	4738398.79		Flow Rate, (lb/h)	4738398.79	
1000 lb	4738.39879		1000 lb	4738.39879	
Cost/1000 lb	4.75		Cost/1000 lb	4.75	
Cost	\$ 22,507.39		Cost	\$ 22,507.39	
Coc	oling Water		Cooli	ing Water	
Co	ndenser 1		Con	denser 1	
Price/1000 gal	\$ 120.00	Phillips	Price/1000 gal	\$ 120.00	Phillips
Inlet CW Flow,			Inlet CW Flow,		
Flow Rate, lb/hr	822827.7519		Flow Rate, lb/hr	822827.7519	
gpm	1651.949275		gpm	1651.949275	
Total Price/yr	\$ 198,233.91		Total Price/yr	\$ 198,233.91	
Density of Water,	1		Density of Water,	1	
Heat Flow, Btu/hr	27153316		Heat Flow, Btu/hr	27153316	
Specific Heat (Water), Btu/lbF	1		Specific Heat (Water), Btu/lbF	1	
CW out Temp, C	120.0		CW out Temp, C	120.0	
CW in Temp, C	87.00		CW in Temp, C	87.00	
Temp Difference	33.0		Temp Difference	33.0	
	Hot Oil		H	lot Oil	
Volume, gal	110.00		Volume, gal	110.00	
Cost	\$ 4,079.90	DME	Cost	\$ 4,079.90	DME

				Optimized	Continuous Process,	T=260					
End of Year	0	1	2	3	4	9	6	7	8	9	10
Sale Price of Spun Nylon 6,6/ Ib		\$ 4.15		\$ 4.15	\$ 4.15	\$ 4.15	\$ 4.15	\$ 4.15	\$ 4.15	\$ 4.15	\$ 4.15
Amount of Nylon 6,6 (lb)		18,357,678	36,715,357	36,715,357	36,715,357	36,715,357	36,715,357	36,715,357	36,715,357	36,715,357	36,715,357
Sale Price of 1,6 Hexanediamine/lb		\$ 1.19			\$ 1.19						
Amount of 1,6 Hexanediamine (lb)		1,518,109.64	3,036,219.29	3,036,219.29	3,036,219.29	3,036,219.29	3,036,219.29	3,036,219.29	3,036,219.29	3,036,219.29	3,036,219.29
Sales Revenue	-	77,990,916	155,981,831	155,981,831	155,981,831	155,981,831	155,981,831	155,981,831	155,981,831	155,981,831	155,981,831
+ Salvage Value		-	-		-	-	-	-	-	-	-
- Royalties ("basis")		-	-		-	-	-	-	-	-	-
Net Revenue		77,990,916	155,981,831	155,981,831	155,981,831	155,981,831	155,981,831	155,981,831	155,981,831	155,981,831	155,981,831
- Raw Material Costs		(41,364,489)	(82,728,978)	(82,728,978)	(82,728,978)	(82,728,978)	(82,728,978)	(82,728,978)	(82,728,978)	(82,728,978)	(82,728,978)
- Other Op Costs		-	-	-		-	-	-	-	-	-
Cooling Water		(130,633)	(261,266)	(261,266)	(261,266)	(261,266	(261,266)	(261,266)	(261,266)	(261,266)	(261,266)
Electricity		(66,521)	(133,043)	(133,043)	(133,043)	(133,043)	(133,043)	(133,043)	(133,043)	(133,043)	(133,043)
Low Pressure Steam		(144,924)	(289,847)	(289,847)	(289,847)	(289,847)	(289,847)	(289,847)	(289,847)	(289,847)	(289,847)
- Operating Labor		(415,016)	(830,032)	(830,032)	(830,032)	(830,032)	(830,032)	(830,032)	(830,032)	(830,032)	(830,032)
- Other Manufacturing Costs		(1,789,276)	(3,578,551)	(3,578,551)	(3,578,551)	(3,578,551	(3,578,551)	(3,578,551)	(3,578,551)	(3,578,551)	(3,578,551)
- Depreciation		(613,443.49)	(2,208,396.56)	(1,766,717.25)	(1,413,373.80)	(1,131,189.79)	(904,215.70)	(803,610.97)	(803,610.97)	(804,837.86)	(803,610.97)
MACRS 10 yr		0.1	0.18	0.144	0.1152	0.0922	0.0737	0.0655	0.0655	0.0656	0.0655
- Waste Treatment		(15,557)	(31,114)	(31,114)	(31,114)	(31,114)	(31,114)	(31,114)	(31,114)	(31,114)	(31,114)
- Writeoff		-	-	-	-	-	-	-	-	-	-
Taxable Income		33,451,056	65,920,603	66,362,282	66,715,626	66,997,810	67,224,784	67,325,389	67,325,389	67,324,162	67,325,389
- Tax @ 40%		(13,380,423)	(26,368,241)	(26,544,913)	(26,686,250)	(26,799,124)	(26,889,914)	(26,930,155)	(26,930,155)	(26,929,665)	(26,930,155)
Net Income		20,070,634	39,552,362	39,817,369	40,029,375	40,198,686	40,334,870	40,395,233	40,395,233	40,394,497	40,395,233
+ Depreciation		613,443	2,208,397	1,766,717	1,413,374	1,131,190	904,216	803,611	803,611	804,838	803,611
+ Writeoff		-	-	-	-	-		-	-	-	-
- Working Capital		-	-	-	-	-	-	-	-	-	-
- Fixed Capital	(12,268,870)	-	-		-	-	-	-	-	-	-
Cash Flow	(12,268,870)	20,684,077	41,760,758	41,584,087	41,442,749	41,329,876	41,239,086	41,198,844	41,198,844	41,199,335	41,198,844
Discount Factor (P/Fi,n)	1.0000	0.8696	0.7561	0.6575	0.5718	0.4972	0.4342	0.3759	0.3269	0.2843	0.2843
Discounted Cash Flow	(12,268,870)	17,986,874	31,575,309	27,341,537	23,696,964	20,549,214	17,906,011	15,486,646	13,467,902	11,712,971	11,712,831
NPV @ i* =	179,167,390										
PWC	(253,689,654)										
DCFROR=	222%										

Optimization T=260C

				Optimized	Continuous Process,	= 270					
End of Year	0	1	2	3	4	5	6	7	/ 8	9	10
Sale Price of Spun Nylon 6,6/ lb		\$ 4.15	\$ 4.15	\$ 4.15	\$ 4.15	\$ 4.15	\$ 4.15	\$ 4.15	\$ 4.15	\$ 4.15	\$ 4.15
Amount of Nylon 6,6 (lb)		18,357,678	36,715,357	36,715,357	36,715,357	36,715,357	36,715,357	36,715,357	36,715,357	36,715,357	36,715,357
Sale Price of 1,6 Hexanediamine/lb		\$ 1.19	\$ 1.19	\$ 1.19	\$ 1.19	\$ 1.19	\$ 1.19	\$ 1.19	\$ 1.19	\$ 1.19	\$ 1.19
Amount of 1,6 Hexanediamine (Ib)		1,518,109.64	3,036,219.29	3,036,219.29	3,036,219.29	3,036,219.29	3,036,219.29	3,036,219.29	3,036,219.29	3,036,219.29	3,036,219.29
Sales Revenue	-	77,990,916	155,981,831	155,981,831	155,981,831	155,981,831	155,981,831	155,981,831	155,981,831	155,981,831	155,981,831
+ Salvage Value		-		-	-	-	-	-	-	-	
- Royalties ("basis")			-	-	-		-	-	-	-	-
Net Revenue		77,990,916	155,981,831	155,981,831	155,981,831	155,981,831	155,981,831	155,981,831	155,981,831	155,981,831	155,981,831
- Raw Material Costs		(41,364,489)	(82,728,978)	(82,728,978)	(82,728,978)	(82,728,978)	(82,728,978)	(82,728,978)	(82,728,978)	(82,728,978)	(82,728,978)
- Other Op Costs		-	-	-	-	-	-	-	-	-	-
Cooling Water		(139,284)	(278,569)	(278,569)	(278,569)	(278,569)	(278,569)	(278,569)	(278,569)	(278,569)	(278,569)
Electricity		(66,521)	(133,043)	(133,043)	(133,043)	(133,043)	(133,043)	(133,043)	(133,043)	(133,043)	(133,043)
Low Pressure Steam		(144,924)	(289,847)	(289,847)	(289,847)	(289,847)	(289,847)	(289,847)	(289,847)	(289,847)	(289,847)
- Operating Labor		(415,016)	(830,032)	(830,032)	(830,032)	(830,032)	(830,032)	(830,032)	(830,032)	(830,032)	(830,032)
- Other Manufacturing Costs		(1,833,752)	(3,667,503)	(3,667,503)	(3,667,503)	(3,667,503)	(3,667,503)	(3,667,503)	(3,667,503)	(3,667,503)	(3,667,503)
- Depreciation		(632,867.35)	(2,278,322.45)	(1,822,657.96)	(1,458,126.37)	(1,167,007.39)	(932,846.47)	(829,056.22)	(829,056.22)	(830,321.96)	(829,056.22)
MACRS 10 yr		0.1	0.18	0.144	0.1152	0.0922	0.0737	0.0655	0.0655	0.0656	0.0655
- Waste Treatment		(15,654)	(31,309)	(31,309)	(31,309)	(31,309)	(31,309)	(31,309)	(31,309)	(31,309)	(31,309)
- Writeoff		-		-	-	-	-	-	-	-	
Taxable Income		33,378,408	65,744,228	66,199,893	66,564,424	66,855,543	67,089,704	67,193,494	67,193,494	67,192,229	67,193,494
- Tax @ 40%		(13,351,363)	(26,297,691)	(26,479,957)	(26,625,770)	(26,742,217)	(26,835,882)	(26,877,398)	(26,877,398)	(26,876,891)	(26,877,398)
Net Income		20,027,045	39,446,537	39,719,936	39,938,654	40,113,326	40,253,822	40,316,097	40,316,097	40,315,337	40,316,097
+ Depreciation		632,867	2,278,322	1,822,658	1,458,126	1,167,007	932,846	829,056	829,056	830,322	829,056
+ Writeoff		-		-	-	-		-	-	-	
- Working Capital		-		-	-	-	-	-	-	-	
- Fixed Capital	(12,657,347)	-	-	-		-	-	-	-		-
Cash Flow	(12,657,347)	20,659,912	41,724,859	41,542,593	41,396,781	41,280,333	41,186,669	41,145,153	41,145,153	41,145,659	41,145,153
Discount Factor (P/Fi,n)	1.0000	0.8696	0.7561	0.6575	0.5718	0.4972	0.4342	0.3759	0.3269	0.2843	0.2843
Discounted Cash Flow	(12,657,347)	17,965,860	31,548,166	27,314,255	23,670,679	20,524,582	17,883,252	15,466,463	13,450,350	11,697,711	11,697,567
NPV @ i* =	178,561,538										
PWC	(253,413,184)										
DCFROR=	216%										

Optimization T=270C

				Cont	inuous Process, Pellet		-		-		
End of Year	0	1	2	3	4	5	6	7	8	9	10
Sale Price of Spun Nylon 6,6/ Ib		\$ 4.15	\$ 4.15	\$ 4.15	\$ 4.15	\$ 4.15	\$ 4.15	\$ 4.15	\$ 4.15	\$ 4.15	\$ 4.15
Amount of Nylon 6,6 (lb)		18,357,678	36,715,357	36,715,357	36,715,357	36,715,357	36,715,357	36,715,357	36,715,357	36,715,357	36,715,357
Sale Price of 1,6 Hexanediamine/lb		\$ 1.19	\$ 1.19	\$ 1.19	\$ 1.19	\$ 1.19	\$ 1.19	\$ 1.19	\$ 1.19	\$ 1.19	\$ 1.19
Amount of 1,6 Hexanediamine (lb)		1,518,109.64	3,036,219.29	3,036,219.29	3,036,219.29	3,036,219.29	3,036,219.29	3,036,219.29	3,036,219.29	3,036,219.29	3,036,219.29
Sales Revenue	-	77,990,916	155,981,831	155,981,831	155,981,831	155,981,831	155,981,831	155,981,831	155,981,831	155,981,831	155,981,831
+ Salvage Value		-	-	-		-	-		-	-	-
- Royalties ("basis")		-	-	-	-	-	-	-	-	-	-
Net Revenue		77,990,916	155,981,831	155,981,831	155,981,831	155,981,831	155,981,831	155,981,831	155,981,831	155,981,831	155,981,831
- Raw Material Costs		(41,364,489)	(82,728,978)	(82,728,978)	(82,728,978)	(82,728,978)	(82,728,978)	(82,728,978)	(82,728,978)	(82,728,978)	(82,728,978)
- Other Op Costs		-	-	-		-	-		-		-
Cooling Water		(147,936)	(295,871)	(295,871)	(295,871)	(295,871)	(295,871)	(295,871)	(295,871)	(295,871)	(295,871)
Electricity		(66,521)	(133,043)	(133,043)	(133,043)	(133,043)	(133,043)	(133,043)	(133,043)	(133,043)	(133,043)
Low Pressure Steam		(144,924)	(289,847)	(289,847)	(289,847)	(289,847)	(289,847)	(289,847)	(289,847)	(289,847)	(289,847)
- Operating Labor		(415,016)	(830,032)	(830,032)	(830,032)	(830,032)	(830,032)	(830,032)	(830,032)	(830,032)	(830,032)
- Other Manufacturing Costs		(1,874,748)	(3,749,496)	(3,749,496)	(3,749,496)	(3,749,496)	(3,749,496)	(3,749,496)	(3,749,496)	(3,749,496)	(3,749,496)
- Depreciation		(650,771.66)	(2,342,777.96)	(1,874,222.37)	(1,499,377.90)	(1,200,022.93)	(959,237.42)	(852,510.87)	(852,510.87)	(853,812.41)	(852,510.87)
MACRS 10 yr		0.1	0.18	0.144	0.1152	0.0922	0.0737	0.0655	0.0655	0.0656	0.0655
- Waste Treatment		(15,752)	(31,504)	(31,504)	(31,504)	(31,504)	(31,504)	(31,504)	(31,504)	(31,504)	(31,504)
- Writeoff		-	-	-	-	-	-	-	-	-	-
Taxable Income		33,310,758	65,580,282	66,048,838	66,423,682	66,723,037	66,963,823	67,070,549	67,070,549	67,069,248	67,070,549
- Tax @ 40%		(13,324,303)	(26,232,113)	(26,419,535)	(26,569,473)	(26,689,215)	(26,785,529)	(26,828,220)	(26,828,220)	(26,827,699)	(26,828,220)
Net Income		19,986,455	39,348,169	39,629,303	39,854,209	40,033,822	40,178,294	40,242,330	40,242,330	40,241,549	40,242,330
+ Depreciation		650,772	2,342,778	1,874,222	1,499,378	1,200,023	959,237	852,511	852,511	853,812	852,511
+ Writeoff			-				-		-		-
- Working Capital		-	-	-	-	-	-		-	-	-
- Fixed Capital	(13,015,433)		-	-	-	-	-	-	-	-	-
Cash Flow	(13,015,433)	20,637,227	41,690,947	41,503,525	41,353,587	41,233,845	41,137,531	41,094,841	41,094,841	41,095,361	41,094,841
Discount Factor (P/Fin)	1.0000	0.8696	0.7561	0.6575	0.5718	0.4972	0.4342	0.3759	0.3269	0.2843	0.2843
Discounted Cash Flow	(13,015,433)	17,946,132	31,522,525	27,288,568	23,645,981	20,501,468	17,861,916	15,447,551	13,433,903	11,683,411	11,683,263
NPV @ i* =	177,999,286										
PWC	(253,927,442)										
DCFROR=	210%										

Optimization T=280C

		•		Oprimizatio	n Continuous Process	T = 290					
End of Year	0	1	2	3	4	5	6	7	8	9	10
Sale Price of Spun Nylon 6,6/ lb		\$ 4.15	\$ 4.15	\$ 4.15	\$ 4.15	\$ 4.15	\$ 4.15	\$ 4.15	\$ 4.15	\$ 4.15	\$ 4.15
Amount of Nylon 6,6 (lb)		18,357,678	36,715,357	36,715,357	36,715,357	36,715,357	36,715,357	36,715,357	36,715,357	36,715,357	36,715,357
Sale Price of 1,6 Hexanediamine/lb		\$ 1.19	\$ 1.19	\$ 1.19	\$ 1.19	\$ 1.19	\$ 1.19	\$ 1.19	\$ 1.19	\$ 1.19	\$ 1.19
Amount of 1,6 Hexanediamine (Ib)		1,518,109.64	3,036,219.29	3,036,219.29	3,036,219.29	3,036,219.29	3,036,219.29	3,036,219.29	3,036,219.29	3,036,219.29	3,036,219.29
Sales Revenue	-	77,990,916	155,981,831	155,981,831	155,981,831	155,981,831	155,981,831	155,981,831	155,981,831	155,981,831	155,981,831
+ Salvage Value		-	-	-	-	-	-	-	-	-	-
- Royalties ("basis")		-	-	-	-	-	-	-	-	-	-
Net Revenue		77,990,916	155,981,831	155,981,831	155,981,831	155,981,831	155,981,831	155,981,831	155,981,831	155,981,831	155,981,831
- Raw Material Costs		(41,364,489)	(82,728,978)	(82,728,978)	(82,728,978)	(82,728,978)	(82,728,978)	(82,728,978)	(82,728,978)	(82,728,978)	(82,728,978)
- Other Op Costs		-	-	-	-	-	-	-	-	-	-
Cooling Water		(156,587)	(313,173)	(313,173)	(313,173)	(313,173)	(313,173)	(313,173)	(313,173)	(313,173)	(313,173)
Electricity		(66,521)	(133,043)	(133,043)	(133,043)	(133,043)	(133,043)	(133,043)	(133,043)	(133,043)	(133,043)
Low Pressure Steam		(144,924)	(289,847)	(289,847)	(289,847)	(289,847)	(289,847)	(289,847)	(289,847)	(289,847)	(289,847)
- Operating Labor		(415,016)	(830,032)	(830,032)	(830,032)	(830,032)	(830,032)	(830,032)	(830,032)	(830,032)	(830,032)
- Other Manufacturing Costs		(1,918,715)	(3,837,430)	(3,837,430)	(3,837,430)	(3,837,430)	(3,837,430)	(3,837,430)	(3,837,430)	(3,837,430)	(3,837,430)
- Depreciation		(669,973.21)	(2,411,903.54)	(1,929,522.83)	(1,543,618.27)	(1,235,430.59)	(987,540.51	(877,664.90)	(877,664.90)	(879,004.85)	(877,664.90)
MACRS 10 yr		0.1	0.18	0.144	0.1152	0.0922	0.0737	0.0655	0.0655	0.0656	0.0655
- Waste Treatment		(15,752)	(31,504)	(31,504)	(31,504)	(31,504)	(31,504)	(31,504)	(31,504)	(31,504)	(31,504)
- Writeoff		-	-	-	-	-	-	-	-	-	-
Taxable Income		33,238,939	65,405,920	65,888,301	66,274,206	66,582,393	66,830,283	66,940,159	66,940,159	66,938,819	66,940,159
- Tax @ 40%		(13,295,576)	(26,162,368)	(26,355,320)	(26,509,682)	(26,632,957)	(26,732,113)	(26,776,064)	(26,776,064)	(26,775,528)	(26,776,064)
Net Income		19,943,363	39,243,552	39,532,981	39,764,523	39,949,436	40,098,170	40,164,095	40,164,095	40,163,291	40,164,095
+ Depreciation		669,973	2,411,904	1,929,523	1,543,618	1,235,431	987,541	877,665	877,665	879,005	877,665
+ Writeoff		-	-	-	-		-	-	-	-	-
- Working Capital		-	-	-	-	-	-	-	-	-	-
- Fixed Capital	(13,399,464)		-	-	-	-	-	-	-	-	-
Cash Flow	(13,399,464)	20,613,336	41,655,456	41,462,503	41,308,142	41,184,867	41,085,711	41,041,760	41,041,760	41,042,296	41,041,760
Discount Factor (P/Fin)	1.0000	0.8696	0.7561	0.6575	0.5718	0.4972	0.4342	0.3759	0.3269	0.2843	0.2843
Discounted Cash Flow	(13,399,464)	17,925,357	31,495,690	27,261,596	23,619,995	20,477,116	17,839,416	15,427,598	13,416,551	11,668,325	11,668,172
NPV @ i* =	177,400,352										
PWC	(254,478,382)										
DCFROR=	205%										

Optimization T=290C

				Optimization	Continuous Process,	T =300C		-			
End of Year	0	1	2	3	4	5	6	7	8	9	10
Sale Price of Spun Nylon 6,6/ lb		\$ 4.15	\$ 4.15	\$ 4.15	\$ 4.15	\$ 4.15	\$ 4.15	\$ 4.15	\$ 4.15	\$ 4.15	\$ 4.15
Amount of Nylon 6,6 (lb)		18,357,678	36,715,357	36,715,357	36,715,357	36,715,357	36,715,357	36,715,357	36,715,357	36,715,357	36,715,357
Sale Price of 1,6 Hexanediamine/lb		\$ 1.19	\$ 1.19	\$ 1.19	\$ 1.19	\$ 1.19	\$ 1.19	\$ 1.19	\$ 1.19	\$ 1.19	\$ 1.19
Amount of 1,6 Hexanediamine (lb)		1,518,109.64	3,036,219.29	3,036,219.29	3,036,219.29	3,036,219.29	3,036,219.29	3,036,219.29	3,036,219.29	3,036,219.29	3,036,219.29
Sales Revenue		77,990,916	155,981,831	155,981,831	155,981,831	155,981,831	155,981,831	155,981,831	155,981,831	155,981,831	155,981,831
+ Salvage Value		-		-	-	-	-	-	-	-	-
- Royalties ("basis")			-	-		-		-	-		-
Net Revenue		77,990,916	155,981,831	155,981,831	155,981,831	155,981,831	155,981,831	155,981,831	155,981,831	155,981,831	155,981,831
- Raw Material Costs		(41,364,489)	(82,728,978)	(82,728,978)	(82,728,978)	(82,728,978)	(82,728,978)	(82,728,978)	(82,728,978)	(82,728,978)	(82,728,978)
- Other Op Costs		-	-	-	-	-	-	-	-	-	-
Cooling Water		(165,238)	(330,476)	(330,476)	(330,476)	(330,476)	(330,476)	(330,476)	(330,476)	(330,476)	(330,476)
Electricity		(66,521)	(133,043)	(133,043)	(133,043)	(133,043)	(133,043)	(133,043)	(133,043)	(133,043)	(133,043)
Low Pressure Steam		(144,923.70656)	(289,847)	(289,847)	(289,847)	(289,847)	(289,847)	(289,847)	(289,847)	(289,847)	(289,847)
- Operating Labor		(830,032)	(830,032)	(830,032)	(830,032)	(830,032)	(830,032)	(830,032)	(830,032)	(830,032)	(830,032)
- Other Manufacturing Costs		(3,947,106)	(3,947,106)	(3,947,106)	(3,947,106)	(3,947,106)	(3,947,106)	(3,947,106)	(3,947,106)	(3,947,106)	(3,947,106)
- Depreciation		(1,387,844.71)	(2,498,120.48)	(1,998,496.38)	(1,598,797.10)	(1,279,592.82)	(1,022,841.55)	(909,038.28)	(909,038.28)	(910,426.13)	(909,038.28)
MACRS 10 yr		0.1	0.18	0.144	0.1152	0.0922	0.0737	0.0655	0.0655	0.0656	0.0655
- Waste Treatment		(31,893)	(31,893)	(31,893)	(31,893)	(31,893)	(31,893)	(31,893)	(31,893)	(31,893)	(31,893)
- Writeoff		-	-	-	-	-	-	-	-	-	-
Taxable Income		30,052,868	65,192,336	65,691,960	66,091,659	66,410,864	66,667,615	66,781,418	66,781,418	66,780,030	66,781,418
- Tax @ 40%		(12,021,147)	(26,076,934)	(26,276,784)	(26,436,664)	(26,564,345)	(26,667,046)	(26,712,567)	(26,712,567)	(26,712,012)	(26,712,567)
Net Income		18,031,721	39,115,402	39,415,176	39,654,996	39,846,518	40,000,569	40,068,851	40,068,851	40,068,018	40,068,851
+ Depreciation		1,387,845	2,498,120	1,998,496	1,598,797	1,279,593	1,022,842	909,038	909,038	910,426	909,038
+ Writeoff		-	-	-	-	-	-	-	-	-	-
- Working Capital		-	-	-	-	-	-	-	-	-	-
- Fixed Capital	(13,878,447)			-	-	-	-	-	-	-	-
Cash Flow	(13,878,447)	19,419,566	41,613,522	41,413,672	41,253,793	41,126,111	41,023,411	40,977,889	40,977,889	40,978,444	40,977,889
Discount Factor (P/Fin)	1.0000	0.8696	0.7561	0.6575	0.5718	0.4972	0.4342	0.3759	0.3269	0.2843	0.2843
Discounted Cash Flow	(13,878,447)	16,887,254	31,463,984	27,229,490	23,588,919	20,447,902	17,812,365	15,403,589	13,395,672	11,650,172	11,650,014
NPV @ i* =	175,650,913										
PWC	(255,166,622)										
DCFROR=	194%										

Optimization T=300C

Storag	e Tank (Diamine)	
	itions and Specifications	
Ini	et Conditions	
Mass Flow HMDA, (kg/day)	-	
Mass Flow Adipic Acid, (kg/day)	-	
Mass Flow Water, (kg/day)	-	
Mass Flow Nylon Salt, (kg/day)	-	
Mass Flow Nylon 6,6, (kg/day)	-	
Mas Flow Diamine, (kg/day)	8756.22	
Temperature, C	110	338.5C= BP at 1 atr
Pressure, (barg)	3.80	
Total Flow, (kg/day)	8756.22	
	g of Equipment	
X _{Diamine}	0.23	Mass Balanc
Density Diamine, (kg/m ³)	839.599	Literatur
Total Flow Rate, (kg/day)	8756.22	
(m³/day)	10.42905264	Density/Mass Flow Rat
(m³/week)	73.00336849	
Time in Vessel, (hr)	168	Store for a Weel
(day)	7	hr/2
Reaction Rate, ()		
Volume, (m³)	73.00336849	Fixed roc
Diameter, (m)	3.1	
L/D	3	Heuristi
Orientation		Vertica
Pressure, (psia)	145	Pressure of Vessel-Literatur
Design Pressure, (psia)	195	
(barg)	12.43	
	keted/Batch Reactor (Ajitat	ted)
Purchase Cost, Cp	227484.6077	Cpo*Fp*Fr
Installed Cost, CBM	535184.2713	Cpo*FBN
Equipment Purchase Cost, Cp0	50816.7765	Сротв
K1 from Table A.1		Volume Min: 0.1 m ³ Max: 35 m
K1 Hom Table A.1	3.4974	Volume Min: 0.1 m ³ Max: 35 m Volume Min: 0.1 m ³ Max: 35 m
	0.4485	Volume Min: 0.1 m ³ Max: 35 m
K3 from Table A.1	0.1074	Volume Min: 0.1 m Max: 35 m
Volume,m3	73.00336849	
Presure Factor, FP C1 from Table A.2		
C2 from Table A.2	0	
C3 from Table A.3	0	
		Vertical Process Vessel (SS alas
Material of Construction Factor, FM from Figure A.18	1	Vertical Process Vessel (SS clac
Identification Number	18	Vertical Process Vessel (SS clac
Bare Module Factor, FBM	10.53164542	B1(B2*Fm*Fp
B1 from Table A.4	2.25	Vertical Process Vesse
B2 from Table A.4	1.85	Vertical Process Vesse
Contingency, Ccont	80277.6407	0.15*CBN
Fee, Cfee	16055.52814 2016 Costs	0.03*CBN
Chemical Engineering Plant Cost Index in 2016	547	
Chemical Engineering Plant Cost Index in 2010	397	
Purchase Cost, Cp	\$ 313,435.97	Cp*(CEPCI ₂₀₁₆ /CEPCI ₂₀₁
Installed Cost, CBM	737394.9532	CBM*(CEPCI ₂₀₁₆ /CEPCI ₂₀₁
Total Contengency	110609.243	
Total Fees	22121.8486	
СТМ	\$ 870,126.04	CBM+Confengency+Fee

Sto	rage Tank (Pellets)	
Process Co	nditions and Specifications	
	Inlet Conditions	
Mass Flow HMDA, (kg/day)	-	
Mass Flow Adipic Acid, (kg/day)	-	
Mass Flow Water, (kg/day)	-	
Mass Flow Nylon Salt, (kg/day)	-	
Mass Flow Nylon 6,6, (kg/day)	105631.1	
Mas Flow Diamine, (kg/day)	0.00	
Temperature, C	290	338.5C= BP at 1 atm
Pressure, (barg)	3.80	
Total Flow, (kg/day)	105631.10	
Siz	ing of Equipment	
X _{Diamine}	0.23	Mass Balance
Density Nylon 6,6, (kg/m ³)	1140.000	Literature
Total Flow Rate, (kg/day)	105631.10	
(m ³ /day)		Donsity/Mass Flow Pata
	92.65885965	Density/Mass Flow Rate
(m ³ /week)	92.65885965	
Time in Vessel, (hr)	168	Store for a Week
(day)	7	hr/24
Reaction Rate, ()		
Volume, (m³)	92.65885965	
Diameter, (m)	3.4	
L/D	3	Heuristic
Orientation		Vertical
Pressure, (psia)	145	Pressure of Vessel-Literature
Design Pressure, (psia)	195	
(barg)	12.43	
Cost Correlation- J	acketed/Batch Reactor (Ajitated)	
Purchase Cost, Cp	299763.7031	Cpo*Fp*Fm
Installed Cost, CBM	694916.5006	Cpo*FBM
Equipment Purchase Cost, Cp0	62379.39998	
K1 from Table A.1	3.4974	
K2 from Table A.1	0.4485	
K3 from Table A.1	0.1074	
Volume,m3	92.65885965	
Presure Factor, FP	4.805491928	
C1 from Table A.2	0	
C2 from Table A.2	0	
C3 from Table A.3	0	
Material of Construction Factor, FM from Figure A.18	1	Vertical Process Vessel (SS clad)
Identification Number	18	Vertical Process Vessel (SS clad)
Bare Module Factor, FBM	11.14016007	B1(B2*Fm*Fp)
B1 from Table A.4 B2 from Table A.4	2.25	Vertical Process Vessel Vertical Process Vessel
Contingency, Ccont	104237.4751	0.15*CBM
		0.13 CBM 0.03*CBM
Fee, Cfee	20847.49502 2016 Costs	0.03*CBM
Chamical Engineering Plant Cast Index in 2016		
Chemical Engineering Plant Cost Index in 2016	547	
Chemical Engineering Plant Cost Index in 2012	397	0. 105500 105550
Purchase Cost, Cp	\$ 413,024.55	Cp*(CEPCI ₂₀₁₆ /CEPCI ₂₀₁₂)
Installed Cost, CBM	\$ 957,479.41	CBM*(CEPCI ₂₀₁₆ /CEPCI ₂₀₁₂)
Total Contengency	\$ 143,621.91 \$ 28,724.38	
Total Fees		

Reactor Sizing and C	osting: Flash Drum	
Process Conditions a	· · ·	
Inlet Con	ditions	
Mass Flow HMDA, (kg/day)	-	
Mass Flow Adipic Acid, (kg/day) Mass Flow Water, (kg/day)	24973	
Mass Flow Nylon Salt, (kg/day)	24975	
Mass Flow Nylon 6,6, (kg/day)	_	
Mas Flow Diamine, (kg/day)	8756.2	342C= BP at 20 psia
Temperature, C	109	•
Pressure, (barg)	3.812	55.3
Total Flow, (kg/day)	33728.72756	
Outlet Co	nditions	
Mass Flow HMDA, (kg/day)	-	
Mass Flow Adipic Acid, (kg/day)	-	
Mass Flow Water, (kg/day)	24972.50756	
Mass Flow Nylon Salt, (kg/day)	-	
Mass Flow Nylon 6,6, (kg/day)	-	
Mas Flow Diamine, (kg/day)	8756.22	342C= BP at 20 psia
Temperature, C	110	109.32C= BP at 20 psia
Pressure, (barg)	0.084	
Total Flow, (kg/day)	33728.72756	
Sizing of Eq	uipment	
Overall Temp, C	109	
Overall Pressure, (barg)	0.084	
X _{Diamine}	0.23	Mass Balance
X _{H2O}	0.77	Mass Balance
Density Diamine, (kg/m ³)	0.116	Literature
Density Water, (kg/m³)	0.018	Literature
Density, (kg/m³)	0.0407	
(ft³/day)	2.257028728	Density/Mass Flow Rate
(m³/day)	79.70634847	Conversion
Volume, (m³)	4.27	
Diameter, (m)	1.219192399	
Pressure, (psia)	20	Pressure of Vessel-
Design Pressure, (psia)	70	
(barg)	3.81280228	
Cost Correlation	n- Evaporator	
Purchase Cost, Cp	89708.39275	Cpo*Fp*Fm
Installed Cost, CBM	227986.1914	Cpo*FBM
Equipment Purchase Cost, Cp0	27566.96214	
K1 from Table A.1	4.1052	Min: 0.1 m ³ Max: 35 m ³
K2 from Table A.1	0.5320	Min: 0.1 m ³ Max: 35 m ³
K3 from Table A.1	-0.0005	Min: 0.1 m ³ Max: 35 m ³
Volume,m3	4.27	
Presure Factor, FP	1.049741755	
C1 from Table A.2	0	
C2 from Table A.2	0	
C3 from Table A.3	0	
Material of Construction Factor, FM from Figure A.18 Identification Number	3.1	Vertical Process Vessel (SS) Vertical Process Vessel (SS)
	8.270268963	
Bare Module Factor, FBM B1 from Table A.4	2.25	B1(B2*Fm*Fp) Vertical Process Vessel
B1 from Table A.4	1.85	Vertical Process Vessel
Contingency, Ccont	34197.92871	0.15*CBM
Fee, Cfee	6839.585743	0.03*CBM
2016 (Costs	
Chemical Engineering Plant Cost Index in 2016	547	
Chemical Engineering Plant Cost Index in 2012	397	
Purchase Cost, Cp	\$ 123,603.25	Cp*(CEPCI ₂₀₁₆ /CEPCI ₂₀₁₂)
Installed Cost, CBM	314127.0698	CBM*(CEPCI ₂₀₁₆ /CEPCI ₂₀₁₂)
Total Contengency	47119.06047	
Total Fees	9423.812094	
СТМ	\$ 370,669.94	CBM+Confengency+Fees

Appendix E: MSDS



Hexamethylenediamine

Chemical Identity

Brand names Chemical name (IUPAC) Synonyms

Rhodiamine HMD Hexane-1,6-diamine HMD; HMDA; 1,6-diaminohexane; 1,6-hexanediamine

CAS number 124-09-4 Molecular formula C6H16N2 Molecular weight 116.20 g/mol

Applications

Hexamethylenediamine (HMD) is produced from adiponitrile and is mainly used in the production of polymers especially as a monomer for the synthesis of nylon 6-6. It is used also in a wide range of applications in coatings, lubricants and water treatment products.

Safety Assessment, Exposure and Risk Management Recommendations

Physical and chemical properties

Property	Result
Physical state	Solid at room temperature
Colour	Colourless to white
Odour	Strong, amine odour
Boiling point	201°C at atmospheric pressure
Melting point range	39 – 41°C at atmospheric pressure
Flammability	Non flammable
Water solubility	Readily soluble
Octanol water partition	Low potential for bioaccumulation

Regulatory information and certifications

Classification and labelling

EU regulation (EC) 1272/2008 (CLP)



Danger

Acute toxicity, Oral, Cat. 4 Acute toxicity, Dermal, Cat. 4 Skin Corrosion, Cat. 1B

H302 Harmful if swallowed H312 Harmful in contact with skin H314 Causes severe skin burns and eye damage H335 May cause respiratory irritation

Health effects



HMD causes adverse effects to human health by dermal, inhalation and oral routes.

Stringent safety measures must be respected for HMD handling. For more details, consult the Safety Data Sheet.

Environmental effects



HMD is harmful to aquatic organisms. It is, however, readily biodegradable, not persistent and has a low potential for bioaccumulation. Industrial sites emissions, disposal, treatment or

recycling must comply with applicable regulations to preserve the environment.

Registration and certification

ISO 9001: 2008 certified EU regulation on chemicals (EC) 1907/2006 (REACH)



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GPS Safety Summary

This Product Safety Summary is intended to provide a general overview of the chemical substance in the context of ICCA Global Product Strategy. The information on the Summary is basic information and is not intended to provide emergency response information, medical information or treatment information. The summary should not be used to provide in-depth safety and health information. In-depth safety and health information can be found on the (extended) Safety Data Sheet (e)SDS for the chemical substance.

Hexamethylenediamine

General Statement

Hexamethylenediamine (HMD) is an organic compound. The colourless solid has a strong amine odour. It is synthesised from adiponitrile.

It is mainly used for the production of polymers and especially as a monomer for the synthesis of nylon 6-6 via condensation with adipic acid. HMD is also used in the chemical industry for a wide range of applications.

The pure substance causes adverse effects to human health, it is corrosive for skin and causes serious eye damage, it may be irritating to the upper respiratory tract and is harmful if swallowed or in contact with skin. It is not classified as dangerous for the environment.

It is handled in industry under stringent safety conditions in accordance with the risk management measures to control the risk of exposure and preserve human health and environment.

Consumer exposure to hexamethylenediamine is not expected.

Chemical Identity

Name:	Hexamethylenediamine
Brand names:	Rhodiamine HMD
Chemical name (IUPAC):	Hexane-1,6-diamine
Synonyms:	HMD; HMDA; 1,6-diaminohexane; 1,6-hexanediamine
CAS number(s):	124-09-4
EC number:	204-679-6
Molecular formula:	$C_6H_{16}N_2$

Structure:





Uses and applications

Hexamethylenediamine is a key intermediate used in industrial yarns, textile, carpet, engineering thermoplastics, resin, and coating applications. It is a precursor to the manufacturing of nylon 6-6 and polyurethanes.

HMD is also used for the formulation of coatings, epoxy curing agents, petroleum additives, adhesives, inks, scale and corrosion inhibitors, and water treatment chemicals.

Hexamethylenediamine is only used for industrial purposes.

Physical/Chemical Properties

Phys/Chem Safety Assessment

Property	Value
Physical state	Solid at 20°C and atmospheric pressure
Form	Crystalline powder
Colour	Colourless to white
Odour	Strong amine odour
Molecular weight	116.20 g/mol
Melting Point range	39 - 41°C at atmospheric pressure
Boiling Point	201°C at atmospheric pressure
Flash point	85°C at atmospheric pressure
Flammability	Non flammable
Explosive properties	Non explosive
Self-ignition temperature	315°C at atmospheric pressure
Vapour pressure	0.27 hPa at 20°C
Water solubility	637 g/l at 20°C, readily soluble
Octanol Water partition coefficient (log Kow)	0.4 at 25°C, low potential for bioaccumulation

Based on available data, hexamethylenediamine is not classified regarding physical and chemical hazards, according to EU regulation (EC) 1272/2008.

Hexamethylenediamine is solid at room temperature; however, for physico-chemical properties relevant for occupational exposure, it has to be considered as a liquid as it is always handled and used in such a state. It is occasionally transported or placed on the market in drums as a mass crystallized solid, but it is always used after melting the product.



Health Effects

Human Health Safety Assessment

Effect Assessment	Result
Acute Toxicity	Harmful if swallowed or in contact with skin.
Oral/inhalation/dermal	No reliable data available by inhalation. Moreover, since the
	substance is corrosive, no further tests are required.
Irritation / corrosion	Causes severe skin burns and eye damage.
Skin/eye/respiratory tract	May cause an irritation of the upper respiratory tract.
Sensitisation	No reliable data available for skin sensitization. Moreover, since the
	substance is corrosive, no further tests are required.
Toxicity after repeated exposure	May cause an irritation of the upper respiratory tract after repeated
Oral/inhalation/dermal	exposure.
Genotoxicity / Mutagenicity	Neither mutagenic nor genetic effect, based on in vitro and in vivo
	tests results
Carcinogenicity	No carcinogenic effects expected.
	Studies showed neither genotoxicity nor systemic toxicity.
	In addition, since the substance is classified as corrosive and irritant
	for respiratory tract, long-term human professional exposure must
	be minimized.
Toxicity for reproduction	No adverse effect on fertility and on development based on results
	from a two generation study and a prenatal development study in
	rats.

All these results are based on available data. Hexamethylenediamine is classified as hazardous for health according to EU regulation (EC) 1272/2008.

Environmental Effects

Environment Safety Assessment

Effect Assessment	Result
Aquatic Toxicity	Harmful to invertebrates
	Not harmful to fish and algae
Fate and behaviour	Result
Fate and behaviour Biodegradation	Result Readily biodegradable

Based on available data, hexamethylenediamine is considered as harmful to aquatic invertebrates, but as it is readily biodegradable and not potentially bioaccumulative, it is not classified as dangerous for the environment according to EU regulation (EC) 1272/2008.



Exposure

Hexamethylenediamine is only used in industry. Considering its industrial lifecycle, from manufacture to its use in chemical synthesis or in preparations, human and environmental exposure have been assessed through exposure scenarios in the REACH dossier.

Pure HMD is a corrosive substance. Frequent and direct contact with the substance must be avoided. Manual phases must be minimized and the substance must be handled under stringent safety conditions in accordance with the risk management measures to control the risk of exposure and to preserve human health and environment.

Human health

On industrial sites, hexamethylenediamine is manufactured and handled as much as possible in closed processes which ensure that the risk is controlled. Where there is a risk of exposure, during (un)loading, mixing, sampling, analysis or maintenance operations, it must be kept as low as possible and at a safe level (strictly below exposure limits, when applied) by the use of appropriate risk management measures as suitable collective and personal protective equipment, good industrial hygiene practices and risk communication through appropriate training of workers.

Environment

Hexamethylenediamine is water soluble and readily biodegradable, it has a low potential for bioaccumulation and for volatilization in the water compartments. Based on its physical and chemical properties, if HMD was released into the environment, it would be mainly distributed in water and would not be persistent.

On the manufacturing site, the risk for the aquatic environment is controlled as effluents that may contain the substance are either directed to an on-site or municipal waste water treatment plant or incinerated onsite in an incinerator allowed to destroy hazardous wastes in compliance with European legislation.

Due to its toxicological and ecotoxicological properties, an indirect risk of human exposure via the environment is not expected for hexamethylenediamine.

Risk Management Recommendations

Hexamethylenediamine is used only in industry; recommendations are based on the risk assessment to preserve human health and environment.

Human health

Workers must be well informed and trained and must refer to the extended Safety Data Sheet (eSDS). In order to control possible risks during the handling of the substance (during (un)loading, mixing, sampling, analysis or maintenance operations), the substance must be contained by technical means. Where this is not possible, handling must be under an effective exhaust ventilation system and appropriate Personal Protective Equipment (PPE) must be worn (safety goggles, gloves, protective suit) as recommended in the eSDS.



In case of risk of exposure to dust, aerosol or vapour of the molten substance, a respirator with approved filter must be worn as the substance may be irritating to the upper respiratory tract.

Hygiene measures must be respected (accessible emergency equipment, well-maintained PPE, wash hands and skin following contact, do not eat, drink or smoke on the workplace).

Environment

All industrial aqueous releases that may contain the substance are controlled in accordance with the risk assessment and must be directed to a waste water treatment plant or incinerated in compliance with local regulation.

Disposal, treatment or recycling of industrial waste must comply with applicable regulations to preserve environment.

State Agency Review

Hexamethylenediamine has been registered EU regulation (EC) 1907/2006 (REACH) under:

Hexamethylenediamine has been reviewed under the following regulatory and/or voluntary programmes:

OECD list of High Production Volume chemicals: UNEP publication in 2002

Regulatory Information / Classification and Labelling

Substance classification and labelling according to EU regulation (EC) 1272/2008 (CLP)*:

Classification

Acute toxicity, Oral, Category 4 Acute toxicity, Dermal, Category 4 Skin corrosion. Category 1B Specific target organ toxicity - single exposure, Category 3 Labelling

Pictogram:

Signal word:

Hazard statements:

- H302 Harmful if swallowed.
- H312 Harmful in contact with skin.
- H314 Causes severe skin burns and eye damage.
- H335 May cause respiratory irritation.

- H302 Harmful if swallowed.
- Harmful in contact with skin. H312
- H314 Causes severe skin burns and eye damage.
- H335 May cause respiratory irritation.



Precautionary statements:

P260 Do not breathe dust/fume/gas/mist/vapours/spray.

P280 Wear protective gloves/ protective clothing/ eye protection/ face protection.

P301 + 330 + 331 IF SWALLOWED: rinse mouth. Do NOT induce vomiting. P303 + P361 + P353 IF ON SKIN (or hair): Remove/ Take off immediately all contaminated clothing. Rinse skin with water/ shower. P305 + P351 + P338 IF IN EYES: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue

rinsing.

P310 Immediately call a POISON CENTER or doctor/ physician.

*Harmonised EU classification and labelling



Contact information within company

For further information on this substance or Product Safety Summaries in general, please contact:

Rhodia Global Product Strategy: http://www.rhodia.com/en/sustainability/global_product_strategy/index.tcm

Contact: globalproductstrategy@eu.rhodia.com

Additional information

ICCA Global Product Strategy: http://www.icca-chem.org/en/Home/ICCA-initiatives/global-product-strategy/

(extended) Safety Data Sheet available on demand: http://www.rhodia.com/en/contact/contact_form_business.tcm

Glossary of technical terms: http://www.rhodia.com/en/sustainability/global_product_strategy/glossary/index.tcm

Date of issue: September 2012 Revision: 0

Disclaimer

The information provided in the present Safety Summary is based on European data available in REACH regulatory dossier (EC N°1907/2006) and is correct to the best of our knowledge, information and belief at the date of its publication. Such information is only intended to provide a general overview of the chemical substance in the context of ICCA Global Product Strategy and is not to be considered as a warranty or quality specification. It does not replace the safety data sheet and technical sheets. Thus, the information provided in this Safety Summary only relates to the designated specific product and may not be applicable if such product is used in combination with other materials or in another manufacturing process, unless otherwise specifically indicated. It does not release the user from ensuring he is in conformity with all regulations linked to its activity.





Material Safety Data Sheet

Adipic acid MSDS

Section 1: Chemical Product and Company Identification		
Product Name: Adipic acid	Contact Information:	
Catalog Codes: SLA3658	Sciencelab.com, Inc.	
CAS# : 124-04-9	14025 Smith Rd. Houston, Texas 77396	
RTECS: AU8400000	US Sales: 1-800-901-7247	
TSCA: TSCA 8(b) inventory: Adipic acid	International Sales: 1-281-441-4400	
CI#: Not available.	Order Online: ScienceLab.com	
nonym: Hexanedioic acid; 1,4-Butane Dicarboxylic	CHEMTREC (24HR Emergency Telephone), call: 1-800-424-9300	
Acid	International CHEMTREC, call: 1-703-527-3887	
Chemical Name: Adipic Acid	For non-emergency assistance, call: 1-281-441-4400	
Chemical Formula: HOOC(CH2)4COOH	Tor non-emergency assistance, can. 1-201-111-100	

Section 2: Composition and Information on Ingredients			
Composition:			
	Name	CAS #	% by Weight
	Adipic acid	124-04-9	100

Toxicological Data on Ingredients: Adipic acid: ORAL (LD50): Acute: >11000 mg/kg [Rat]. 1900 mg/kg [Mouse]. >11000 mg/kg [Rabbit].

Section 3: Hazards Identification

Potential Acute Health Effects: Hazardous in case of skin contact (irritant), of eye contact (irritant), of ingestion, of inhalation.

Potential Chronic Health Effects:

Slightly hazardous in case of inhalation (lung sensitizer). CARCINOGENIC EFFECTS: Not available. MUTAGENIC EFFECTS: Not available. TERATOGENIC EFFECTS: Not available. DEVELOPMENTAL TOXICITY: Not available. The substance may be toxic to the nervous system, gastrointestinal tract. Repeated or prolonged exposure to the substance can produce target organs damage.

Section 4: First Aid Measures

Eye Contact:

Check for and remove any contact lenses. In case of contact, immediately flush eyes with plenty of water for at least 15 minutes. Cold water may be used. Get medical attention.

Skin Contact:

In case of contact, immediately flush skin with plenty of water. Cover the irritated skin with an emollient. Remove contaminated clothing and shoes. Cold water may be used. Wash clothing before reuse. Thoroughly clean shoes before reuse. Get medical attention.

Serious Skin Contact:

Wash with a disinfectant soap and cover the contaminated skin with an anti-bacterial cream. Seek medical attention.

Inhalation:

If inhaled, remove to fresh air. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. Get medical attention.

Serious Inhalation: Not available.

Ingestion:

Do NOT induce vomiting unless directed to do so by medical personnel. Never give anything by mouth to an unconscious person. Loosen tight clothing such as a collar, tie, belt or waistband. Get medical attention if symptoms appear.

Serious Ingestion: Not available.

Section 5: Fire and Explosion Data

Flammability of the Product: May be combustible at high temperature.

Auto-Ignition Temperature: 420°C (788°F)

Flash Points: CLOSED CUP: 196°C (384.8°F).

Flammable Limits: Not available.

Products of Combustion: These products are carbon oxides (CO, CO2).

Fire Hazards in Presence of Various Substances:

Slightly flammable to flammable in presence of heat. Non-flammable in presence of shocks.

Explosion Hazards in Presence of Various Substances:

Risks of explosion of the product in presence of mechanical impact: Not available. Slightly explosive in presence of open flames and sparks, of heat.

Fire Fighting Media and Instructions:

SMALL FIRE: Use DRY chemical powder. LARGE FIRE: Use water spray, fog or foam. Do not use water jet.

Special Remarks on Fire Hazards: Not available.

Special Remarks on Explosion Hazards: Dust generation can form an explosive mixture if dispersed in a sufficient quantity of air.

Section 6: Accidental Release Measures

Small Spill:

Use appropriate tools to put the spilled solid in a convenient waste disposal container. Finish cleaning by spreading water on the contaminated surface and dispose of according to local and regional authority requirements.

Large Spill:

Use a shovel to put the material into a convenient waste disposal container. Be careful that the product is not present at a concentration level above TLV. Check TLV on the MSDS and with local authorities.

Section 7: Handling and Storage

Precautions:

Keep away from heat. Keep away from sources of ignition. Empty containers pose a fire risk, evaporate the residue under a fume hood. Ground all equipment containing material. Do not ingest. Do not breathe dust. Wear suitable protective clothing. In case of insufficient ventilation, wear suitable respiratory equipment. If ingested, seek medical advice immediately and show the container or the label. Avoid contact with skin and eyes. Keep away from incompatibles such as oxidizing agents.

Storage: Keep container tightly closed. Keep container in a cool, well-ventilated area. Do not store above 25°C (77°F).

Section 8: Exposure Controls/Personal Protection

Engineering Controls:

Use process enclosures, local exhaust ventilation, or other engineering controls to keep airborne levels below recommended exposure limits. If user operations generate dust, fume or mist, use ventilation to keep exposure to airborne contaminants below the exposure limit.

Personal Protection:

Splash goggles. Lab coat. Dust respirator. Be sure to use an approved/certified respirator or equivalent. Gloves.

Personal Protection in Case of a Large Spill:

Splash goggles. Full suit. Dust respirator. Boots. Gloves. A self contained breathing apparatus should be used to avoid inhalation of the product. Suggested protective clothing might not be sufficient; consult a specialist BEFORE handling this product.

Exposure Limits:

TWA: 5 (mg/m3) from ACGIH (TLV) [United States] Inhalation Consult local authorities for acceptable exposure limits.

Section 9: Physical and Chemical Properties

Physical state and appearance: Solid. (crystalline powder.)

Odor: Odorless.

Taste: Tart

Molecular Weight: 146.14 g/mole

Color: White.

pH (1% soln/water): Not available.

Boiling Point: 337.5°C (639.5°F)

Melting Point: 152°C (305.6°F)

Critical Temperature: Not available.

Specific Gravity: 1.36 (Water = 1)

Vapor Pressure: Not applicable.

Vapor Density: 5.04 (Air = 1)

Volatility: Not available.

Odor Threshold: Not available.

Water/Oil Dist. Coeff.: The product is equally soluble in oil and water; log(oil/water) = 0.1

Ionicity (in Water): Not available.

Dispersion Properties: See solubility in water, methanol, acetone.

Solubility:

Easily soluble in methanol. Soluble in hot water, acetone. Partially soluble in cold water. Insoluble in Acetic acid, Petroleum Benzin, Benzene, Petroleum Ether. Slightly soluble in Cyclohexane. Freely soluble in Ethanol.

Section 10: Stability and Reactivity Data

Stability: The product is stable.

Instability Temperature: Not available.

Conditions of Instability: Excess heat, excess dust generation, ignition sources, incompatible materials

Incompatibility with various substances: Reactive with oxidizing agents.

Corrosivity: Not available.

Special Remarks on Reactivity: Not available.

Special Remarks on Corrosivity: Aqueous solutions of Adipic acid are corrosive

Polymerization: Will not occur.

Section 11: Toxicological Information

Routes of Entry: Inhalation. Ingestion.

Toxicity to Animals: Acute oral toxicity (LD50): 1900 mg/kg [Mouse].

Chronic Effects on Humans: May cause damage to the following organs: the nervous system, gastrointestinal tract.

Other Toxic Effects on Humans: Hazardous in case of skin contact (irritant), of ingestion, of inhalation.

Special Remarks on Toxicity to Animals: Not available.

Special Remarks on Chronic Effects on Humans: Not available.

Special Remarks on other Toxic Effects on Humans:

Acute Potential Health Effects: May cause skin irritation. Eyes: May cause eye irritation. Inhalation: Expected to be a low hazard for ususal industrial handling. May cause respiratory tract. Symptoms may include coughing, sneezing, and blood-tinged mucous. Ingestion: Expected to be a low ingestion hazard if small amounts (less than a mouthful) are ingested. Ingestion of large amounts may cause gastrointestinal tract irritation with hypermotility, and diarrhea. May also affect behavior (somnolence, convulsions), and metabolism, and may cause hemorrhaging. Chronic Potential Health Effects: Inhalation: Repeated or prolonged contact by inhalation may cause asthma.

Section 12: Ecological Information

Ecotoxicity: Not available.

BOD5 and COD: Not available.

Products of Biodegradation:

Possibly hazardous short term degradation products are not likely. However, long term degradation products may arise.

Toxicity of the Products of Biodegradation: The product itself and its products of degradation are not toxic.

Special Remarks on the Products of Biodegradation: Not available.

Section 13: Disposal Considerations

Waste Disposal:

Waste must be disposed of in accordance with federal, state and local environmental control regulations.

Section 14: Transport Information

DOT Classification: Not a DOT controlled material (United States).

Identification: : Adipic Acid UNNA: NA9077 PG: III

Special Provisions for Transport: Not applicable.

Section 15: Other Regulatory Information

Federal and State Regulations:

Connecticut hazardous material survey.: Adipic acid Illinois chemical safety act: Adipic acid New York release reporting list: Adipic acid Rhode Island RTK hazardous substances: Adipic acid Pennsylvania RTK: Adipic acid Massachusetts RTK: Adipic acid Massachusetts spill list: Adipic acid New Jersey: Adipic acid New Jersey spill list: Adipic acid Louisiana spill reporting: Adipic acid TSCA 8(b) inventory: Adipic acid CERCLA: Hazardous substances.: Adipic acid: 5000 lbs. (2268 kg)

Other Regulations:

OSHA: Hazardous by definition of Hazard Communication Standard (29 CFR 1910.1200). EINECS: This product is on the European Inventory of Existing Commercial Chemical Substances.

Other Classifications:

WHMIS (Canada): Not controlled under WHMIS (Canada).

DSCL (EEC):

R36/38- Irritating to eyes and skin. S2- Keep out of the reach of children. S46- If swallowed, seek medical advice immediately and show this container or label.

HMIS (U.S.A.):

Health Hazard: 2

Fire Hazard: 1

Reactivity: 0

Personal Protection: E

National Fire Protection Association (U.S.A.):

Health: 2

Flammability: 1

Reactivity: 0

Specific hazard:

Protective Equipment:

Gloves. Lab coat. Dust respirator. Be sure to use an approved/certified respirator or equivalent. Splash goggles.

Section 16: Other Information

References: Not available.

Other Special Considerations: Not available.

Created: 10/11/2005 11:13 AM

Last Updated: 05/21/2013 12:00 PM

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Revision -1 on 10-02-07

Material Safety Data Sheet Nvlon-66 Thermoplastic Resin CHEMICAL PRODUCT/ COMPANY NAME **Product Identifier:** Polyamide 66 commonly known as Nylon 66 or PA66 **Product Description:** Nylon 66 with Flame Retardant, Rubber, Glass Fiber and/or Mica DGAXXX, DTGXXX, DTTXXX, DGGXX, DOGXXX, DOAXXX, **Product Grades:** DGKXXX, DGEXXX (XXX=3 digit number) example: DGA606 or DOA007 **Product Use:** May be used to produce molded or extruded articles or as a component of other industrial products. **Company Identification:** MANUFACTURER/DISTRIBUTER Edinburg Plastics, Inc. 18537 Vineyard Point LN Phone# (518) 438-7656 USA Cornelius, NC 28031-7989 USA (Country Code= 001) **COMPOSITION / INGREDIENT INFORMATION** % **Materials** CAS Number > 45-85 Polyamide 66 commonly known as Nylon 66 or PA66 032131-17-2 <45 **Glass Fiber** 065997-17-3 <25 014808-60-7 Mica <25 Non-Regulated: Rubber / Toughener / Impact modifiers NA <20 Bis-(hexachlorocyclopentadieno) Cyclo-octane (Declorane Plus) 013560-89-9 <10 Antimony Trioxide 001309-64-4 <12 Non-Regulated: Lubricators, Colorants, And Stabilizers NA Titanium dioxide 013463-67-7 <3 Carbon Black 001333-86-4 <3 Polycaprolactam 025038-54-4

Note: (> = Greater then) and (< = Less then) the number following the < or > symbol.

Material is not known to contain Toxic Chemicals under Section 313 of Title III of the Super fund Amendments and Reauthorization Act of 1986 and 40 CFR part 372.

HAZARDS IDENTIFICATION

Emergency Overview:

Solid pellets with slight or no odor. Spilled pellets create slipping hazard. Can burn in a fire creating dense toxic smoke. Molten plastic can cause severe thermal burns. Fumes produced during melt processing may cause eye, skin and respiratory tract irritation. Secondary operations, such as grinding, sanding or sawing, can produce dust which may present a respiratory hazard. Product in pellet form is unlikely to cause irritation.

Chronic/Carcinogenicity:

None of the components present in this material are listed by IARC, NTP, Q

Msds-Nylon 66 Logo

Page 1

Melt Processing Health Effects: Molten plastic can cause severe burns.

Processing fumes may cause irritation to the eyes, skin and respiratory tract, and in cases of severe overexposure, nausea and headache.

Medical Restrictions: There are no known human health effects aggravated by exposure to this product. However, certain sensitive individuals and individuals with respiratory impairments may be affected by exposure to components in the processing fumes.

FIRST AID MEASURES

	Eyes:	Immediately flush eyes with plenty of water for at least 15 minutes. Call a physician.
	Skin:	The compound is not likely to be hazardous by skin contact, but cleansing the skin after use is advisable. If molten polymer gets on skin, cool rapidly with cold water. do not attempt to peel polymer from skin. Obtain medical treatment for thermal burn.
	Ingestion:	No specific intervention is indicated as compound is not likely to be hazardous by ingestion. Consult a physician if necessary.
	Inhalation:	No specific intervention is indicated as the compound is not likely to be hazardous by inhalation. Consult a physician if necessary. If exposed to fumes from overheating or combustion,
		move to fresh air. Consult a physician if symptoms persist.
coughing	, difficult breath	
coughing even if s For skin	, difficult breath ymptoms develo contact with fum	move to fresh air. Consult a physician if symptoms persist. alation irritation, leave contaminated area and breathe fresh air. If ing or any other symptoms develop, seek medical attention at once,
coughing even if s For skin If irritatio	g, difficult breath ymptoms develo contact with fum n develops, see	move to fresh air. Consult a physician if symptoms persist. alation irritation, leave contaminated area and breathe fresh air. If ing or any other symptoms develop, seek medical attention at once, p at a later time. he condensate, immediately wash thoroughly with soap and water. k medical attention.
coughing even if s For skin If irritatio	g, difficult breath ymptoms develo contact with fum n develops, see MEASURES	move to fresh air. Consult a physician if symptoms persist. alation irritation, leave contaminated area and breathe fresh air. If ing or any other symptoms develop, seek medical attention at once, p at a later time. he condensate, immediately wash thoroughly with soap and water. k medical attention.
coughing even if sy For skin If irritatio FIRE FIGHTING Fire Fig	y, difficult breath ymptoms develo contact with fum n develops, see MEASURES hting:	move to fresh air. Consult a physician if symptoms persist. alation irritation, leave contaminated area and breathe fresh air. If ing or any other symptoms develop, seek medical attention at once, p at a later time. The condensate, immediately wash thoroughly with soap and water. k medical attention. Keep personnel removed and upwind of fire. Wear self-contained
coughing even if sy For skin If irritatio FIRE FIGHTING Fire Fig Extingu	y, difficult breath ymptoms develo contact with fum n develops, see MEASURES thting:	move to fresh air. Consult a physician if symptoms persist. alation irritation, leave contaminated area and breathe fresh air. If ing or any other symptoms develop, seek medical attention at once, p at a later time. The condensate, immediately wash thoroughly with soap and water. It medical attention. Keep personnel removed and upwind of fire. Wear self-contained breathing apparatus.

General:

Review FIRE FIGHTING MEASURES and HANDLING Sections.

Handling:	See FIRST AID and PERSONAL PROTECTIVE EQUIPMENT SECTIONS.
Storage:	Store in a cool, dry place. Keep containers tightly closed to prevent moisture absorption and contamination.
XPOSURE CONTROLS/PE	RSONAL PROTECTION
Engineering Controls:	Use local ventilation to control fumes from hot processing.
Personal Protection:	
Eye/Face:	Wear safety glasses. Wear coverall chemical splash goggles and face shield when possibility exists for eye and face contact due to splashing or spraying of molten material. A full face mask respirator provides protection from eye irritation.
Skin:	If there is potential contact with hot/molten material, wear heat resistant clothing and footwear.
Respiratory:	A NIOSH/MSHA approved air purifying respirator with an organic vapor cartridge with a dust/mist filter may be permissible under certain circumstances where airborne concentrations are expected to exceed exposure limits. Protection provided by air purifying respirator if there is any potential for an uncontrolled release, exposure levels are not known, or any other circumstances where air purifying respirators may not provide adequate protection.
HYSICAL AND CHEMICAL	PROPERTIES
Physical State:	Solid
Odor:	Possibly a slight organic odor
Melting Point:	220°C (428°F) - 250°C (482F°)
Specific Gravity (water	=1): >1.1
Water Solubility:	Insoluble
%Volatiles:	Not Determined
TABILITY AND REACTIVIT	
Stability:	Stable
Polymerization:	Polymerization will not occur
	Expoxure to open flame or temperatures >570°F for pro-longed tim
Incompatabilities:	Other Materials

	AQUATIC TOXICITY:	No information is available. Toxicity is expected to be low based on insolubility in water.
DISPOSA		
6	Waste Disposal:	Preferred options for disposal are (1) recycling, (2) incineration with energy recovery, and (3) landfill. The high fuel value of this product makes option 2 very desirable for material that cannot be recycled, but incinerator must be capable of scrubbing out acidic combustion products. Treatment, storage, transportation, and disposal must be in accordance with applicable federal, state/provincial, and local regulations.
TRANSP	ORTATION INFORM	IATION
	DOT Hazard Class: Proper Shipping Name: Identification Number:	
REGULA		DN .
Federal R	egulations	
	TSCA Status: WHMIS Classification:	In compliance with TSCA Inventory requirements for commercial purposes. Not a controlled product.
State Rec	This product does not cor notification.	tain reportable quantities of substances subject to supplier
	<u>Chemical Name</u> Polycaprolactam Titanium dioxide	CAS number State RTK 025038-54-4 MA, NJ, PA 013463-67-7 MA, NJ, PA
OTHER	N.V	
	Medical Use:	CAUTION: Do not use in medical applications involving permanent implantation in the human body.
	User Responsibility:	Each user should read and understand this information and incorporate it into individual site safety programs in accordance wi applicable hazard communication standards and regulations.





Material Safety Data Sheet 1,6-hexanediamine MSDS

Section 1: Chemical Product and Company Identification

Product Name: 1,6-hexanediamine

Catalog Codes: SLH2881

CAS#: 124-09-4

RTECS: MO1180000

TSCA: TSCA 8(b) inventory: 1,6-hexanediamine

Cl#: Not available.

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Synonym: Hexamethylenediamine

Chemical Formula: C6H16N2

Contact Information:

Sciencelab.com, Inc. 14025 Smith Rd. Houston, Texas 77396

US Sales: **1-800-901-7247** International Sales: **1-281-441-4400**

Order Online: ScienceLab.com

CHEMTREC (24HR Emergency Telephone), call: 1-800-424-9300

International CHEMTREC, call: 1-703-527-3887

For non-emergency assistance, call: 1-281-441-4400

Section 2: Composition and Information on Ingredients

Co	Composition:			
	Name	CAS #	% by Weight	
	{1,6-}hexanediamine	124-09-4	100	

Toxicological Data on Ingredients: 1,6-hexanediamine: ORAL (LD50): Acute: 750 mg/kg [Rat]. DERMAL (LD50): Acute: 1110 mg/kg [Rabbit].

Section 3: Hazards Identification

Potential Acute Health Effects:

Extremely hazardous in case of skin contact (irritant), of eye contact (irritant). Very hazardous in case of skin contact (corrosive). Hazardous in case of skin contact (sensitizer), of inhalation. The amount of tissue damage depends on length of contact. Eye contact can result in corneal damage or blindness. Skin contact can produce inflammation and blistering. Inhalation of dust will produce irritation to gastro-intestinal or respiratory tract, characterized by burning, sneezing and coughing. Severe over-exposure can produce lung damage, choking, unconsciousness or death. Inflammation of the eye is characterized by redness, watering, and itching. Skin inflammation is characterized by itching, scaling, reddening, or, occasionally, blistering.

Potential Chronic Health Effects:

Extremely hazardous in case of skin contact (irritant), of eye contact (irritant). Very hazardous in case of skin contact (corrosive). Hazardous in case of skin contact (sensitizer), of inhalation. CARCINOGENIC EFFECTS: Not available. MUTAGENIC EFFECTS: Not available. TERATOGENIC EFFECTS: Not available. DEVELOPMENTAL TOXICITY: Not available. The substance is toxic to blood, kidneys, lungs, liver. Repeated or prolonged exposure to the substance can produce target organs damage. Repeated exposure of the eyes to a low level of dust can produce eye irritation. Repeated skin exposure can produce local skin destruction, or dermatitis. Repeated inhalation of dust can produce varying degree of respiratory irritation or lung damage. Repeated or prolonged inhalation of dust may lead to chronic respiratory irritation.

Section 4: First Aid Measures

Eye Contact:

Check for and remove any contact lenses. Immediately flush eyes with running water for at least 15 minutes, keeping eyelids open. Cold water may be used. Do not use an eye ointment. Seek medical attention.

Skin Contact:

If the chemical got onto the clothed portion of the body, remove the contaminated clothes as quickly as possible, protecting your own hands and body. Place the victim under a deluge shower. If the chemical got on the victim's exposed skin, such as the hands : Gently and thoroughly wash the contaminated skin with running water and non-abrasive soap. Be particularly careful to clean folds, crevices, creases and groin. Cold water may be used. If irritation persists, seek medical attention. Wash contaminated clothing before reusing.

Serious Skin Contact:

Wash with a disinfectant soap and cover the contaminated skin with an anti-bacterial cream. Seek immediate medical attention.

Inhalation: Allow the victim to rest in a well ventilated area. Seek immediate medical attention.

Serious Inhalation:

Evacuate the victim to a safe area as soon as possible. Loosen tight clothing such as a collar, tie, belt or waistband. If breathing is difficult, administer oxygen. If the victim is not breathing, perform mouth-to-mouth resuscitation. WARNING: It may be hazardous to the person providing aid to give mouth-to-mouth resuscitation when the inhaled material is toxic, infectious or corrosive. Seek immediate medical attention.

Ingestion:

Do not induce vomiting. Examine the lips and mouth to ascertain whether the tissues are damaged, a possible indication that the toxic material was ingested; the absence of such signs, however, is not conclusive. Loosen tight clothing such as a collar, tie, belt or waistband. If the victim is not breathing, perform mouth-to-mouth resuscitation. Seek immediate medical attention.

Serious Ingestion: Not available.

Section 5: Fire and Explosion Data

Flammability of the Product: May be combustible at high temperature.

Auto-Ignition Temperature: 285°C (545°F)

Flash Points: CLOSED CUP: 81.1°C (178°F).

Flammable Limits: LOWER: 0.7% UPPER: 6.3%

Products of Combustion: These products are carbon oxides (CO, CO2), nitrogen oxides (NO, NO2...).

Fire Hazards in Presence of Various Substances: Not available.

Explosion Hazards in Presence of Various Substances:

Risks of explosion of the product in presence of mechanical impact: Not available. Risks of explosion of the product in presence of static discharge: Not available.

Fire Fighting Media and Instructions:

SMALL FIRE: Use DRY chemical powder. LARGE FIRE: Use water spray, fog or foam. Do not use water jet.

Special Remarks on Fire Hazards: Material in powder form, capable of creating a dust explosion.

Special Remarks on Explosion Hazards: Not available.

Section 6: Accidental Release Measures

Small Spill: Use appropriate tools to put the spilled solid in a convenient waste disposal container.

Large Spill:

Corrosive solid. Stop leak if without risk. Do not get water inside container. Do not touch spilled material. Use water spray to reduce vapors. Prevent entry into sewers, basements or confined areas; dike if needed. Eliminate all ignition sources. Call for assistance on disposal.

Section 7: Handling and Storage

Precautions:

Keep container dry. Keep away from heat. Keep away from sources of ignition. Empty containers pose a fire risk, evaporate the residue under a fume hood. Ground all equipment containing material. Do not ingest. Do not breathe dust. Never add water to this product In case of insufficient ventilation, wear suitable respiratory equipment If ingested, seek medical advice immediately and show the container or the label. Avoid contact with skin and eyes

Storage:

Keep container dry. Keep in a cool place. Ground all equipment containing material. Corrosive materials should be stored in a separate safety storage cabinet or room.

Section 8: Exposure Controls/Personal Protection

Engineering Controls:

Use process enclosures, local exhaust ventilation, or other engineering controls to keep airborne levels below recommended exposure limits. If user operations generate dust, fume or mist, use ventilation to keep exposure to airborne contaminants below the exposure limit.

Personal Protection:

Splash goggles. Lab coat. Vapor and dust respirator. Be sure to use an approved/certified respirator or equivalent. Gloves.

Personal Protection in Case of a Large Spill:

Splash goggles. Full suit. Vapor and dust respirator. Boots. Gloves. A self contained breathing apparatus should be used to avoid inhalation of the product. Suggested protective clothing might not be sufficient; consult a specialist BEFORE handling this product.

Exposure Limits: Not available.

Section 9: Physical and Chemical Properties

Physical state and appearance: Solid.

Odor: Not available.

Taste: Not available.

Molecular Weight: 116.21 g/mole

Color: Not available.

pH (1% soln/water): Not available.

Boiling Point: 204°C (399.2°F)

Melting Point: 42°C (107.6°F)

Critical Temperature: Not available.

Specific Gravity: 0.8477 (Water = 1)

Vapor Pressure: Not applicable.

Vapor Density: 4 (Air = 1)

Volatility: 100% (v/v).

Odor Threshold: Not available.

Water/Oil Dist. Coeff.: Not available.

lonicity (in Water): Not available.

Dispersion Properties: See solubility in water.

Solubility: Easily soluble in cold water.

Section 10: Stability and Reactivity Data

Stability: The product is stable.

Instability Temperature: Not available.

Conditions of Instability: Not available.

Incompatibility with various substances: Not available.

Corrosivity: Not available.

Special Remarks on Reactivity: Not available.

Special Remarks on Corrosivity: Not available.

Polymerization: No.

Section 11: Toxicological Information

Routes of Entry: Eye contact. Inhalation.

Toxicity to Animals:

Acute oral toxicity (LD50): 750 mg/kg [Rat]. Acute dermal toxicity (LD50): 1110 mg/kg [Rabbit].

Chronic Effects on Humans: The substance is toxic to blood, kidneys, lungs, liver.

Other Toxic Effects on Humans:

Extremely hazardous in case of skin contact (irritant). Very hazardous in case of skin contact (corrosive). Hazardous in case of skin contact (sensitizer), of inhalation.

Special Remarks on Toxicity to Animals: Not available.

Special Remarks on Chronic Effects on Humans: Not available.

Special Remarks on other Toxic Effects on Humans: Not available.

Section 12: Ecological Information

Ecotoxicity: Not available.

BOD5 and COD: Not available.

Products of Biodegradation:

Possibly hazardous short term degradation products are not likely. However, long term degradation products may arise.

Toxicity of the Products of Biodegradation: The products of degradation are more toxic.

Special Remarks on the Products of Biodegradation: Not available.

Section 13: Disposal Considerations

Waste Disposal:

Section 14: Transport Information

DOT Classification: CLASS 8: Corrosive solid.

Identification: : Hexamethylenediamine : UN2280 PG: III

Special Provisions for Transport: Not available.

Section 15: Other Regulatory Information

Federal and State Regulations:

Massachusetts RTK: 1,6-hexanediamine TSCA 8(b) inventory: 1,6-hexanediamine

Other Regulations: OSHA: Hazardous by definition of Hazard Communication Standard (29 CFR 1910.1200).

Other Classifications:

WHMIS (Canada): CLASS E: Corrosive solid.

DSCL (EEC):

R21/22- Harmful in contact with skin and if swallowed. R34- Causes burns. R43- May cause sensitization by skin contact.

HMIS (U.S.A.):

Health Hazard: 3

Fire Hazard: 2

Reactivity: 0

Personal Protection: j

National Fire Protection Association (U.S.A.):

Health: 3

Flammability: 2

Reactivity: 0

Specific hazard:

Protective Equipment:

Gloves. Lab coat. Vapor and dust respirator. Be sure to use an approved/certified respirator or equivalent. Wear appropriate respirator when ventilation is inadequate. Splash goggles.

Section 16: Other Information

References: Not available.

Other Special Considerations: Not available.

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Appendix F: 10 Year Plant Life Analysis

Factor in Profitability Analysis	Probable Variation from Forecasts over 10-year Plant Life, %
Cost of fixed capital investment*	-10 to +25
Construction time	-5 to +50
Start-up costs and time	-10 to +100
Sales volume	-50 to +150
Price of product	-50 to +20
Plant replacement and maintenance costs	-10 to +100
Income tax rate	-5 to +15
Inflation rates	-10 to +100
Interest rates	-50 to + 50
Working capital	-20 to +50
Raw material availability and price	-25 to +50
Salvage value	-100 to +10
Profit	-100 to +10
For capital cost estimations using CAPCOST, a mo From Jelen's Cost and Optimization Engineering, 3rd optimization of the McGraw-Hill Companies, Inc.	ed., by K. K. Humphreys (1991), reproduced