To: Management of Manufacturing Facility for Nylon 6 6
From: Anna Condacse, Delany McCauley, Ranjini Musuvathy, Thomas Wilkins
Date: 9 March 2017
Subject: AIChE 2017 Student Design Competition

Management of Manufacturing Facility for Nylon 6 6

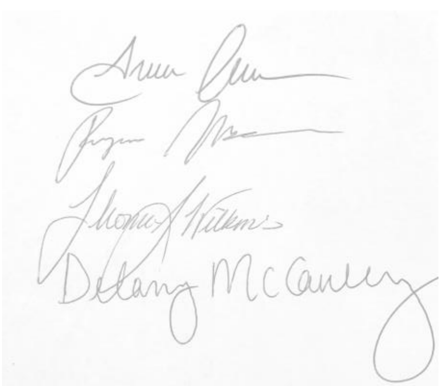
Enclosed is the report for the proposed manufacturing facility of Nylon 6 6 in Calvert City, Kentucky. As per the project statement, the task was to perform a preliminary design and conduct an economic analysis for a grass roots plant producing 85 MM lbs/yr of Nylon 6 6.

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

Anna Condacse
Delany McCauley
Ranjini Musuvathy
Thomas Wilkins

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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.

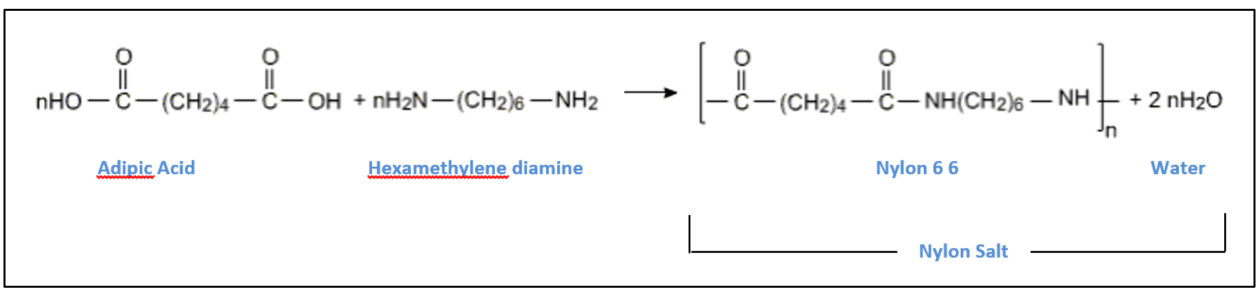


Figure 1: Synthesis of Nylon 6 6

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].

Table 1: Component Prices

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

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.

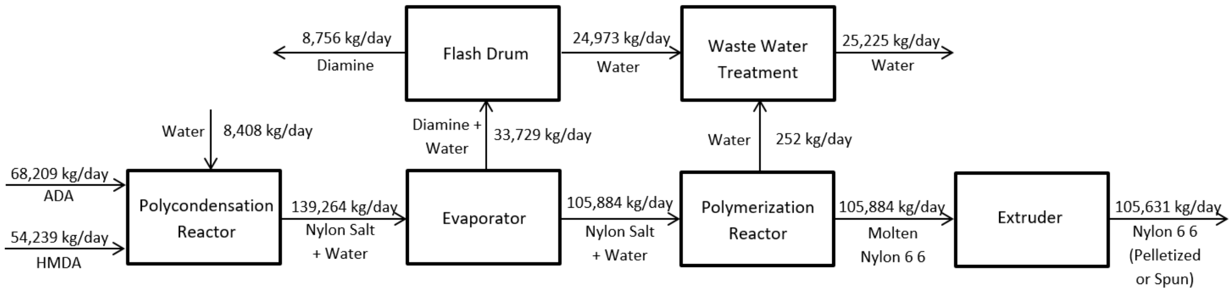


Figure 2: Block Flow Diagram

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).

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

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

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]:

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

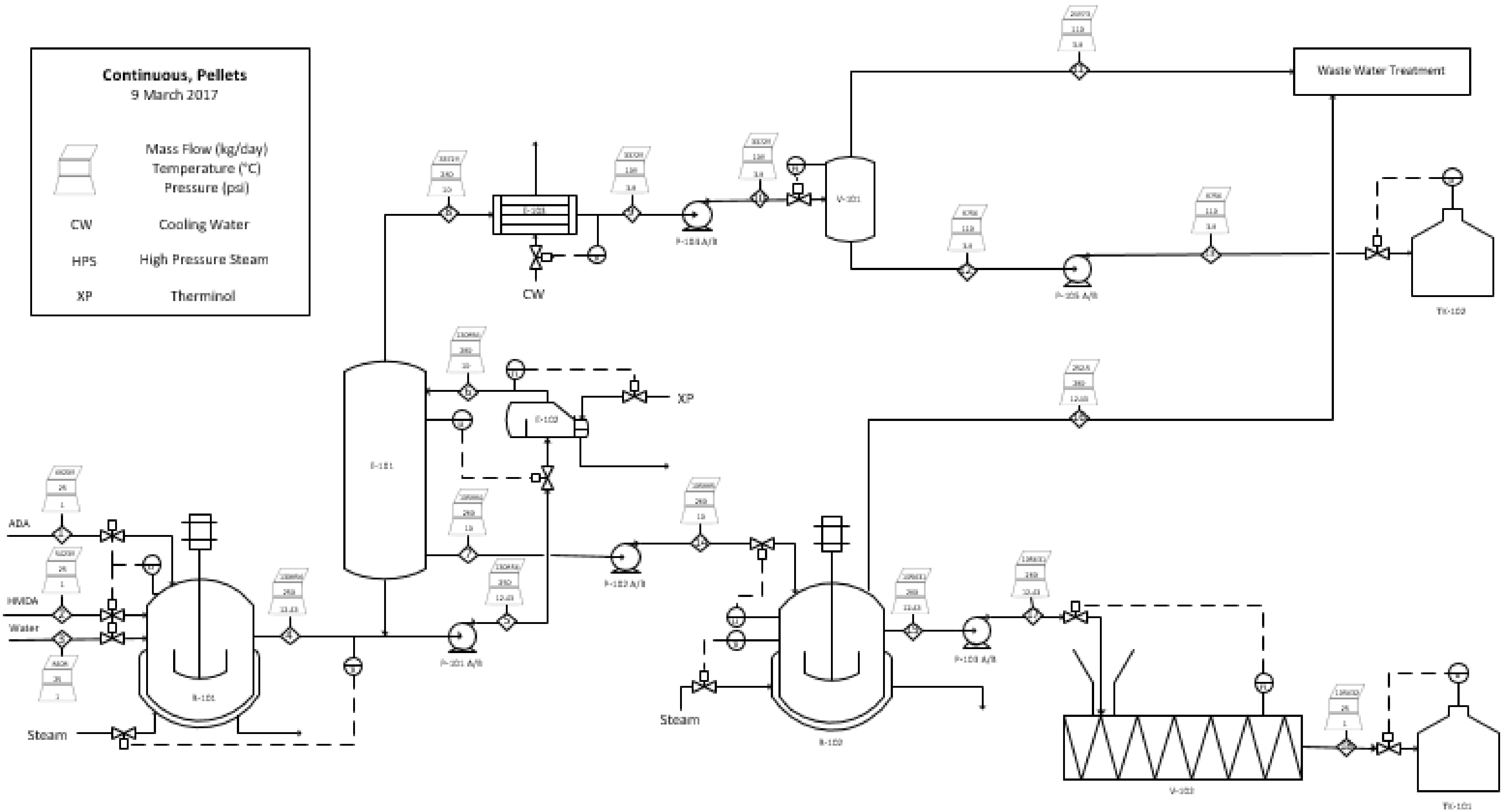
According to the reaction mechanism displayed in Figure 1, two moles of water are released for every mole of Nylon salt produced. However, water must be added to the polycondensation reactor initially to aid the formation of Nylon salt; therefore, it was assumed that an equimolar amount of water was 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.

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

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.

R-101	E-101	P-101 A/B	E-102	E-103	R-102	P-102 A/B	P-103 A/B	P-104 A/B	P-105 A/B	V-101	TK-101	TK-102	V-102
CSTR Reactor	Evaporator	Reflux Pump	Kettle Reboiler	Diamine/Water Condenser	CSTR Reactor	Pump	Pump	Pump	Pump	Flash Drum	Nylon 6 6 Storage	Diamine Storage	Twin Screw Extruder

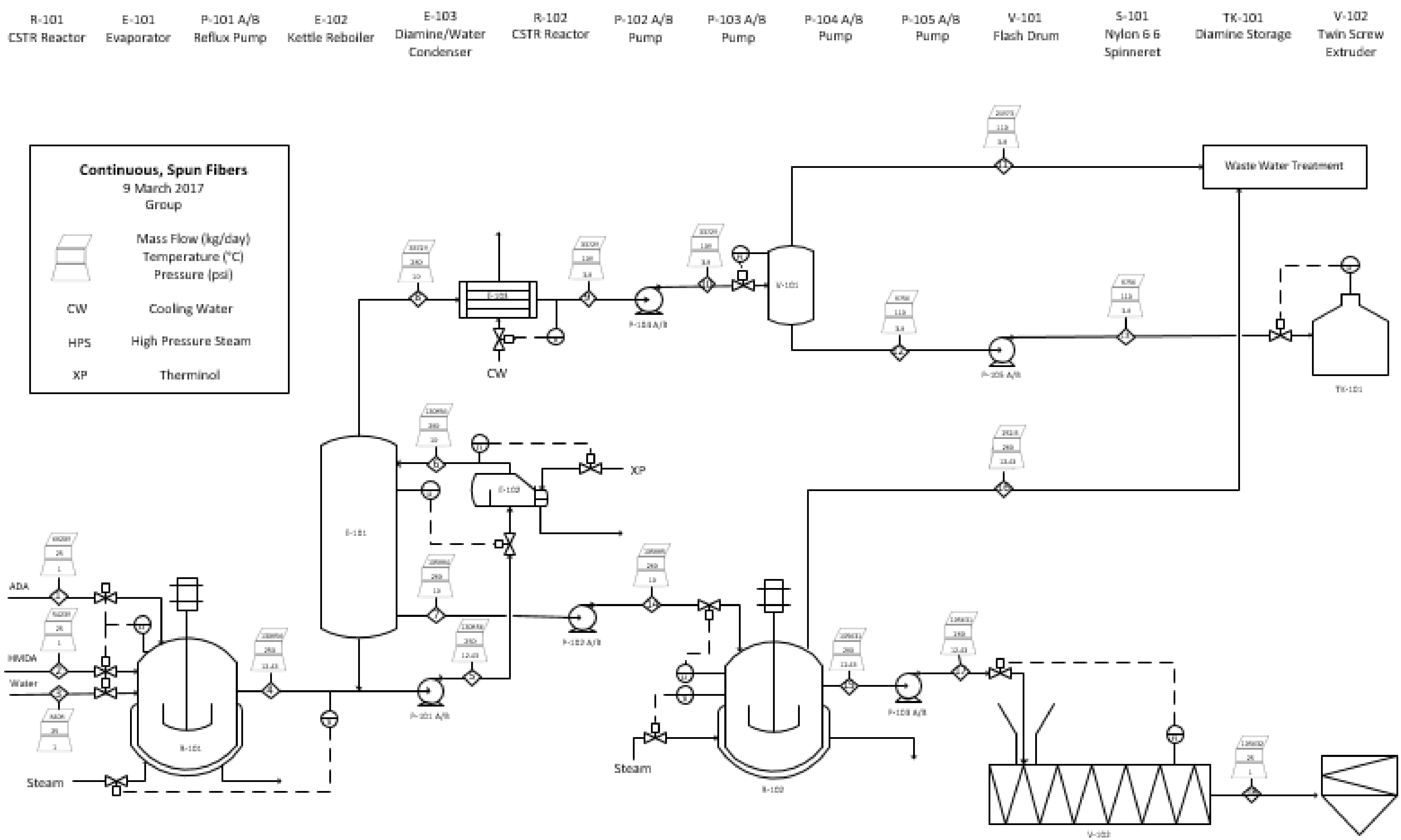


Stream Summary Table for Pelletized Continuous Process

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


R-101
CSTR Reactor
E-101
Evaporator
P-101 A/B
Reflux Pump
E-102
Kettle Reboiler
E-103
Diamine/Water
Condenser
R-102
CSTR Reactor
P-102 A/B
Pump
P-103 A/B
Pump
P-104 A/B
Pump
P-105 A/B
Pump
V-101
Flash Drum
S-101
Nylon 6 6
Spinneret
TK-101
Diamine Storage
V-102
Twin Screw
Extruder
Continuous, Spun Fibers
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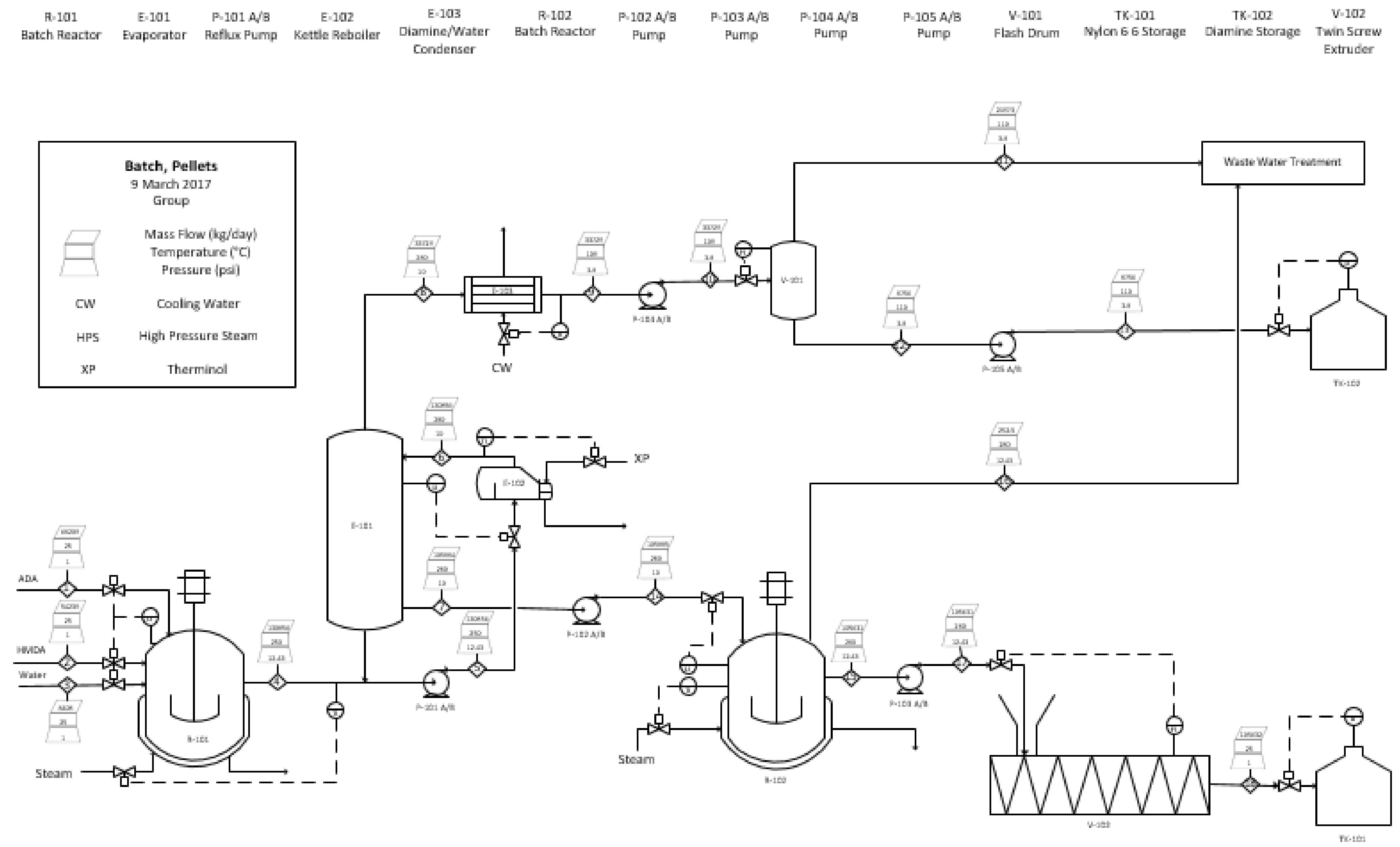
Group
Mass Flow (kg/day)
Temperature (°C)
Pressure (psi)
CW
Cooling Water
HPS
High Pressure Steam
XP
Therminol
Waste Water Treatment
CW
XP
ADA
HMDA
Water
Steam
Steam

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 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


R-101 Batch Reactor
E-101 Evaporator
P-101 A/B Reflux Pump
E-102 Kettle Reboiler
E-103 Diamine/Water Condenser
R-102 Batch Reactor
P-102 A/B Pump
P-103 A/B Pump
P-104 A/B Pump
P-105 A/B Pump
V-101 Flash Drum
TK-101 Nylon 6 6 Storage
TK-102 Diamine Storage
V-102 Twin Screw Extruder
Batch, Pellets
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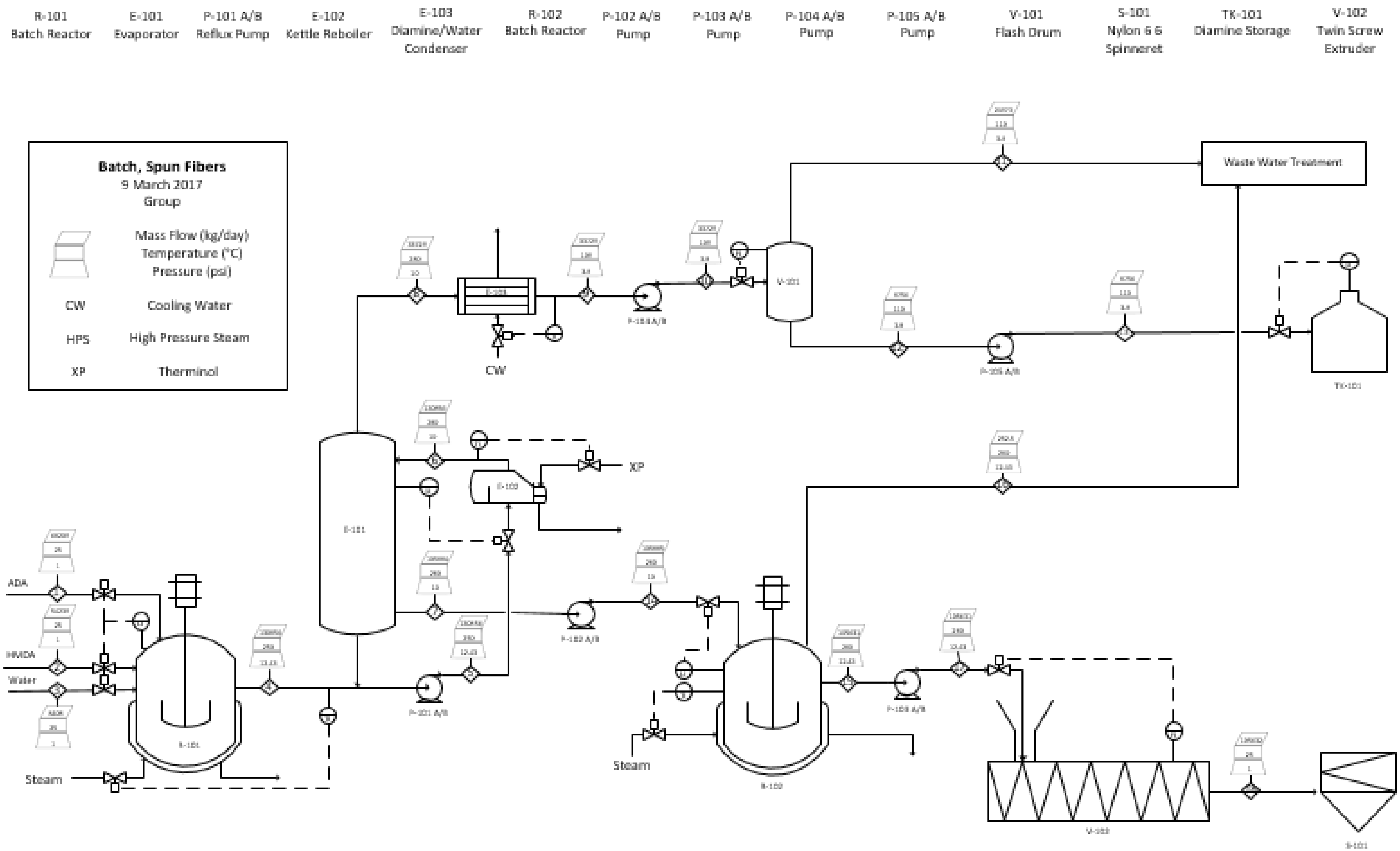
Group
Mass Flow (kg/day)
Temperature (°C)
Pressure (psi)
CW Cooling Water
HPS High Pressure Steam
XP Therminol
Waste Water Treatment
CW
XP
ADA
HMDA
Water
Steam
Steam

Stream Summary Table for Pelletized Batch 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


R-101
Batch Reactor
E-101
Evaporator
P-101 A/B
Reflux Pump
E-102
Kettle Reboiler
E-103
Diamine/Water Condenser
R-102
Batch Reactor
P-102 A/B
Pump
P-103 A/B
Pump
P-104 A/B
Pump
P-105 A/B
Pump
V-101
Flash Drum
S-101
Nylon 6 6 Spinneret
TK-101
Diamine Storage
V-102
Twin Screw Extruder
Batch, Spun Fibers
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Group
Mass Flow (kg/day)
Temperature (°C)
Pressure (psi)
CW
Cooling Water
HPS
High Pressure Steam
XP
Therminol
Waste Water Treatment
CW
XP
ADA
HMDA
Water
Steam
Steam

Stream Summary Table for Spun Batch 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 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

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.

$$Flow = \frac{Q}{\lambda} \tag{6}$$

Where:

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.

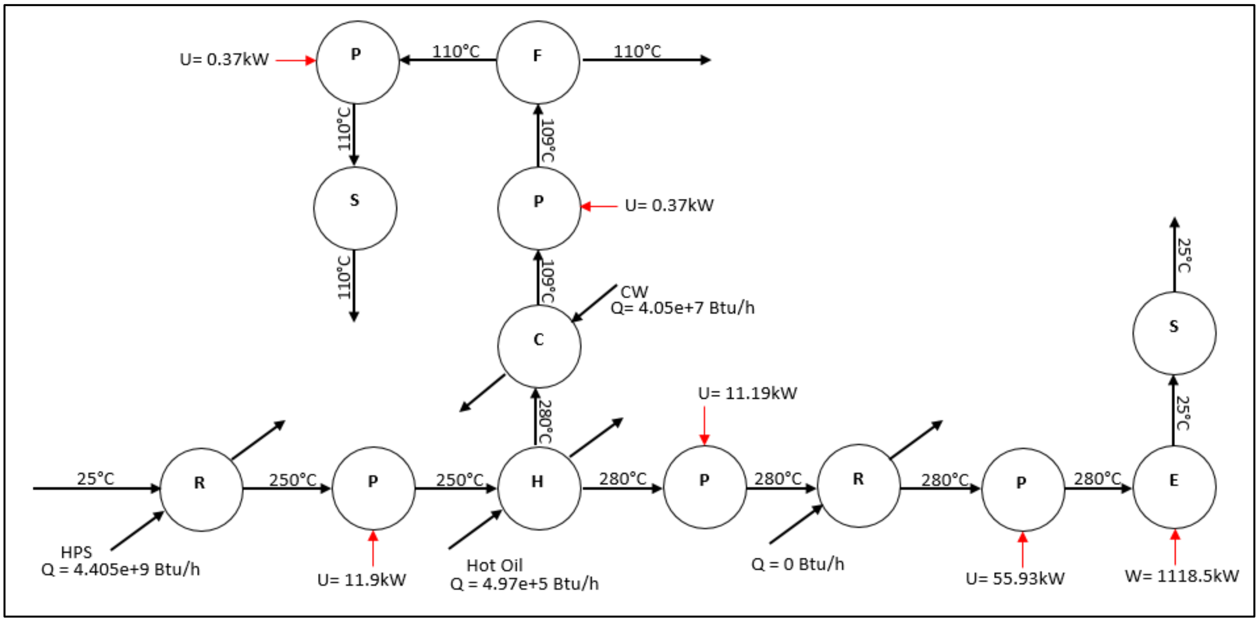

Figure 3: Energy Balance Flow Diagram

Table 2: 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)	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 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 (gal)	-	110	-	-	-	-	-
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:

$$\underset{C}{R_1 - COOH} \;+\; \underset{A}{H_2N - R_2} \rightleftarrows \underset{L}{R_1 - CONH - R_2} \;+\; \underset{W}{H_2O} \qquad (8)$$

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]:

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

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

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

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

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.

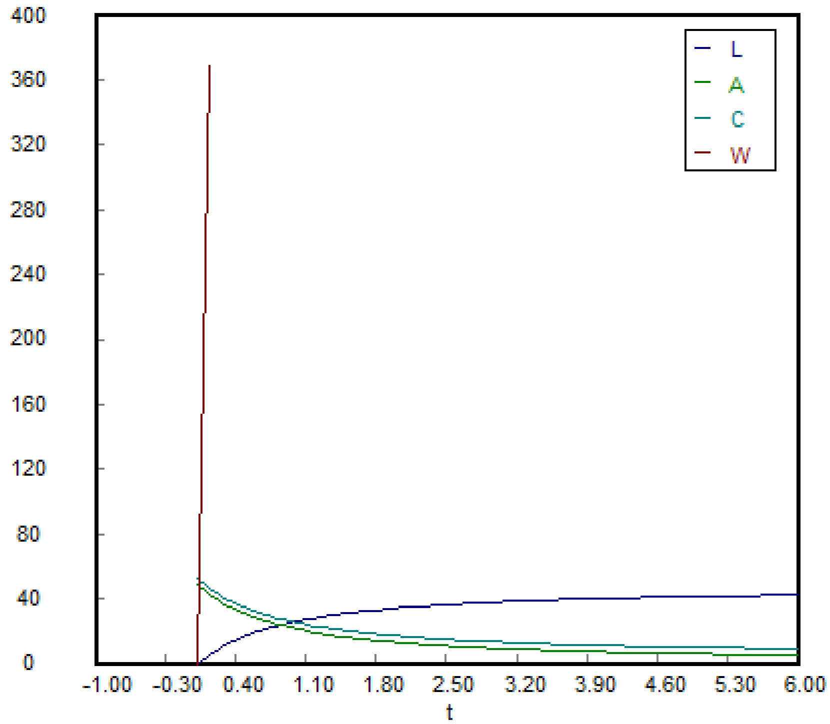

Figure 4: Functional Group Concentration Changes in Polycondensation as Reaction Time Increases (h)

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]:

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

Where:

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 [m^3]

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:

$$\begin{array}{ccccccccc} \text{ADA} & + & \text{HMDA} & \rightarrow & \text{NYLON 6 6} & + & 2\ H_2O \\ A & + & B & \rightarrow & C & + & 2\ D \end{array} \tag{16}$$

Therefore, the following second order rate law was developed:

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

Where:

k = 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 x $10^{-4}\ \frac{kg}{mol\ s}$. 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 °C, which was the optimal temperature required to achieve the desired conversion [9]:

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

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 [m^3/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:

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

$$\Delta H_{Rx} = \sum \Delta H^0_{f\,products} - \sum \Delta H^0_{f\,reactants} \tag{20}$$

$$\dot{W}_s = -\sum_{i=1}^{n} F_i P \tilde{V}_i |_{in} + \sum_{i=1}^{n} F_i P \tilde{V}_i |_{iout} \tag{21}$$

Where:

$\dot{m}$ = mass flow rate [kg/s]
T_a = steam temperature [°C]
T = desired reaction temperature [°C]
ΔH^0_f = heat of formation [kJ/mol]
$\tilde{V}_i$ = specific volume [m^3/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.

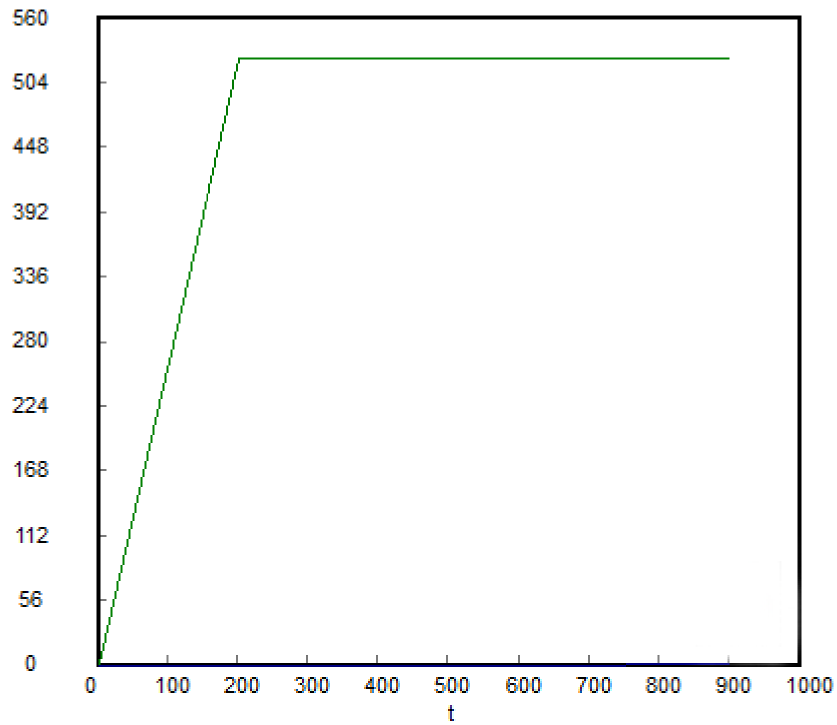

Figure 5: Temperature [K] Changes in Batch Reactor 1 for Polycondensation Reaction as Reaction Time Increases [sec]

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 m^3. The volume was calculated by determining the volumetric flow of the components in the reactor per cycle and rounding to the next largest m^3 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%.

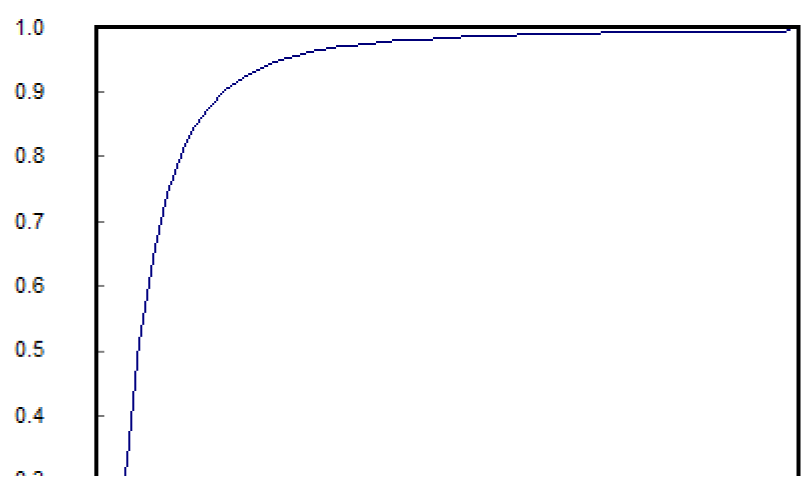

Figure #. Conversion [X] in Batch Reactor 1 for Polycondensation Reaction as Reaction Time Increases [seconds]

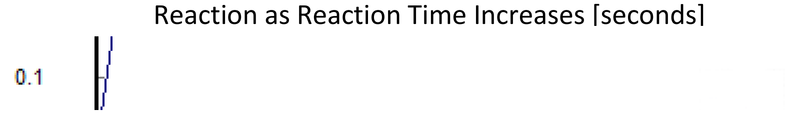

Figure 6: The Effect of Temperature on Conversion of Batch Polycondensation

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.

Table 4: Typical Cycle Times for a Batch Polymerization Process

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

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:

$$\text{Nylon Salt} \rightarrow \text{NYLON 6 6} + 2\,H_2O \qquad (22)$$
$$A \rightarrow B + 2\,C$$

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 step-growth polymerization reaction was 1.3 x 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.

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

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.

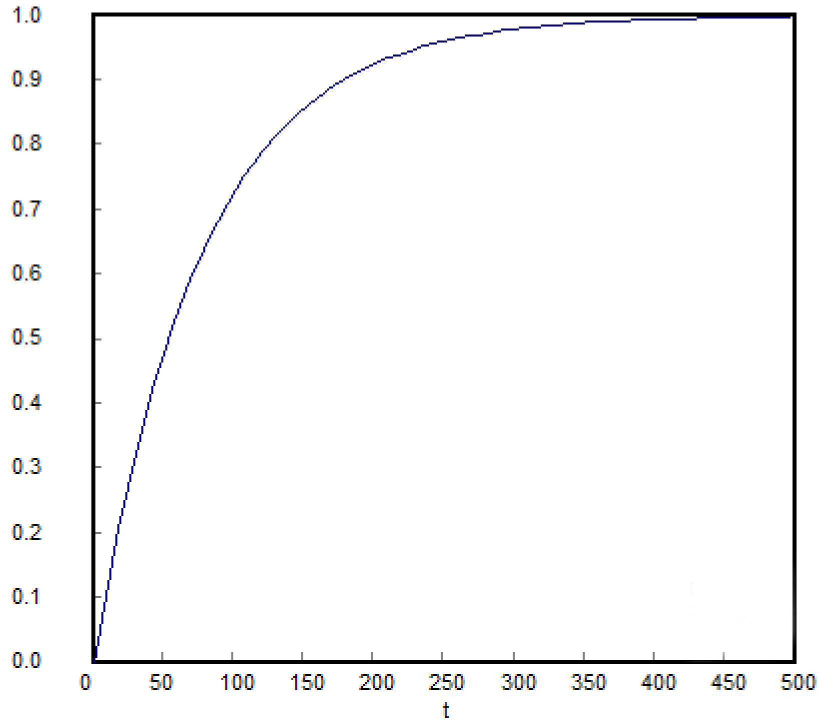

Figure 7: Conversion [X] in Batch Reactor 2 for Step-Growth Polymerization Reaction as Reaction Time Increases [seconds]

In addition, the temperature of the reaction reached a maximum value of 553°C. The volume was calculated to be 24 m^3 by using the volumetric flow rate of the Nylon 6 6 per cycle rounding to the next largest m^3 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]:

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

Where:

V= volume [m^3]

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:

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

Where:

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

$$\kappa = \frac{UA}{F_{A0}C_{p0}} \quad (28)$$

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

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 m^3.

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 m^3.

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^{o}C to 280^{o}C. This increase in temperature to 280^{o}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:

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

Where:

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

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

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

Where:

A_o = Heat transfer area (m^2)
U_o = Overall heat transfer coefficient (kJ/m^{2}day^{o}C)

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.

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

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

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

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 (m^2)
U_o = Overall heat transfer coefficient (kJ/m^{2}day°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 m^3 [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:

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

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/m^3]
ρ_V = Vapor density [kg/m^3]

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

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

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

Where:

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

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

P = Feed pressure [barg]

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

Z= Compressibility Factor

R = 0.008314 [m^3barg/molK]

T= 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]:

$$Z = 1 + ß - qß\frac{Z-\beta}{Z(Z+\beta)} \tag{38}$$

Where:

ß = $\Omega\frac{P_r}{T_r}$

q=$\frac{\varphi}{\Omega}T_r^{-3/2}$

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]:

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

Where:

$F_{lv} = \frac{W_L}{W_V}\sqrt{\frac{\rho_V}{\rho_L}}$ (W_L and W_V are liquid flow rates)

c= 1097.28 kg/day

A, B, C, D, E = constants defined in Appendix C

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

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

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 m^3.

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 m^3, 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)

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

Where:

η= pump efficiency (assumed to be 65%)

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

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

$$Purchased\ hP = \frac{BHP}{\eta_{motor}} \tag{44}$$

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.

CONTINUOUS STIRRED TANK REACTOR 1

Identification: Item *CST Reactor 1*
Item No. R-101
No. Required 1

Date: 3 March 2017
By: Team 2017

Function: Mixing of ADA, HMDA and H_2O to initiate the polycondensation reaction needed for polymerization

Operation: Continuous

Materials Handled:	*Feed*		*Outlet*	
Quantity (kg/day)	130855.8		130855.8	
Composition:				
HMDA	54239.2			
ADA	68208.9			
Water	8408.2		8408.2	
Nylon Salt			122447.6	
Diamine				
Nylon 6 6				
Therminol XP				
Stabilizer				
Temperature (°C)	250		255	

Design Data:

Pressure: 12.43 barg
Volume: 4.18 m^3
Diameter: 1.2 m
Duty: 12.28 kW

Utilities: High Pressure Steam at 4738000 lb/hr
Controls: Flow control valve on feed streams
Tolerances:
Comments and Drawings: See Process Flow Diagram

VI. Equipment Specification Sheets

BATCH REACTOR 1

Identification: Item	*Batch Reactor 1*		
Item No.	R-101		Date: 3 March 2017
No. Required	1		By: Team 2017

Function: Mixing of ADA, HMDA and H_2O to initiate the polycondensation reaction needed for polymerization

Operation: Batch

Materials Handled:	*Feed*		*Outlet*	
Quantity (kg/day)	130855.8		130855.8	
Composition:				
HMDA	54239.2			
ADA	68208.9			
Water	8408.2		8408.2	
Nylon Salt			122447.6	
Diamine				
Nylon 6 6				
Therminol XP				
Stabilizer				
Temperature (°C)	250		255	

Design Data:

Pressure: 12.43 barg
Volume: 15 m^3
Diameter: 1.9 m
Duty: 57.34kW

Utilities: High Pressure Steam
Controls: Flow control valve on feed streams
Tolerances:
Comments and Drawings: See Process Flow Diagram

CONTINUOUS STIRRED TANK REACTOR 2

Identification: Item *CRT Reactor 2*
Item No. R-102 Date: 3 March 2017
No. Required 1 By: Team 2017

Function: Excess water removal and formation of heavy weight oligomers through step growth polymerization

Operation: Continuous

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				
Temperature (°C)	280		280	

Design Data:
Pressure: 12.43 barg
Volume: 6.87 m^3
Area: 1.4 m
Duty: 0 kW

Utilities: NA
Controls: Level Control Valve and Steam Vent
Tolerances:
Comments and Drawings: See Process Flow Diagram

BATCH REACTOR 2

Identification: Item *Batch Reactor 2*
Item No. R-102 Date: 3 March 2017
No. Required 1 By: Team 2017

Function: Excess water removal and formation of heavy weight oligomers through step growth polymerization

Operation: Batch

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				
Temperature (°C)	280		280	

Design Data:
Pressure: 12.43 barg
Volume: 15 m^3
Area: 1.9 m
Duty: 0 kW

Utilities: NA
Controls: Steam Vent
Tolerances:
Comments and Drawings: See Process Flow Diagram

EVAPORATOR

Identification: Item *Evaporator*
Item No. E-101
No. Required 1

Date: 3 March 2017
By: Team 2017

Function: Remove excess water from the nylon salt as well as any monomers present in the salt mixture

Operation: Continuous and Batch

Materials Handled:	*Inlet Stream*		*Vapor Stream*	*Liquid Stream*
Quantity (kg/day)	130855.8		33728.7	105884.23
Composition:				
HMDA				
ADA				
Water	8408.2		24973	
Nylon Salt	122447.6			105884.23
Diamine			8756.2	
Nylon 6 6				
Therminol XP				
Stabilizer				
Temperature (°C)	250		280	280

Design Data:

Pressure: 10 barg
Volume: 0.879 m^3
Area: 0.407 m^2
Diameter: 2.26 m
Correction Factor: 0.995
LMTD: 83.49 °F

Utilities: Hot oil loop with Therminol XP to allow for proper heat exchange within the evaporation unit
Controls: Temperature Control, and flow control valve
Tolerances:
Comments and Drawings: See Process Flow Diagram

CONDENSER

Identification: Item	*Condenser*	
Item No.	E-103	Date: 3 March 2017
No. Required	1	By: Team 2017

Function: Condense the vapor stream leaving the evaporation unit to allow for separation into its components

Operation: Continuous and Batch

Materials Handled:	*Inlet Stream*		*Outlet Stream*	
Quantity (kg/day)	33728.7		33728.7	
Composition:				
HMDA				
ADA				
Water	24973		24973	
Nylon Salt				
Nylon Salt				
Diamine	8756.2		8756.2	
Nylon 6 6				
Therminol XP				
Stabilizer				
Temperature (°C)	280		109	

Design Data:

Pressure: 3.8 barg
Area: 8.22 m^2
Duty: 6.76e+7 Btu/day
LMTD: 140.29 °F
Correction Factor: 0.995

Utilities: Cooling water at a flow rate of 4110.1 annual gpm
Controls: Temperature Control
Tolerances:
Comments and Drawings: See Process Flow Diagram

FLASH DRUM

Identification: Item *Flash Drum*
Item No. V-101
No. Required 1

Date: 3 March 2017
By: Team 2017

Function: Separate the condensed stream into its components of H_2O and liquid diamine

Operation: Continuous and Batch

Materials Handled:	*Input Stream*		*Vapor Stream*	*Liquid Stream*
Quantity (kg/day)	33728.7		24973	8756.2
Composition:				
HMDA				
ADA				
Water	24973		24973	
Nylon Salt				
Diamine	8756.2			8756.2
Nylon 6 6				
Therminol XP				
Stabilizer				
Temperature (°C)	109		110	110

Design Data:
Pressure: 3.8 barg
Volume: 2.86 m^3
Diameter: 1.07 m

Utilities: Electrical pressurized drum allows separation to occur
Controls: Temperature and Pressure Controls
Tolerances:
Comments and Drawings: See Process Flow Diagram

STORAGE TANK 2

Identification: Item *Storage Tank 1*
Item No. TK-102
No. Required 1

Date: 3 March 2017
By: Team 2017

Function: Store the liquid diamine on a weekly basis

Operation: Continuous and Batch

Materials Handled:	*Inlet Stream*			
Quantity (kg/day)	8756.2			
Composition:				
HMDA				
ADA				
Water				
Nylon Salt				
Diamine	8756.2			
Nylon 6 6				
Therminol XP				
Stabilizer				
Temperature (°C)	110			

Design Data:

Pressure: 3.8 barg
Volume: 73.0 m^3
Diameter: 3.1 m
Orientation: Vertical
Time in Vessel: 168 hours

Utilities: NA
Controls: Pressure Control
Tolerances:
Comments and Drawings: See Process Flow Diagram

EXTRUDER

Identification: Item *Extruder*
Item No. V-102
No. Required 1

Date: 3 March 2017
By: Team 2017

Function: Solidification and shaping of the molten Nylon 6 6 into pelletized or fiber form

Operation: Continuous and Batch

Materials Handled:	*Inlet Stream*		*Outlet Stream*	
Quantity (kg/day)	105631.1		105631.1	
Composition:				
HMDA				
ADA				
Water				
Nylon Salt				
Diamine				
Nylon 6 6	105631.1		105631.1	
Therminol XP				
Stabilizer				
Temperature (°C)	280		280	

Design Data:

Max Screw Speed: 600 RPM
Motor/Drive: 1500 HP AC
Temperature Control Unit (TCU)
Nitride Tool Steel Process Section
Allen Bradley Electrical Control System
8-0 Adapter

Utilities: Electricity to power heaters and motor
Controls: Temperature and Flow Control
Tolerances:
Comments and Drawings: See Process Flow Diagram

STORAGE TANK 1

Identification: Item *Equipment Name*
Item No. TK-101
No. Required

Date: 3 March 2017
By: Team 2017

Function: Storage of the Nylon 6 6 pellets formed after the extrusion process

Operation: Continuous

Materials Handled:	*Inlet Conditions*			
Quantity (kg/day)	105631.1			
Composition:				
HMDA				
ADA				
Water				
Nylon Salt				
Diamine				
Nylon 6 6	105631.1			
Therminol XP				
Stabilizer				
Temperature (°F)	290			

Design Data:

Pressure: 3.8 barg
Volume: 92.6 m^3
Diameter: 3.4 m
Orientation: Vertical
Time in Vessel: 168 hours ((before emptied)

Utilities: NA
Controls: Flow Control
Tolerances:
Comments and Drawings: See Process Flow Diagram

PUMP 1

Identification: Item	*Pump 1*	
Item No.	P-101	Date: 3 March 2017
No. Required	2	By: Team 2017

Function: Pump nylon salt from the evaporation unit to the second reactor

Operation: Continuous and Batch

Materials Handled:	*Inlet Stream*		*Outlet Stream*	
Quantity (kg/day)	105884.23		105884.23	
Composition:				
HMDA				
ADA				
Water				
Nylon Salt	105884.23		105884.23	
Diamine				
Nylon 6 6				
Therminol XP				
Stabilizer				
Temperature (°C)	280		280	

Design Data:

Pressure Change: 2.43 barg
Shaft Power: 9.6 hp
Motor Efficiency: 0.849
Purchased Horsepower: 11.5 hp
Hydraulic Horsepower: 6.3 hp
Actual Horsepower: 15 hp
Power Consumption: 11.9 kW

Utilities: Electricity
Controls: Flow Transmitter, Pressure Indicator
Tolerances:
Comments and Drawings: See Process Flow Diagram

PUMP 2

Identification: Item	*Pump 2*	
Item No.	P-102	Date: 3 March 2017
No. Required	2	By: Team 2017

Function: Pump condensed fluid to the flash drum from the condenser

Operation: 67% Capacity Continuous

Materials Handled:	*Input Stream*		*Outlet Stream*	*Liquid Stream*
Quantity (kg/day)	33728.73		33728.73	
Composition:				
HMDA				
ADA				
Water	24973		24973	
Nylon Salt				
Diamine	8756.2		8756.2	
Nylon 6 6				
Therminol XP				
Stabilizer				
Temperature (°C)	109		109	

Design Data:

Pressure Change: 0.20 barg
Shaft Power: 0.169 hp
Motor Efficiency: 0.6758
Purchased Horsepower: 0.3731 hp
Hydraulic Horsepower: 0.1639 hp
Actual Horsepower: 0.5 hp
Power Consumption: 0.37 kW

Utilities: Electricity
Controls: Flow Transmitter, Pressure Indicator
Tolerances:
Comments and Drawings: See Process Flow Diagram

PUMP 3

Identification: Item *Pump 3*
Item No. P-103 Date: 3 March 2017
No. Required 2 By: Team 2017

Function: Pumping of 1,6 hexanediamine from the flash drum to the storage tank

Operation: 67% Capacity Continuous

Materials Handled:	*Inlet Stream*		*Outlet Stream*	
Quantity (kg/day)	8756.2		8756.2	
Composition:				
HMDA				
ADA				
Water				
Nylon Salt				
Diamine	8756.2		8756.2	
Nylon 6 6				
Therminol XP				
Stabilizer				
Temperature (°C)	110		110	

Design Data:

Pressure Change: 0.165 barg
Shaft Power: 0.0540 hp
Motor Efficiency: 0.5801
Purchased Horsepower: 0.0931 hp
Hydraulic Horsepower: 0.0351 hp
Actual Horsepower: 0.5 hp
Power Consumption: 0.37 kW

Utilities: Electricity
Controls: Flow Transmitter, Pressure Indicator
Tolerances:
Comments and Drawings: See Process Flow Diagram

PUMP 4

Identification: Item *Pump 4*
Item No. P-104
No. Required 2

Date: 3 March 2017
By: Team 2017

Function: Pumping molten Nylon 6 6 from the second reactor to the extruder

Operation: 67% Capacity Continuous

Materials Handled:	*Inlet Stream*		*Outlet Stream*	
Quantity (kg/day)	105631.1		105631.1	
Composition:				
HMDA				
ADA				
Water				
Nylon Salt				
Diamine				
Nylon 6 6	105631.1		105631.1	
Therminol XP				
Stabilizer				
Temperature (°C)	280		280	

Design Data:
- **Pressure Change:** 17.57 barg
- **Shaft Power:** 64.41 hp
- **Motor Efficiency:** 0.9089
- **Purchased Horsepower:** 70.87 hp
- **Hydraulic Horsepower:** 45.09 hp
- **Actual Horsepower:** 75 hp
- **Power Consumption:** 55.93 kW

Utilities: Electricity
Controls: Flow Transmitter, Pressure Indicator
Tolerances:
Comments and Drawings: See Process Flow Diagram

PUMP 5

Identification: Item *Pump 5*
Item No. P-105
No. Required 2

Date: 3 March 2017
By: Team 2017

Function: Circulation of nylon salt within the evaporation unit to ensure removal of H_2O

Operation: 67% Capacity Continuous

Materials Handled:	*Inlet Stream*		*Outlet Stream*	
Quantity (kg/day)	130856.8		130856.8	
Composition:				
HMDA				
ADA				
Water	8409.33		8409.33	
Nylon Salt	122447.5		122447.5	
Diamine				
Nylon 6 6				
Therminol XP				
Stabilizer				
Temperature (°C)	280		280	

Design Data:

Pressure Change: 2.43 barg
Shaft Power: 11.9hp
Motor Efficiency: 0.856
Purchased Horsepower: 13.9 hp
Hydraulic Horsepower: 7.7 hp
Actual Horsepower: 15 hp
Power Consumption: 11.19 kW

Utilities: Electricity
Controls: Flow Transmitter, Pressure Indicator
Tolerances:
Comments and Drawings: See Process Flow Diagram

CONTINUOUS STIRRED TANK REACTOR 1

Identification: Item	*CST Reactor 1*	
Item No.	R-101	Date: 3 March 2017
No. Required	1	By: Team 2017

Function: Mixing of ADA, HMDA and H_2O to initiate the polycondensation reaction needed for polymerization

Operation: 67% Capacity Continuous

Materials Handled:	*Feed*		*Outlet*	
Quantity (kg/day)	87673.78		87673.78	
Composition:				
HMDA	36340.19			
ADA	45700.01			
Water	5633.58		5633.58	
Nylon Salt			82039.83	
Diamine				
Nylon 6 6				
Therminol XP				
Stabilizer				
Temperature (°C)	25		250	

Design Data:

Pressure: 12.43 barg
Volume: 4.18 m^3
Diameter: 1.2 m
Duty: 12.28 kW

Utilities: High Pressure Steam at 4738000 lb/hr
Controls: Flow control valve on feed streams
Tolerances:
Comments and Drawings: See Process Flow Diagram

CONTINUOUS STIRRED TANK REACTOR 2

Identification: Item *CRT Reactor 2*
Item No. R-102 Date: 3 March 2017
No. Required 1 By: Team 2017

Function: Excess water removal and formation of heavy weight oligomers through step growth polymerization

Operation: 67% 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: 12.43 barg
Volume: 6.87 m^3
Area: 1.4 m
Duty: 0 kW
Reaction Rate Constant:

Utilities: NA
Controls: Level Control Valve and Steam Vent
Tolerances:
Comments and Drawings: See Process Flow Diagram

EVAPORATOR

Identification: Item *Evaporator*
Item No. E-101 Date: 3 March 2017
No. Required 1 By: Team 2017

Function: Remove excess water from the nylon salt as well as any monomers present in the salt mixture

Operation: 67% Capacity Continuous

Materials Handled:	*Inlet Stream*		*Vapor Stream*	*Liquid Stream*
Quantity (kg/day)	87673.41		22598.67	70942.43
Composition:				
HMDA				
ADA				
Water	5633.58		16372	
Nylon Salt	82039.83			70942.43
Diamine			5866.87	
Nylon 6 6				
Therminol XP				
Stabilizer				
Temperature (°C)	250		280	280

Design Data:
- **Pressure:** 10 barg
- **Volume:** 0.879 m^3
- **Area**: 0.407 m^2
- **Diameter:** 2.26 m
- **Correction Factor**: 0.995
- **LMTD:** 83.23 °F

Utilities: Hot oil loop with Therminol XP to allow for proper heat exchange within the evaporation unit
Controls: Temperature Control, and flow control valve
Tolerances:
Comments and Drawings: See Process Flow Diagram

CONDENSER

Identification: Item	*Condenser*	
Item No.	E-103	Date: 3 March 2017
No. Required	1	By: Team 2017

Function: Condense the vapor stream leaving the evaporation unit to allow for separation into its components

Operation: 67% Capacity Continuous

Materials Handled:	*Inlet Stream*		*Outlet Stream*	
Quantity (kg/day)	22598.67		22598.67	
Composition:				
HMDA				
ADA				
Water	16372		16372	
Nylon Salt				
Nylon Salt				
Diamine	5866.87		5866.87	
Nylon 6 6				
Therminol XP				
Stabilizer				
Temperature (°C)	280		109	

Design Data:

Pressure: 3.8 barg
Area: 8.22 m^2
Duty: 6.76e+7 Btu/day
LMTD: 140.29 °F
Correction Factor: 0.995

Utilities: Cooling water at a flow rate of 4110.1 annual gpm
Controls: Temperature Control
Tolerances:
Comments and Drawings: See Process Flow Diagram

FLASH DRUM

Identification: Item *Flash Drum*
Item No. V-101
No. Required 1

Date: 3 March 2017
By: Team 2017

Function: Separate the condensed stream into its components of H_2O and liquid diamine

Operation: 67% Capacity Continuous

Materials Handled:	*Input Stream*		*Vapor Stream*	*Liquid Stream*
Quantity (kg/day)	22598.67		16372	5866.87
Composition:				
HMDA				
ADA				
Water	16372		16372	
Nylon Salt				
Diamine	5866.87			5866.87
Nylon 6 6				
Therminol XP				
Stabilizer				
Temperature (°C)	109		110	110

Design Data:

Pressure: 3.8 barg
Volume: 2.86 m^3
Diameter: 1.07 m

Utilities: Electrical pressurized drum allows separation to occur
Controls: Temperature and Pressure Controls
Tolerances:
Comments and Drawings: See Process Flow Diagram

STORAGE TANK 2

Identification: Item *Storage Tank 1*
Item No. TK-102
No. Required 1

Date: 3 March 2017
By: Team 2017

Function: Store the liquid diamine on a weekly basis

Operation: 67% Capacity Continuous

Materials Handled:	*Inlet Stream*			
Quantity (kg/day)	5866.87			
Composition:				
HMDA				
ADA				
Water				
Nylon Salt				
Diamine	5866.87			
Nylon 6 6				
Therminol XP				
Stabilizer				
Temperature (°C)	110			

Design Data:

Pressure: 3.8 barg
Volume: 73.0 m^3
Diameter: 3.1 m
Orientation: Vertical
Time in Vessel: 168 hours

Utilities: NA
Controls: Pressure Control
Tolerances:
Comments and Drawings: See Process Flow Diagram

EXTRUDER

Identification: Item *Extruder*
Item No. V-102
No. Required 1

Date: 3 March 2017
By: Team 2017

Function: Solidification and shaping of the molten Nylon 6 6 into pelletized or fiber form

Operation: 67% Capacity Continuous

Materials Handled:	*Inlet Stream*		*Outlet Stream*	
Quantity (kg/day)	70772.84		70772.84	
Composition:				
HMDA				
ADA				
Water				
Nylon Salt				
Diamine				
Nylon 6 6	70772.84		70772.84	
Therminol XP				
Stabilizer				
Temperature (°C)	280		280	

Design Data:

Max Screw Speed: 600 RPM
Motor/Drive: 1500 HP AC
Temperature Control Unit (TCU)
Nitride Tool Steel Process Section
Allen Bradley Electrical Control System
8-0 Adapter

Utilities: Electricity to power heaters and motor
Controls: Temperature and Flow Control
Tolerances:
Comments and Drawings: See Process Flow Diagram

STORAGE TANK 1

Identification: Item *Equipment Name*
Item No. TK-101
No. Required

Date: 3 March 2017
By: Team 2017

Function: Storage of the Nylon 6 6 pellets formed after the extrusion process

Operation: 67% Capacity Continuous

Materials Handled:	*Inlet Conditions*			
Quantity (kg/day)	70772.84			
Composition:				
HMDA				
ADA				
Water				
Nylon Salt				
Diamine				
Nylon 6 6	70772.84			
Therminol XP				
Stabilizer				
Temperature (°F)	290			

Design Data:

Pressure: 3.8 barg
Volume: 92.6 m^3
Diameter: 3.4 m
Orientation: Vertical
Time in Vessel: 168 hours ((before emptied)

Utilities: NA
Controls: Flow Control
Tolerances:
Comments and Drawings: See Process Flow Diagram

PUMP 1

Identification: Item	*Pump 1*	
Item No.	P-101	Date: 3 March 2017
No. Required	2	By: Team 2017

Function: Pump nylon salt from the evaporation unit to the second reactor

Operation: 67% Capacity Continuous

Materials Handled:	*Inlet Stream*		*Outlet Stream*	
Quantity (kg/day)	70942.43		70942.43	
Composition:				
HMDA				
ADA				
Water				
Nylon Salt	70942.43		70942.43	
Diamine				
Nylon 6 6				
Therminol XP				
Stabilizer				
Temperature (°C)	280		280	

Design Data:

Pressure Change: 2.43 barg
Shaft Power: 9.6 hp
Motor Efficiency: 0.849
Purchased Horsepower: 11.5 hp
Hydraulic Horsepower: 6.3 hp
Actual Horsepower: 15 hp
Power Consumption: 11.9 kW

Utilities: Electricity
Controls: Flow Transmitter, Pressure Indicator
Tolerances:
Comments and Drawings: See Process Flow Diagram

PUMP 2

Identification: Item	*Pump 2*	
Item No.	P-102	Date: 3 March 2017
No. Required	2	By: Team 2017

Function: Pump condensed fluid to the flash drum from the condenser

Operation: 67% Capacity Continuous

Materials Handled:	*Input Stream*		*Outlet Stream*	*Liquid Stream*
Quantity (kg/day)	22598.67		22598.67	
Composition:				
HMDA				
ADA				
Water	16372		16372	
Nylon Salt				
Diamine	5866.87		5866.87	
Nylon 6 6				
Therminol XP				
Stabilizer				
Temperature (°C)	109		109	

Design Data:

Pressure Change: 0.20 barg
Shaft Power: 0.169 hp
Motor Efficiency: 0.6522
Purchased Horsepower: 0.259 hp
Hydraulic Horsepower: 0.1098 hp
Actual Horsepower: 0.5 hp
Power Consumption: 0.37 kW

Utilities: Electricity
Controls: Flow Transmitter, Pressure Indicator
Tolerances:
Comments and Drawings: See Process Flow Diagram

PUMP 3

Identification: Item *Pump 3*
Item No. P-103
No. Required 2

Date: 3 March 2017
By: Team 2017

Function: Pumping of 1,6 hexanediamine from the flash drum to the storage tank

Operation: 67% Capacity Continuous

Materials Handled:	*Inlet Stream*		*Outlet Stream*	
Quantity (kg/day)	5866.87		5866.87	
Composition:				
HMDA				
ADA				
Water				
Nylon Salt				
Diamine	5866.87		5866.87	
Nylon 6 6				
Therminol XP				
Stabilizer				
Temperature (°C)	110		110	

Design Data:
Pressure Change: 0.165 barg
Shaft Power: 0.0540 hp
Motor Efficiency: 0.5801
Purchased Horsepower: 0.0931 hp
Hydraulic Horsepower: 0.0351 hp
Actual Horsepower: 0.5 hp
Power Consumption: 0.37 kW

Utilities: Electricity
Controls: Flow Transmitter, Pressure Indicator
Tolerances:
Comments and Drawings: See Process Flow Diagram

PUMP 4

Identification: Item *Pump 4*
Item No. P-104
No. Required 2

Date: 3 March 2017
By: Team 2017

Function: Pumping molten Nylon 6 6 from the second reactor to the extruder

Operation: 67% Capacity Continuous

Materials Handled:	*Inlet Stream*		*Outlet Stream*	
Quantity (kg/day)	70772.84		70772.84	
Composition:				
HMDA				
ADA				
Water				
Nylon Salt				
Diamine				
Nylon 6 6	70772.84		70772.84	
Therminol XP				
Stabilizer				
Temperature (°C)				

Design Data:

Pressure Change: 17.57 barg
Shaft Power: 46.48 hp
Motor Efficiency: 0.900
Purchased Horsepower: 51.64 hp
Hydraulic Horsepower: 30.21 hp
Actual Horsepower: 55 hp
Power Consumption: 41.01 kW

Utilities: Electricity
Controls: Flow Transmitter, Pressure Indicator
Tolerances:
Comments and Drawings: See Process Flow Diagram

PUMP 5

Identification: Item	*Pump 5*			
Item No.	P-105			Date: 3 March 2017
No. Required	2			By: Team 2017

Function: Circulation of nylon salt within the evaporation unit to ensure removal of H_2O

Operation: 67% Capacity Continuous

Materials Handled:	*Inlet Stream*		*Outlet Stream*	
Quantity (kg/day)	87673.41		87673.41	
Composition:				
HMDA				
ADA				
Water	5633.58		5633.58	
Nylon Salt	82039.83		82039.83	
Diamine				
Nylon 6 6				
Therminol XP				
Stabilizer				
Temperature (°C)				

Design Data:

Pressure Change: 2.43 barg
Shaft Power: 8.0 hp
Motor Efficiency: 0.841
Purchased Horsepower: 9.5 hp
Hydraulic Horsepower: 5.2 hp
Actual Horsepower: 10 hp
Power Consumption: 7.46 kW

Utilities: Electricity
Controls: Flow Transmitter, Pressure Indicator
Tolerances:
Comments and Drawings: 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*.

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 Pricing	Design Book Costing Parameters	Design Book Costing Parameters	Design Book Costing Parameters	Quotation from Manufacturer	Design Book Costing Parameters	Design Book Costing Parameters	Design Book Costing 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 Pricing	Design Book Costing Parameters	Design Book Costing Parameters	Design Book Costing Parameters	Design Book Costing Parameters	Design Book Costing Parameters	Design Book Costing Parameters	-

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	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 Pricing	Design Book Costing Parameters	Design Book Costing Parameters	Design Book Costing Parameters	Quotation from Manufacturer	Design Book Costing Parameters	Design Book Costing Parameters	Design Book Costing 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 Pricing	Design Book Costing Parameters	Design Book Costing Parameters	Design Book Costing Parameters	Design Book Costing Parameters	Design Book Costing Parameters	Design Book Costing Parameters	Quotation from Manufacturer

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 Pricing	Design Book Costing Parameters	Design Book Costing Parameters	Design Book Costing Parameters	Quotation from Manufacturer	Design Book Costing Parameters	Design Book Costing Parameters	Design Book Costing 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 Pricing	Design Book Costing Parameters	Design Book Costing Parameters	Design Book Costing Parameters	Design Book Costing Parameters	Design Book Costing Parameters	Design Book Costing Parameters	**-**

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	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 Pricing	Design Book Costing Parameters	Design Book Costing Parameters	Design Book Costing Parameters	Quotation from Manufacturer	Design Book Costing Parameters	Design Book Costing Parameters	Design Book Costing 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 Pricing	Design Book Costing Parameters	Design Book Costing Parameters	Design Book Costing Parameters	Design Book Costing Parameters	Design Book Costing Parameters	Design Book Costing Parameters	Quotation from Manufacturer

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 Pricing	Design Book Costing Parameters	Design Book Costing Parameters	Design Book Costing Parameters	Quotation from Manufacturer	Design Book Costing Parameters	Design Book Costing Parameters	Design Book Costing 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 Pricing	Design Book Costing Parameters	Design Book Costing Parameters	Design Book Costing Parameters	Design Book Costing Parameters	Design Book Costing Parameters	Design Book Costing Parameters	**-**

Table 9: 67% Capacity 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 Pricing	Design Book Costing Parameters	Design Book Costing Parameters	Design Book Costing Parameters	Quotation from Manufacturer	Design Book Costing Parameters	Design Book Costing Parameters	Design Book Costing 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 Pricing	Design Book Costing Parameters	Design Book Costing Parameters	Design Book Costing Parameters	Design Book Costing Parameters	Design Book Costing Parameters	Design Book Costing Parameters	Quotation from Manufacturer

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	m^2
Process Vessels	Volume	m^3
Pumps	Power	kW
Evaporators	Area	m^2
Reactors	Volume	m^3

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

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

Where:

K values = constants
A = capacity or sizing parameter
C_p^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.

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

Where:

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

For all other process equipment the following was used.

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

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,

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

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:

$$C_{BM} = F_{BM} C_p^o \quad (49)$$

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}).

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

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.

Table 11: Chemical Properties of Materials

Chemical	Stability	Flammability	Corrosiveness	Acute Toxicity	Boiling Point (°C)
Adipic Acid	Stable	Combustible at high temperatures; combustion products: carbon oxides (CO, CO_2)	Aqueous solutions of ADA are corrosive	Inhalation and ingestion; irritant to skin	337.5
Hexamethyldiamine	Stable	Non flammable	Corrosive	Harmful if ingested or comes in contact with skin	201.0
Nylon salt	Stable	Non flammable	Not corrosive	Very low	N/A Decomposition before boiling
1, 6-hexanediamine	Stable	Combustible at high temperatures; combustion products: carbon oxides (CO, CO_2) and nitrogen oxides (NO, NO_2)	Not available	Extremely hazardous in case of contact with skin	204.0
Nylon 6 6	Stable	Non flammable	Not available	Irritation unlikely in pellet form	342.0

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.

Table 12: HAZOP for Polycondensation Reaction

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

Table 13: HAZOP for Evaporation

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

Table 14: HAZOP for Polymerization Reaction

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

Table 15: HAZOP for Flash Drum

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

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:

$$\text{Risk} = \text{Toxicity} \times \text{Severity of Exposure} \times \text{Exposure Length}$$

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 over-pressurization. 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.

Table 16: Operation Pricing Factors

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	$0.06C_{TM}$
Operating Supplies	$0.009C_{TM}$
Operating Overhead	
Local Taxes and Insurance	$0.032C_{TM}$
General plant overhead	$0.036C_{TM}+0.708C_{OL}$
Administrative expense	$.009C_{TM}+0.177C_{OL}$

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.

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	\$110,500
Total	\$432,880

Table 18: Operating Costs in Continuous 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 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

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

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 (gal)	-	$4,080	-	-	-	-	-
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

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 (gal)	-	$4,080	-	-	-	-	-
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

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.

Continuous Process, Pellet											
End of Year	0	1	2	3	4	5	6	7	8	9	10
Sale Price of Spun Nylon 6,6/ (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		(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 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		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/F$_{i,n}$)	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	(12,691,997)	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
NPV @ i* =	11,298,087										
PVC	(253,326,574)										
DCFROR=	34%										

Figure 8: Economic Analysis for Continuous Pellet Process

Continuous Process, Spun											
End of Year	0	1	2	3	4	5	6	7	8	9	10
Sale Price of Spun Nylon 6,6/ (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		(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)	(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 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		33,444,428	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/F$_{i,n}$)	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	(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 Process, Pellet											
End of Year	0	1	2	3	4	5	6	7	8	9	10
Sale Price of Spun Nylon 6,6/ (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 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		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 $(P/F_{i,n})$	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	(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 6,6/ (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 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		33,325,602	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 $(P/F_{i,n})$	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	(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
NPV @ i* =	176,196,548										
PVC	(256,471,728)										
DCFROR=	172%										

Figure 11: Economic Analysis for Batch Spun Process

67% Continuous Process, Pellet											
End of Year	0	1	2	3	4	5	6	7	8	9	10
Sale Price of Spun Nylon 6,6/ (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 10 yr		*0.1*	*0.18*	*0.144*	*0.1152*	*0.0922*	*0.0737*	*0.0655*	*0.0655*	*0.0656*	*0.0655*
- Waste Treatment		(15,203)	(30,405)	(30,405)	(30,405)	(30,405)	(30,405)	(30,405)	(30,405)	(30,405)	(30,405)
- Writeoff		-	-	-	-	-	-	-	-	-	-
Taxable 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 $(P/F_{i,n})$	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	(12,691,997)	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
NPV @ 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.

Table 24: Breakeven Processing Cost for Manufacturing Nylon 6 6

Case	Breakeven Processing Cost of Nylon 6 6 [$]	Original Price [$]	Difference [$]
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

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%.

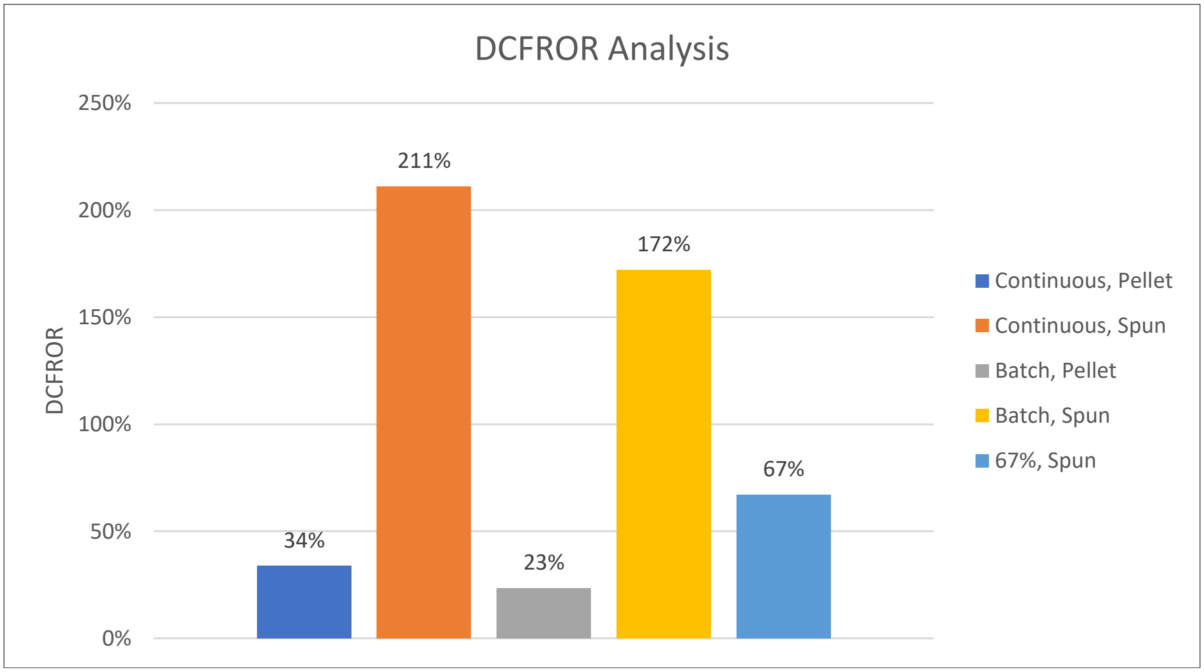

Figure 4: DCFROR Analysis

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.

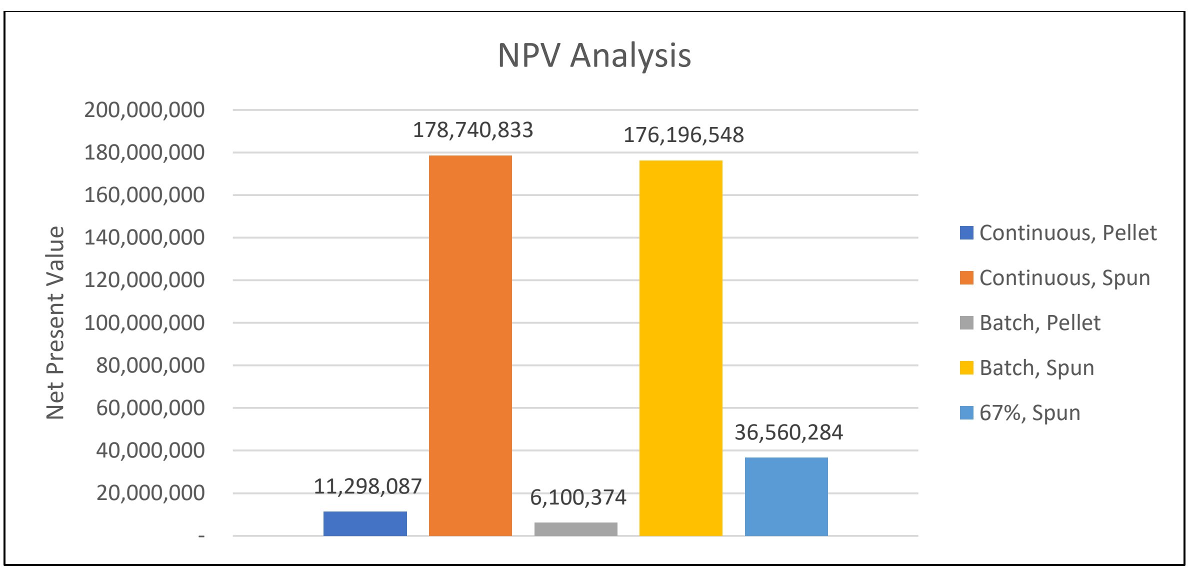

Figure 14: NPV Analysis

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.

Table 25: Payback Period

Payback Period	Years
Batch, pellet	5.18
Batch, spun	1.57
Continuous, pellet	3.84
Continuous, spun	1.57

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 ($5m^2$) of the costing constants for a forced circulation evaporator.

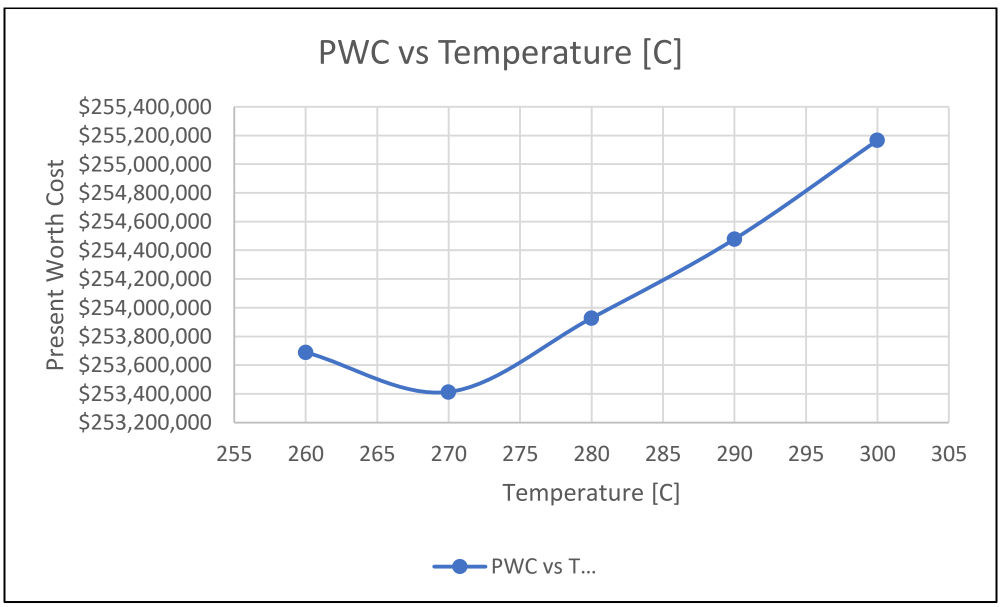

Figure 55: Effect of Temperature on Present Worth Cost

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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.

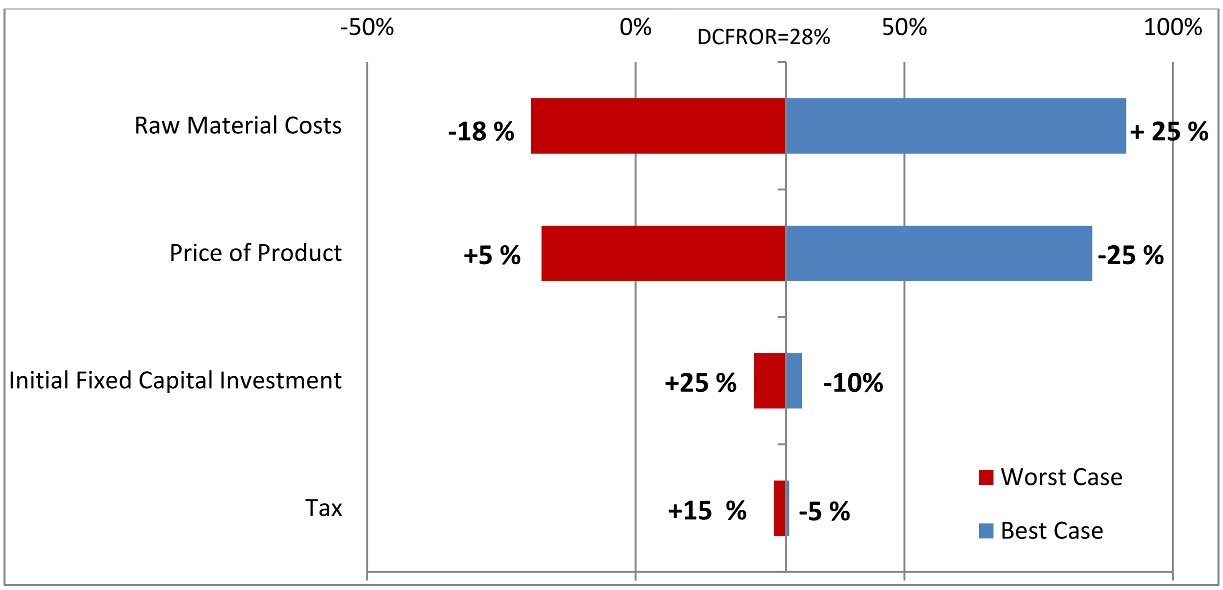

Figure 16: Sensitivity Analysis for Batch Pellet Process

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.

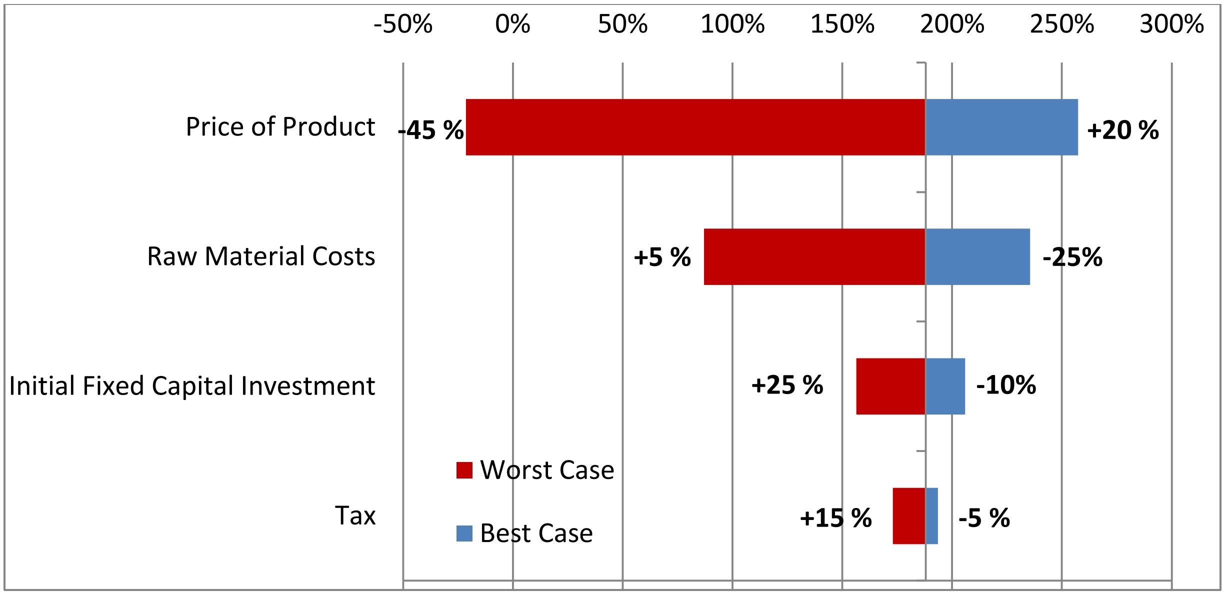

Figure 17: Sensitivity Analysis for Batch Spun Process

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.

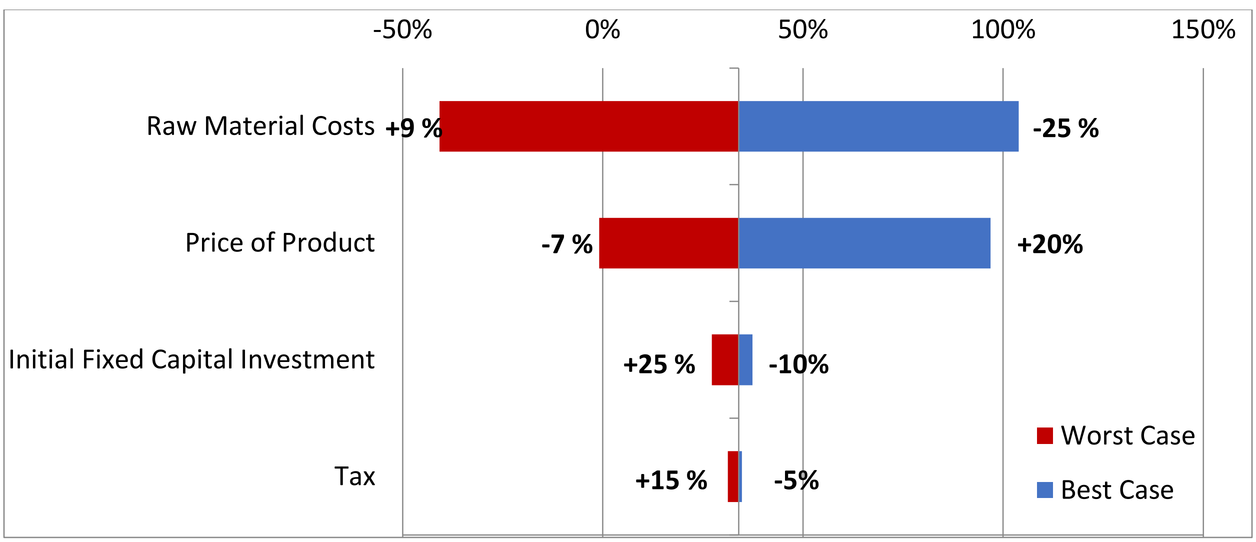

Figure 186: Sensitivity Analysis for Continuous Pellet Process

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.

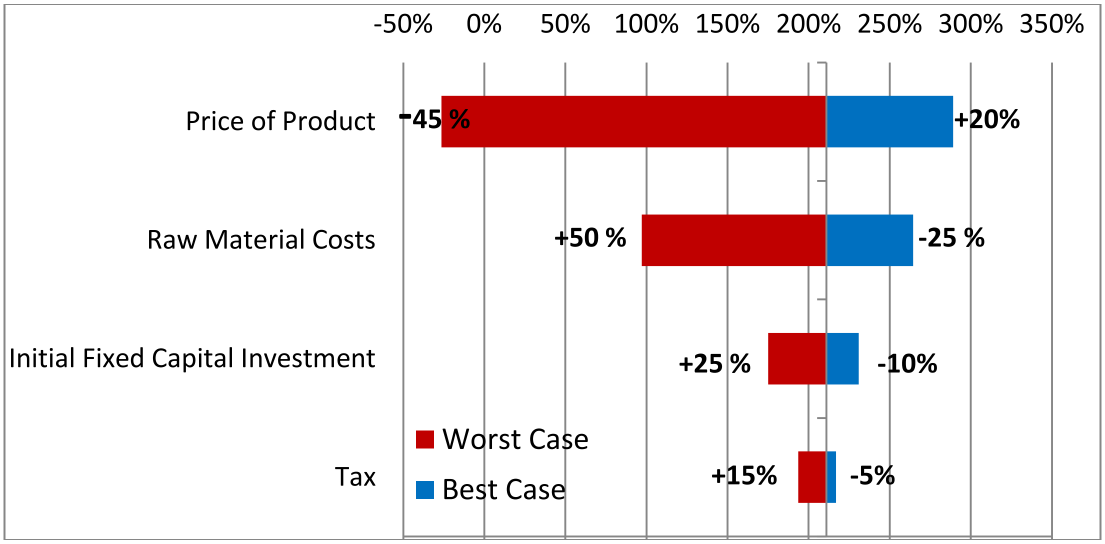

Figure 19: Sensitivity Analysis for Continuous Spun Process

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.

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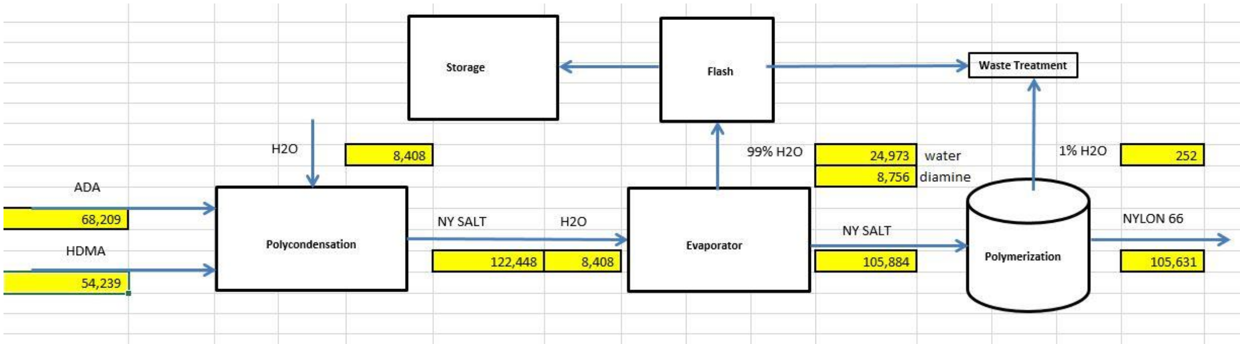
XIX. Appendix

Appendix A: Material Balances

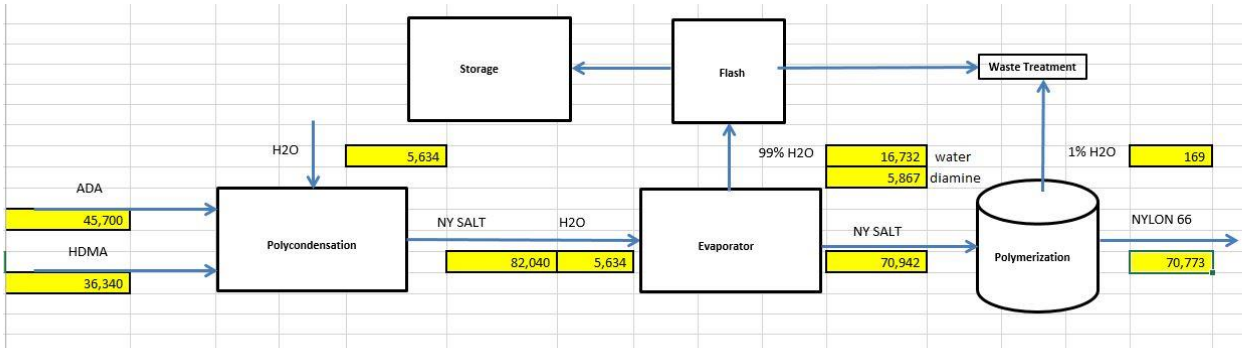


Specified		lb/yr	kg/day
$\dot{m}_{out}$	Nylon 66	8.5.E+07	105,631

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

$\dot{m}_{component}$	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



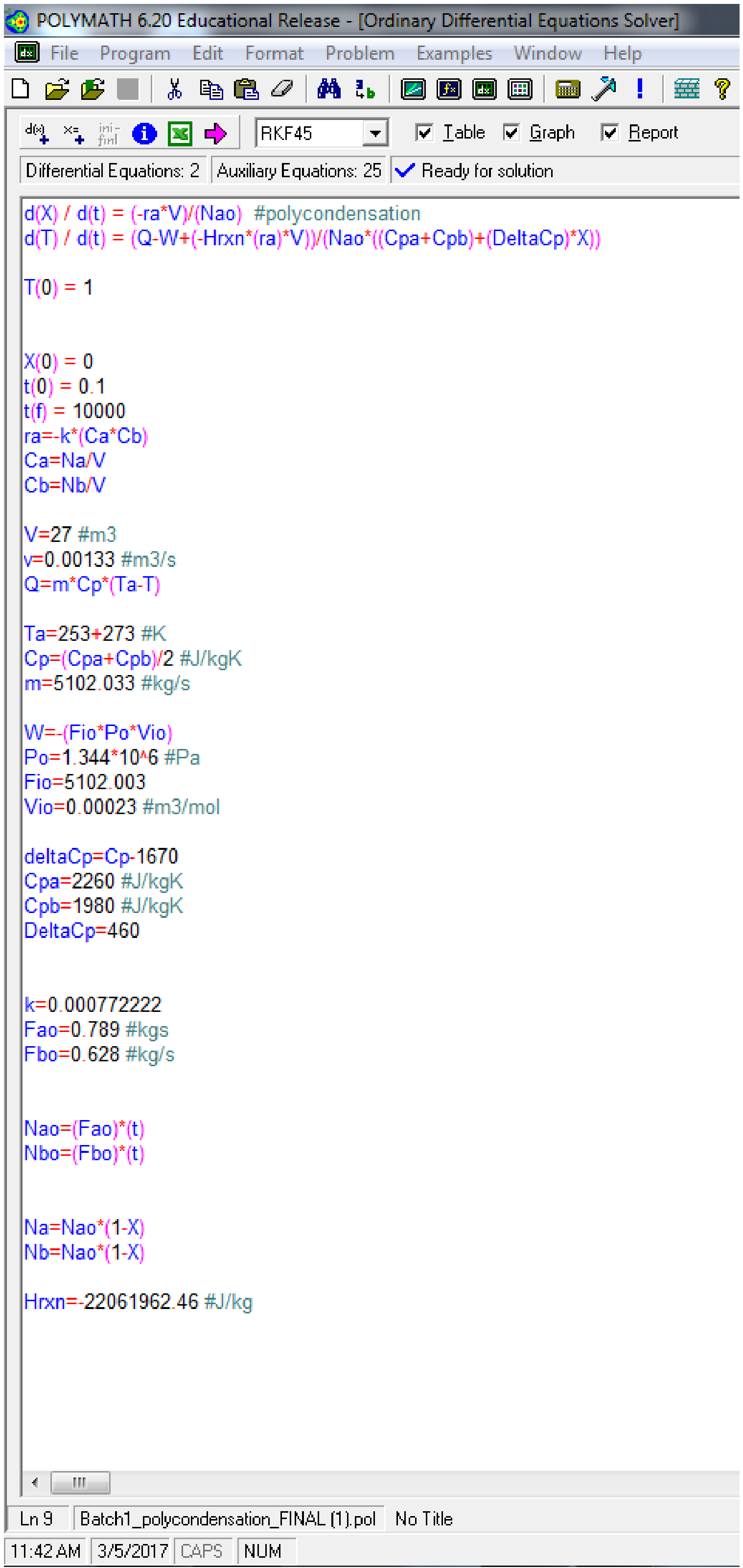
Specified		lb/yr	kg/day	67% Turndown
$\dot{m}_{out}$	Nylon 66	8.5.E+07	105,631	70,772.84

Component Properties		g/mol	kg/mol
Repeat MW	Nylon 66	226.32	0.226
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

$\dot{m}_{component}$	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

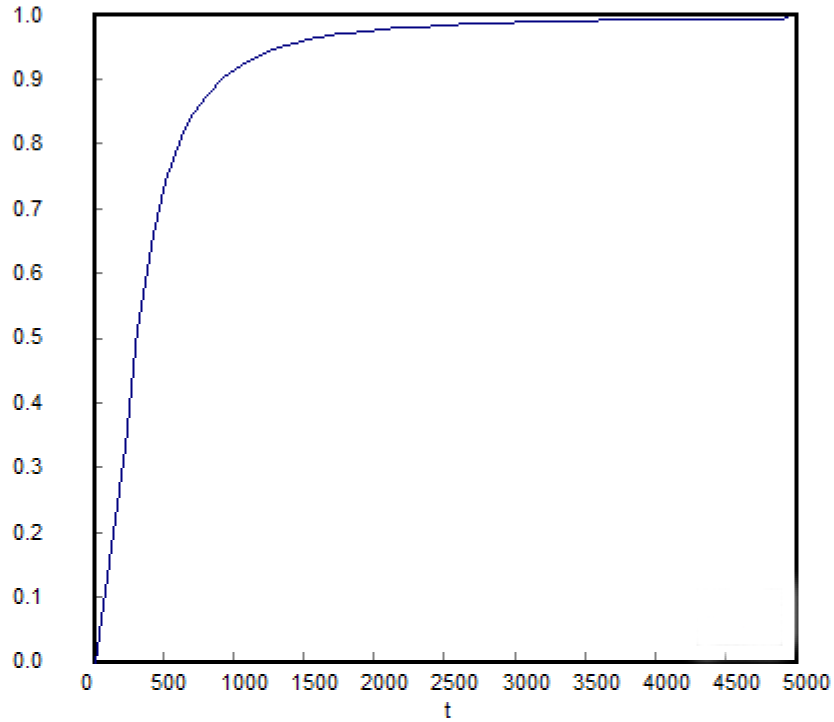


Batch 1 Polymath Code

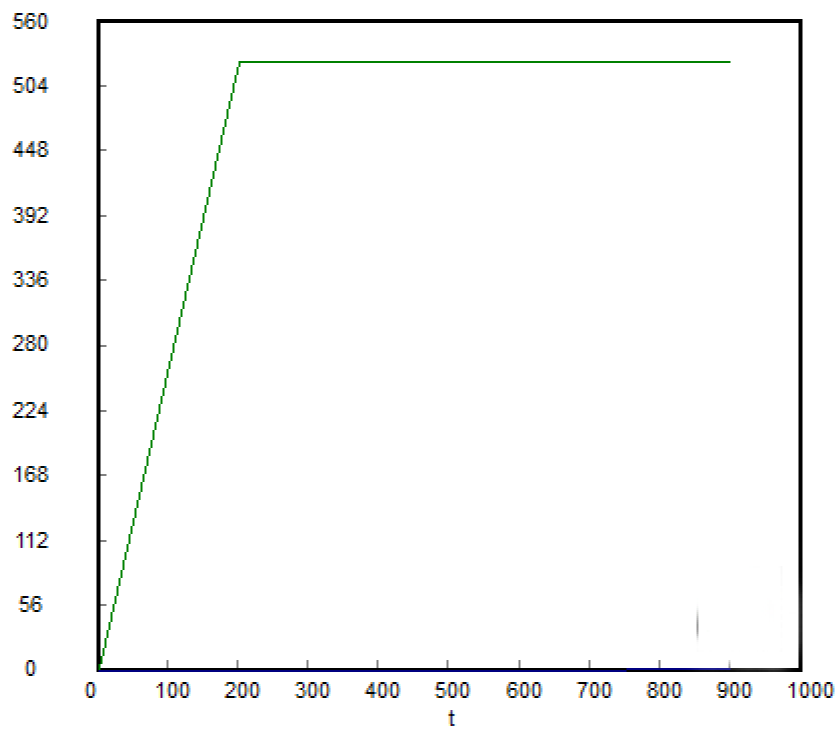
Calculated values of DEQ variables

	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	Cp	2120.	2120.	2120.	2120.
4	Cpa	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	Po	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	T	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	X	0	0	0.9991145	0.9991145

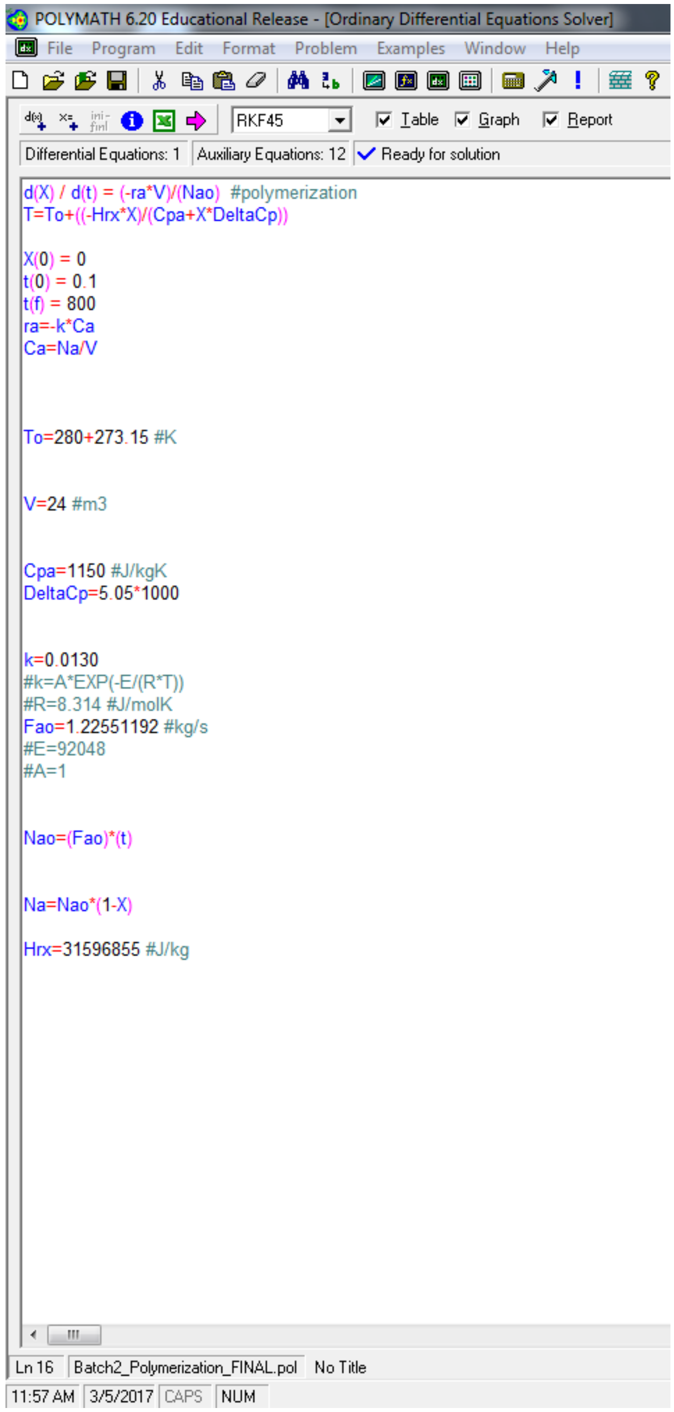
Batch 1 Polymath Solutions



Batch 1 Conversion Graph



Batch 1 Temperature Graph

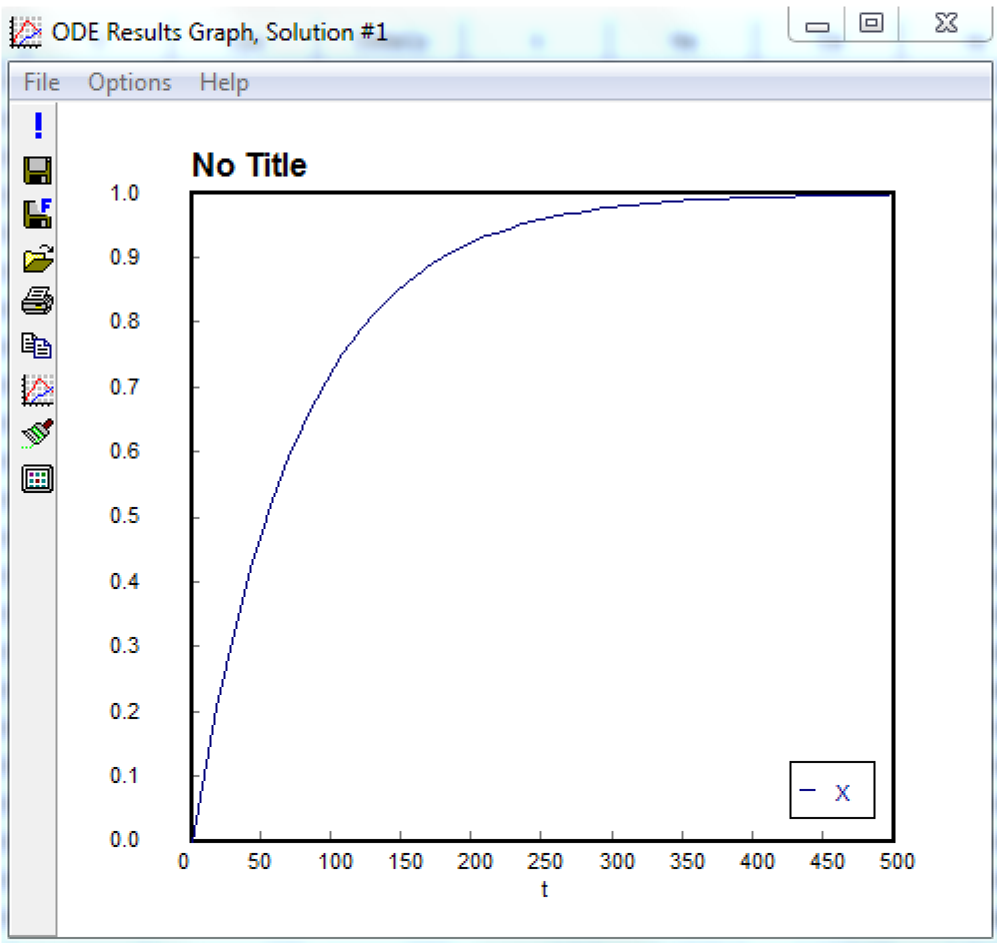


Batch 2 Polymath Code

Calculated values of DEQ variables

	Variable	Initial value	Minimal value	Maximal value	Final value
1	Ca	0.0051063	0.0012448	1.446688	0.0012448
2	Cpa	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	T	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

Batch 2 Code Solutions



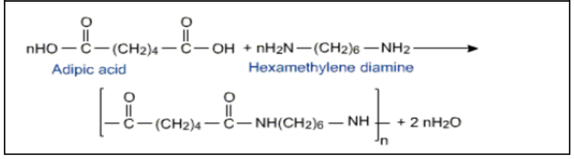
Batch 2 Conversion Graph

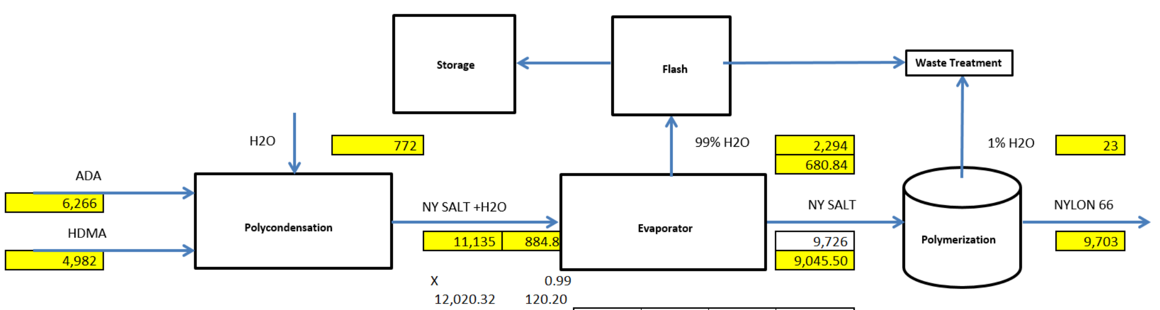
Appendix C: Continuous Process (CSTR)

Specified		lb/yr	lb/hr
$\dot{m}_{out}$	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

Reaction Chemistry





$\dot{m}_{component}$	lb/hr
ADA	6,266
HDMA	4,982
NY SALT	11,248
H2O (IN)	772
H2O (TOTOUT)	2,317

delta H rx	-3779		(J/kg)
Cp	2.89		(kJ/kgC)
Ta	377	191.6667	C
Q	-5.9E+10		
UA	3.54E+08		
k	1.000		
Tc	108.3333		C
T	-538.935		C

CSTR Material Balance

Polycondensation **CSTR**

	kg/day	kg/s	mol/s	Density (kg/m3)	Volumetric Flow m3/s
Fao ADA	68208.97707	0.7894558	5.402006779	1360	0.000580482
Fbo HDMA	54239.08676	0.6277672	5.402006779	840	0.000747342
	TOTAL	1.417223		TOTAL	0.001327824

Specific Heat 1670 J/kg*K

ΔHrxn	881.0320124	KJ/mol	ΔHrxn	-22061.96246	kJ/kg
Heat of Form	ADA	-994.3	KJ/mol	-6803.693962	kJ/kg
Heat of form	HDMA	-205	KJ/mol	-1764.047844	kJ/kg
Heat of Form	Nylon 66	253.73201	kJ/mol	1121.120592	kJ/kg
Heat of Form	H2O	-286	KJ/mol	-15875.41243	kJ/kg

-22061962.46 J/kg

X	0.995	conv
Cp	2.89	KJ/kgC
	2890	J/kg*C
Ta	253	C
m	1.417222961	kg/s
T	250	C
Q	12287.32307	J/s
UA	54.61032476	J/m2C
kappa	0.013333333	J/sm2
Tc	28	
T	-7430.11652	C
E	22	kcal/mol
	92.048	kJ/mol
	0.406716154	KJ/g
	406.7161541	J/g
k	0.000772222	

231 cal/g

967.1508 kJ/g

51

-7156.96652 K

92048 J/mol

22	kcal/mol
119.53	kJ/mol

119530 J/mol

1.590667

ra=-k*Ca*Cb*Cc	
X	V
0	0
0.1	5.21793E-05
0.2	0.000132079
0.3	0.000258767
0.4	0.000469614
0.5	0.000845305
0.6	0.001584948
0.7	0.003287299
0.8	0.008453054
0.9	0.038038744
0.91	0.047483206
0.92	0.060756328
0.93	0.08021776
0.94	0.11035932
0.95	0.160608032
0.96	0.25359163
0.97	0.455525705
0.98	1.035499154
0.99	4.184261889
0.995	16.8215781 *Size of first CSTR*
1	#DIV/0!

Ca=(Fao*(1-X))/v

Cb=(Fao*(1-X))/v

Cc=(Fao*(1-X))/v

Polymerization **CSTR**

	kg/day	kg/s	mol/s	Density (kg/m3)	Volumetric Flow m3/s
Fao Nylon Salt	105884.23	1.225511921	4.671286149	1150	0.001065663
	TOTAL	1.225511921		TOTAL	0.001065663

~~ΔH=m*s*ΔT~~	~~mol~~	~~kg/mol~~	~~m (mass, kg)~~	~~8.85~~
~~ADA~~	~~1~~	~~0.1461412~~	~~0.1461412~~	
~~HDMA~~	~~1~~	~~0.11621~~	~~0.11621~~	

Specific Heat 1670 J/kg*K

ΔHrxn	#REF!	KJ/mol	ΔHrxn	31596.85506	
Heat of Form	Nylon Salt	253.7320124	kJ/mol	967.1508	kJ/kg
Heat of Form	Nylon 66	253.7320124	KJ/mol	1121.120592	kJ/kg
Heat of Form	H2O	-286	KJ/mol	-15875.41243	kJ/kg

X	0.99	conv
Cp	2.89	KJ/kgC
	2890	J/kg*C
Ta	286	C
m	1.225511921	kg/s
T	253	C
Q	116877.0719	J/s
UA	512.6187365	J/m2C
kappa	0.144736842	s/m2
Tc	39.32183908	
T	48.77714423	C
E	22	kcal/mol
	92.048	kJ/mol
	#DIV/0!	KJ/g
	#DIV/0!	J/g
R	8.314	J/molK
A	6	
k	0.0130	s^-1

321.9271442 K

taken from 2.29*10^-3 hr

46.74

0.012983333

168264

ra=-k*Ca*Cb*Cc

X	V
0	0
0.1	0.009119919
0.2	0.020519818
0.3	0.035176831
0.4	0.054719514
0.5	0.082079271
0.6	0.123118907
0.7	0.1915183
0.8	0.328317086
0.9	0.738713442
0.91	0.829912633
0.92	0.943911621
0.93	1.090481748
0.94	1.285908585
0.95	1.559506156
0.96	1.969902513
0.97	2.653896442
0.98	4.021884298
0.99	8.125847867 *Size of first CSTR*
0.995	16.33377501
1	#DIV/0!

Ca=(Fao*(1-X))/v

Cb=(Fao*(1-X))/v

Cc=(Fao*(1-X))/v

CSTR Sizing Polymerization

Determine Vapor Pressure of Water		
p=exp[(a1t+a2t^1.5+a3t^3+a4t^3.5+a5t^4+a6t^7.5)*(Tc/T)]*pc		
Tc	K	647.096
Pc	kPa	22064
a1		-7.85951783
a2		1.84408259
a3		-11.7866497
a4		22.6807411
a5		-15.9618719
a6		1.80122502
T	C	300
T	K	573.15
t	1-T/Tc	0.114273616
p	kPa	8587.867486
P	psia	1245.567124
P	psig	1230.867124

CSTR Vapor Pressure of Water

Reactor Sizing and Costing: Evaporator		
Process Conditions and Specifications		
Inlet 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 atm
Pressure, (barg)	10.00	
Total Flow, (kg/day)	139264.5	
Outlet 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	
Temperature of Hot Oil, F	599.000	Low Pressure Steam
C	315.000	
Total Flow, (kg/day)	139613.0	
Sizing 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	
Cost Correlation- 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**	
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	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	
CTM	$ 1,499,957.77	CBM+Confengency+Fees

Reactor Sizing and Costing: Condenser from Evaporator		
Process Conditions and Specifications		
Shell Side Information		
Inlet Conditions		
Inlet Process Temp, C	280	536
Pressure, psia	159.7	
Pressure, (barg)	10.00	
Outlet Conditions		
Outlet Process Temp, C	109	228.2
Pressure, psia	70.0	
Shell Side Design Pressure, barg	3.8	
Tube Side Information		
Inlet Conditions		
Inlet Cooling WaterTemp, F	87	
Inlet Cooling WaterTemp, C	30.56	
Outlet Conditions		
Outlet Steam Temp, F	120.0	
Outlet Steam Temp, C	48.9	
Design Specs		
Equipment Description		
Equipment Type	HEX	
Equipment Description	Tubular	
Tube Material	Stainless	
Shell Material	Stainless	
Tube Side	Cooling Water	
Shell Side	Process	
HEX TEMA Type	AES	
Equipment Description	Floating Head	
HEX Calculations		
Density of Cooling Water, (lb/m^3)	2195.1	.652/.688btu/lbF
Mass Flow Input Process Stream, (lb/day)	307794.1356	
Cp Steam, (btu/lbF)	1	Engineering Toolbox
Cp Diamine, (btu/lbF)	1.20237E-06	JCT Document
$X_{Diamine}$	0.23	Mass Balance Entering
X_{H2O}	0.77	Mass Balance Entering
Total Cp, (btu/lbF)	0.770000277	Calculated
Heat Flow (Qo), Btu/day	40527268	m*Cp*LMTD
Area of Heat Transfer (A0), m2	53.13726	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	
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	
Cost Correlation- HEX		
Purchase Cost, Cp	$ 55,405.91	
Installed Cost, CBM	$ 148,570	
Equipment Purchase Cost, Cp0	$ 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*CBM
Fee, Cfee	4457.105167	0.03*CBM
2016 Costs		
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	
CTM	$ 241,551.90	CBM+Confengency+Fees

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	Units	
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	kg/mol
Molar Flowrate	Diamine	75,174.76	mol/day
Molar Flowrate	H2O	1386194.45	mol/day
xD	**Diamine**	0.99	
xH	**H2O**	0.01	
yD	**Diamine**	0.01	
yH	**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	C
Temp	Flash Drum	382.15	K
V	H2O vapor	1386194.45	mol/day
Wv	H2O vapor	26337.59406	kg/day
L	Diamine liquid	75,174.76	mol/day
Wl	Diamine liquid	8,681.98	kg/day
Flv	Flash Drum	0.002551517	
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	-1.877478097	
B	Constant	-0.81458046	
C	Constant	-0.187074409	
D	Constant	-0.014522867	
E	Constant	-0.001014852	
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	in
D	6 inch increment	48	in
D	vertical drum	1.2192	m
Volume	V=pir2*h	4.270079867	m3

Redlich Kwong		
Tc	647.1	K
Pc	22.06	Mpa
	22060	kPa
Tr	0.590558	
Pr	0.000381	
Z=B+Z(Z+B)*((1+B-Z)/(qB))		
q	10.87186	
B	5.6E-05	
Z	0.999447	6.73E-08

Redlich Kwong Vaules

Reactor Sizing and Costing: Jacketed/CSTR 1 (Ajitated)		
Process Conditions and Specifications		
Inlet Conditions		
Mass Flow HMDA, (kg/day)	54239.17058	
Mass Flow Adipic Acid, (kg/day)	68208.897	
Mass Flow Water, (kg/day)	8408.234904	
Mass Flow Nylon Salt, (kg/day)	-	
Mass Flow Nylon 6,6, (kg/day)	-	
Temperature, C	25	
Outlet Conditions		
Mass Flow HMDA, (kg/day)	-	
Mass Flow Adipic Acid, (kg/day)	-	
Mass Flow Water, (kg/day)	8408.23	
Mass Flow Nylon Salt, (kg/day)	122447.6	
Mass Flow Nylon 6,6, (kg/day)	-	
Temperature, C	255	
Sizing of Equipment		
Total Mass Flow Out, (kg/day)	130855.83	
X_{ADA}	0.52	Mass Balance
X_{HMDA}	0.41	Mass Balance
X_{H2O}	0.06	Mass Balance
Density ADA, (kg/m^3)	1359.998997	Literature
Density HMDA, (kg/m^3)	840	Literature
Density Water, (kg/m^3)	999.997995	Literature
Density, (kg/m^3)	1112	
Total Flow Rate, (kg/hr)	5452.345937	
(m^3/day)	4.904955996	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)	16.82	Material Balance
Diameter, (m)	1.9	
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- Jacketed/Batch Reactor (Ajitated)		
Purchase Cost, Cp	519966.8581	Cpo*Fp*Fm
Installed Cost, CBM	1090399.487	Cpo*FBM
Equipment 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	
Presure Factor, FP	2.937824624	
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	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
Contingency, Ccont	163559.9231	0.15*CBM
Fee, Cfee	32711.98461	0.03*CBM
2016 Costs		
Chemical Engineering Plant Cost Index in 2017	547	
Chemical Engineering Plant Cost Index in 2012	397	
Purchase Cost, Cp	$ 716,427.89	Cp*($CEPCI_{2016}$/$CEPCI_{2012}$)
Installed Cost, CBM	$ 1,502,389.22	CBM*($CEPCI_{2016}$/$CEPCI_{2012}$)
Total Contengency	225358.3827	
Total Fees	45071.67653	
CTM	$ 1,772,819.28	CBM+Confengency+Fees

Reactor Sizing and Costing: Evaporator		
Process Conditions and Specifications		
Inlet 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 atm
Pressure, (barg)	10.00	
Total Flow, (kg/day)	139264.5	
Outlet 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	
Temperature of Hot Oil, F	599.000	Low Pressure Steam
C	315.000	
Total Flow, (kg/day)	139613.0	
Sizing 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	
Cost Correlation- 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**	
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	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	
CTM	$ 1,499,957.77	CBM+Confengency+Fees

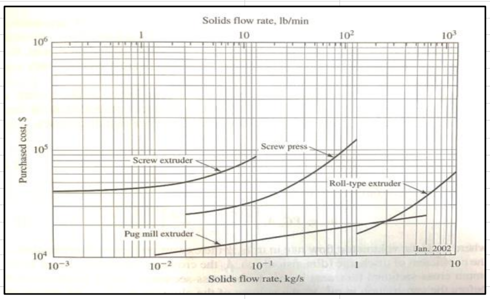
Reactor Sizing and Costing: Flash Drum		
Process Conditions and Specifications		
Inlet Conditions		
Mass Flow HMDA, (kg/day)	-	
Mass Flow Adipic Acid, (kg/day)	-	
Mass Flow Water, (kg/day)	24973	
Mass Flow Nylon Salt, (kg/day)	-	
Mass Flow Nylon 6,6, (kg/day)	-	
Mas Flow Diamine, (kg/day)	8756.2	342C= BP at 20 psia
Temperature, C	109	
Pressure, (barg)	3.812	55.3
Total Flow, (kg/day)	33728.72756	
Outlet Conditions		
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 Equipment		
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/m^3)	0.0407	
(ft^3/day)	2.257028728	Density/Mass Flow Rate
(m^3/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- 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	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
B2 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	
CTM	$ 370,669.94	CBM+Confengency+Fees

Storage Tank (Diamine)		
Process Conditions 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)	-	
Mas Flow Diamine, (kg/day)	8756.22	
Temperature, C	110	338.5C= BP at 1 atm
Pressure, (barg)	3.80	
Total Flow, (kg/day)	8756.22	
Sizing of Equipment		
$X_{Diamine}$	0.23	Mass Balance
Density Diamine, (kg/m^3)	839.599	Literature
Total Flow Rate, (kg/day)	8756.22	
(m^3/day)	10.42905264	Density/Mass Flow Rate
(m^3/week)	73.00336849	
Time in Vessel, (hr)	168	Store for a Week
(day)	7	hr/24
Reaction Rate, ()		
Volume, (m^3)	73.00336849	Fixed roof
Diameter, (m)	3.1	
L/D	3	Heuristic
Orientation		Vertical
Pressure, (psia)	145	Pressure of Vessel-Literature
Design Pressure, (psia)	195	
(barg)	12.43	
Cost Correlation- Jacketed/Batch Reactor (Ajitated)		
Purchase Cost, Cp	227484.6077	Cpo*Fp*Fm
Installed Cost, CBM	535184.2713	Cpo*FBM
Equipment Purchase Cost, Cp0	50816.7765	
K1 from Table A.1	3.4974	Volume Min: 0.1 m^3 Max: 35 m^3
K2 from Table A.1	0.4485	Volume Min: 0.1 m^3 Max: 35 m^3
K3 from Table A.1	0.1074	Volume Min: 0.1 m^3 Max: 35 m^3
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*CBM
Fee, Cfee	16055.52814	0.03*CBM
2016 Costs		
Chemical Engineering Plant Cost Index in 2016	547	
Chemical Engineering Plant Cost Index in 2012	397	
Purchase Cost, Cp	$ 313,435.97	Cp*($CEPCI_{2016}$/$CEPCI_{2012}$)
Installed Cost, CBM	737394.9532	CBM*($CEPCI_{2016}$/$CEPCI_{2012}$)
Total Contengency	110609.243	
Total Fees	22121.8486	
CTM	$ 870,126.04	CBM+Confengency+Fees

Reactor Sizing and Costing: Condenser from Evaporator		
Process Conditions and Specifications		
Shell Side Information		
Inlet Conditions		
Inlet Process Temp, C	280	536
Pressure, psia	159.7	
Pressure, (barg)	10.00	
Outlet Conditions		
Outlet Process Temp, C	109	228.2
Pressure, psia	70.0	
Shell Side Design Pressure, barg	3.8	
Tube Side Information		
Inlet Conditions		
Inlet Cooling WaterTemp, F	87	
Inlet Cooling WaterTemp, C	30.56	
Outlet Conditions		
Outlet Steam Temp, F	120.0	
Outlet Steam Temp, C	48.9	
Design Specs		
Equipment Description		
Equipment Type	HEX	
Equipment Description	Tubular	
Tube Material	Stainless	
Shell Material	Stainless	
Tube Side	Cooling Water	
Shell Side	Process	
HEX TEMA Type	AES	
Equipment Description	Floating Head	
HEX Calculations		
Density of Cooling Water, (lb/m^3)	2195.1	.652/.688btu/lbF
Mass Flow Input Process Stream, (lb/day)	307794.1356	
Cp Steam, (btu/lbF)	1	Engineering Toolbox
Cp Diamine, (btu/lbF)	1.20237E-06	JCT Document
$X_{Diamine}$	0.23	Mass Balance Entering
X_{H2O}	0.77	Mass Balance Entering
Total Cp, (btu/lbF)	0.770000277	Calculated
Heat Flow (Qo), Btu/day	40527268	m*Cp*LMTD
Area of Heat Transfer (A0), m2	53.13726	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	
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	
Cost Correlation- HEX		
Purchase Cost, Cp	$ 55,405.91	
Installed Cost, CBM	$ 148,570	
Equipment Purchase Cost, Cp0	$ 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*CBM
Fee, Cfee	4457.105167	0.03*CBM
2016 Costs		
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	
CTM	$ 241,551.90	CBM+Confengency+Fees

Reactor Sizing and Costing: Jacketed/CSTR 2 (Ajitated)		
Process Conditions 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)	105884.23	
Mass Flow Nylon 6,6, (kg/day)	-	
Temperature, C	280	
Outlet Conditions		
Mass Flow HMDA, (kg/day)	0	
Mass Flow Adipic Acid, (kg/day)	0	
Mass Flow Water, (kg/day)	252.25	
Mass Flow Nylon Salt, (kg/day)	-	
Mass Flow Nylon 6,6, (kg/day)	105631.1	
Temperature, C	280	
Sizing of Equipment		
Total Mass Flow Out, (kg/hr)	4411.80625	
$X_{Nylon\ 66}$	0.99762	Mass Balance
X_{H2O}	0.00238	Mass Balance
Density Nylon 66, (kg/m3)	1139.999166	Literature
Density Water, (kg/m3)	999.997995	Literature
Density, (kg/m3)	1140	
Total Flow Rate, (kg/hr)	4411.842917	
(m^3/day)	3.871171957	Density/Mass Flow Rate
Time in Vessel, (hr)	-	Reaction Time
(day)		hr/24
Reaction Rate Constant, (kg/mol/s)		From Literature 95% Confidence
Volume, (m^3)	16.33	Levenspiel Plot
Diameter, (m)	1.9	
L/D	3	Heuristic
Pressure, (psia)	145	Pressure of Vessel-Literature
Design Pressure, (psia)	195	
(barg)	12.43	
Duty, (J/s)	0	Adiabatic
Cost Correlation- Jacketed/Batch Reactor (Ajitated)		
Purchase Cost, Cp	507705.6675	Cpo*Fp*Fm
Installed Cost, CBM	1065716.161	Cpo*FBM
Equipment Purchase Cost, Cp0	56204.7451	
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	16.33	
Presure Factor, FP	2.913918059	
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	18.96132007	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	159857.4242	0.15*CBM
Fee, Cfee	31971.48484	0.03*CBM
2016 Costs		
Chemical Engineering Plant Cost Index in 2016	547	
Chemical Engineering Plant Cost Index in 2012	397	
Purchase Cost, Cp	$ 699,534.01	Cp*($CEPCI_{2016}$/$CEPCI_{2012}$)
Installed Cost, CBM	1468379.698	CBM*($CEPCI_{2016}$/$CEPCI_{2012}$)
Total Contengency	220256.9548	
Total Fees	44051.39095	
CTM	$ 1,732,688.04	CBM+Confengency+Fees

Reactor Sizing and Costing: Extruder		
Process Conditions and Specifications		
Inlet Conditions		
Nylon 6,6 Flow Rates, (kg/day)	105,631	
kg/s	1.223	
Temperature, C	280	
kW	51.352	
Type of Extruder	Twin Screw	Peters and Timmerhause
Pressure, (barg)		
Cp based on Flow	$ 130,000.00	Top Price
CBM	532303.36	
CTM		
Fees	15969.1008	
Contengency	79845.504	
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
CTM	$ 949,900.04	$ 949,890.00



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

Spinnerett		
Pressure, (barg)		
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 Tank (Pellets)		
Process Conditions 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	
Sizing 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)	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, (m^3)	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- Jacketed/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	2.25	Vertical Process Vessel
B2 from Table A.4	1.85	Vertical Process Vessel
Contingency, Ccont	104237.4751	0.15*CBM
Fee, Cfee	20847.49502	0.03*CBM
2016 Costs		
Chemical Engineering Plant Cost Index in 2016	547	
Chemical Engineering Plant Cost Index in 2012	397	
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	
Total Fees	$ 28,724.38	
CTM	$ 1,129,825.70	CBM+Confengency+Fees

Pump 1: Evaporator to CSTR 2		
Design Specs		
Pressure Change, (barg)	2.43	
Flowrate, (lb/day)	105884	
Inlet flowrate, (lb/hr)	4412	
Hydraulic Power, hp	6.3	
Shaft Power, Brake hp	9.6	
Pump Efficiency	0.65	Set by Design Group
Purchased Power, hp	11.3	
Motor Efficiency	0.849	
Actual Purchase Power, hp	15	Set by Design Group
Actual Purchase Power, kW	11.19	
Pump pressure, barg	2.4	
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	

Pump 2: Condenser to Flash Tank		
Design Specs		
Pressure Change, (barg)	0.20	
Flowrate, (lb/day)	33728.73	
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	
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	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	3.3892	
K2 from Table A.1	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	38	
Bare Module Factor, FBM	4.32	
B1 from Table A.4	1.89	
B2 from Table A.4	1.35	
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	
Purchase Cost, Cp	$ 5,126	
Installed Cost, CBM	$ 14,751	
Total Contingency, Ccont	$ 2,213	
Total Fees, Cfee	$ 443	
Total Module Capital, CTM	$ 17,406	

Pump 3: Flash to Storage Tank		
Design Specs		
Pressure Change, (barg)	0.165	
Flowrate, (lb/day)	8756	
Inlet flowrate, (lb/hr)	365	
Hydraulic Power, hp	0.0351	
Shaft Power, Brake hp	0.0540	
Pump Efficiency	0.65	Set by Design Group
Purchased Power, hp	0.0931	
Motor Efficiency	0.5801	
Actual Purchase Power, hp	0.5	Set by Design Group
Actual Purchase Power, kW	0.37	
Pump pressure, barg	0.165	
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	3.3892	
K2 from Table A.1	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	38	
Bare Module Factor, FBM	4.32	
B1 from Table A.4	1.89	
B2 from Table A.4	1.35	
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	
Purchase Cost, Cp	$ 5,126	
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		
Pressure Change, (barg)	17.570	Based on Extruder Pressure
Flowrate, (lb/day)	105631.1	
Inlet flowrate, (lb/hr)	4401	
Hydraulic Power, hp	45.0908	
Shaft Power, Brake hp	64.4155	
Pump Efficiency	0.7	Set by Design Group
Purchased Power, hp	70.8682	
Motor Efficiency	0.9089	
Actual Purchase Power, hp	75	Set by Design Group
Actual Purchase Power, kW	55.93	
Pump pressure, barg	17.570	
Pump Type	Centrifugal	Set by Design Group
Pump Material	Carbon Steel	Set by Design Group
Cost Correlation- Pump		
Purchase Cost, Cp	16759.20905	
Installed Cost, CBM	48229.97325	
Equipment Purchase Cost, Cp0	8966.188094	
K1 from Table A.1	3.3892	
K2 from Table A.1	0.0536	
K3 from Table A.1	0.1538	
Shaft Power, KW	55.9	
Presure Factor, FP	1.25	
C1 from Table A.2	-0.39350	
C2 from Table A.2	0.39570	10<Pressure<100
C3 from Table A.3	-0.00226	
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	7234.495987	
Fee, Cfee	1446.899197	
2016 Costs		
Chemical Engineering Plant Cost Index in 2016	547	
Chemical Engineering Plant Cost Index in 2012	397	
Purchase Cost, Cp	$ 23,091	
Installed Cost, CBM	$ 66,453	
Total Contingency, Ccont	$ 9,968	
Total Fees, Cfee	$ 1,994	
Total Module Capital, CTM	$ 78,414	

Pump 5: Evaporator Pump		
Design Specs		
Pressure Change, (barg)	2.43	
Flowrate, (lb/day)	139264.5	From HYSYS
Inlet flowrate, (lb/hr)	5803	From HYSYS
Hydraulic Power, hp	8.2	
Shaft Power, hp	12.6	
Pump Efficiency	0.65	Set by Design Group
Purchased/Break Power, hp	14.7	
Motor Efficiency	0.859	
Actual Purchase Power, hp	15	Set by Design Group
Actual Purchase Power, kW	11.19	
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	

Utilities (Pelletized)			
Service Factor			
Service Factor		0.95	
Days/yr		365	
Hours/ day		24	
Operation Hours/yr		8322	
Pump Electricity			
Total kW		180.05	
Total kW-hr		1498369.442	
Pice per kW-hr	$	0.0545	Calvert City, KS
Total Price/yr	$	81,661.13	
Reactor Electricity (stiring)			
Total kW		63.64	
Total kW-hr		529570.47	
Pice per kW-hr	$	0.0545	Calvert City, KS
Total Price/yr	$	28,861.59	
Reactor Heating (Steam Jacket)			
Duty (J/s)		1291116458	
(Btu/h)		4405289355	
Flow Rate, (lb/h)		4738398.79	
1000 lb		4738.39879	
Cost/1000 lb		4.75	
Cost	$	22,507.39	
Cooling Water			
Condenser 1			
Price for annual gpm	$	120.00	Phillips
Inlet CW Flow,			
Flow Rate, lb/hr		1228099.042	
gpm		2465.591757	
Total Price/yr	$	295,871.01	
Density of Water,		1	
Heat Flow, Btu/hr		40527268	
Specific Heat (Water), Btu/lbF		1	
CW out Temp, C		120.0	
CW in Temp, C		87.00	
Temp Difference		33.0	
Hot Oil			
Volume, gal		110.00	
Cost	$	4,079.90	DME

Utilities (Spun)			
Service Factor			
Service Factor		0.95	
Days/yr		365	
Hours/ day		24	
Operation Hours/yr		8322	
Pump Electricity			
Total kW		180.05	
Total kW-hr		1498369.442	
Pice per kW-hr	$	0.0545	Calvert City, KS
Total Price/yr	$	81,661.13	
Reactor Electricity (stiring)			
Total kW		113.29	
Total kW-hr		942782.736	
Pice per kW-hr	$	0.0545	Calvert City, KS
Total Price/yr	$	51,381.66	
Reactor Heating (Steam Jacket)			
Duty (J/s)		1291116458	
(Btu/h)		4405289355	
Flow Rate, (lb/h)		4738398.79	
1000 lb		4738.39879	
Cost/1000 lb		4.75	
Cost	$	22,507.39	
Cooling Water			
Condenser 1			
Price/1000 gal	$	120.00	Phillips
Inlet CW Flow,			
Flow Rate, lb/hr		1228099.042	
gpm		2465.591757	
Total Price/yr	$	295,871.01	
Density of Water,		1	
Heat Flow, Btu/hr		40527268	
Specific Heat (Water), Btu/lbF		1	
CW out Temp, C		120.0	
CW in Temp, C		87.00	
Temp Difference		33.0	
Hot Oil			
Volume, gal		110.00	
Cost	$	4,079.90	DME

Appendix D: Batch Production Process

Reactor Sizing and Costing: Jacketed/Batch 1 (Ajitated)		
Process Conditions and Specifications		
Inlet Conditions		
Mass Flow HMDA, (kg/day)	54239.17058	
Mass Flow Adipic Acid, (kg/day)	68208.897	
Mass Flow Water, (kg/day)	8408.234904	
Mass Flow Nylon Salt, (kg/day)	-	
Mass Flow Nylon 6,6, (kg/day)	-	
Temperature, C	25	
Outlet Conditions		
Mass Flow HMDA, (kg/day)	-	
Mass Flow Adipic Acid, (kg/day)	-	
Mass Flow Water, (kg/day)	8408.234904	
Mass Flow Nylon Salt, (kg/day)	122447.614	
Mass Flow Nylon 6,6, (kg/day)	-	
Temperature, C	250	
Sizing of Equipment		
Total Mass Flow Out, (kg/day)	130855.8489	
X_{ADA}	0.52	Mass Balance
X_{HMDA}	0.41	Mass Balance
X_{H2O}	0.06	Mass Balance
Density ADA, (kg/m^3)	1359.998997	Literature
Density HMDA, (kg/m^3)	840052384	Literature
Density Water, (kg/m^3)	999.997995	Literature
Density, (kg/m^3)	344422245	
Total Flow Rate, (kg/hr)	5452.345937	
(m^3/day)	1.58304E-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)	27	Material Balance
Diameter, (m)	2.3	
L/D	3	Heuristic
Pressure, (psia)	145	Pressure of Vessel-Literature
Design Pressure, (psia)	195	
(barg)	12.43	
Duty, (kW)	57.34084483	Shaft Work
Cost Correlation- Jacketed/Batch Reactor (Ajitated)		
Purchase Cost, Cp	763199.1005	Cpo*Fp*Fm
Installed Cost, CBM	1577055.05	Cpo*FBM
Equipment 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	
Presure Factor, FP	3.35440143	
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	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
Contingency, Ccont	236558.2576	0.15*CBM
Fee, Cfee	47311.65151	0.03*CBM
2016 Costs		
Chemical Engineering Plant Cost Index in 2017	547	
Chemical Engineering Plant Cost Index in 2012	397	
Purchase Cost, Cp	1051561.481	Cp*(CEPCI$_{2016}$/CEPCI$_{2012}$)
Installed Cost, CBM	2172919.679	CBM*(CEPCI$_{2016}$/CEPCI$_{2012}$)
Total Contengency	325937.9518	
Total Fees	65187.59037	
CTM	$ 2,564,045.22	CBM+Confengency+Fees

Reactor Sizing and Costing: Evaporator		
Process Conditions and Specifications		
Inlet Conditions		
Mass Flow HMDA, (kg/day)	-	
Mass Flow Adipic Acid, (kg/day)	-	
Mass Flow Water, (kg/day)	16817	
Mass Flow Nylon Salt, (kg/day)	122447.614	
Mass Flow Nylon 6,6, (kg/day)	-	
Temperature, C	250	338.5C= BP at 1 atm
Pressure, (barg)	10.00	
Total Flow, (kg/day)	139264.614	
Outlet 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	
Temperature of Hot Oil, F	599.000	Low Pressure Steam
C	315.000	
Total Flow, (kg/day)	139613	
Sizing 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	
Cost Correlation- 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**	
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	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	
CTM	$ 1,499,957.77	CBM+Confengency+Fees

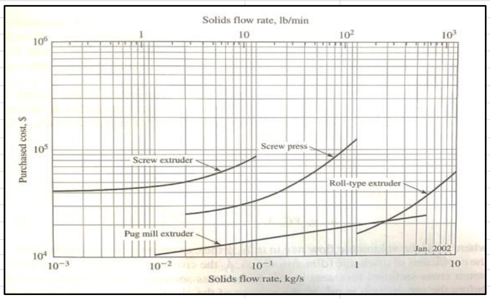
Reactor Sizing and Costing: Flash Drum		
Process Conditions and Specifications		
Inlet Conditions		
Mass Flow HMDA, (kg/day)	-	
Mass Flow Adipic Acid, (kg/day)	-	
Mass Flow Water, (kg/day)	24973	
Mass Flow Nylon Salt, (kg/day)	-	
Mass Flow Nylon 6,6, (kg/day)	-	
Mas Flow Diamine, (kg/day)	8756.22	342C= BP at 20 psia
Temperature, C	109	
Pressure, (barg)	3.812	55.3
Total Flow, (kg/day)	33728.72756	
Outlet Conditions		
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 Equipment		
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/m^3)	0.0407	
(ft^3/day)	2.257028728	Density/Mass Flow Rate
(m^3/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- 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	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
B2 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	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 Tank (Diamine)		
Process Conditions 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)	-	
Mas Flow Diamine, (kg/day)	8756.22	
Temperature, C	255	338.5C= BP at 1 atm
Pressure, (barg)	3.80	
Total Flow, (kg/day)	8756.22	
Sizing of Equipment		
$X_{Diamine}$	0.23	Mass Balance
Density Diamine, (kg/m^3)	839.599	Literature
Total Flow Rate, (kg/day)	8756.22	
(m^3/day)	10.42905264	Density/Mass Flow Rate
(m^3/week)	73.00336849	
Time in Vessel, (hr)	168	Store for a Week
(day)	7	hr/24
Reaction Rate, ()		
Volume, (m^3)	73.00336849	
Diameter, (m)	3.1	
L/D	3	Heuristic
Orientation		Vertical
Pressure, (psia)	145	Pressure of Vessel-Literature
Design Pressure, (psia)	195	
(barg)	12.43	
Cost Correlation- Jacketed/Batch Reactor (Ajitated)		
Purchase Cost, Cp	227484.6077	Cpo*Fp*Fm
Installed Cost, CBM	535184.2713	Cpo*FBM
Equipment Purchase Cost, Cp0	50816.7765	
K1 from Table A.1	3.4974	Volume Min: 0.1 m^3 Max: 35 m^3
K2 from Table A.1	0.4485	Volume Min: 0.1 m^3 Max: 35 m^3
K3 from Table A.1	0.1074	Volume Min: 0.1 m^3 Max: 35 m^3
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*CBM
Fee, Cfee	16055.52814	0.03*CBM
2016 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	110609.243	
Total Fees	22121.8486	
CTM	$ 870,126.04	CBM+Confengency+Fees

Reactor Sizing and Costing: Condenser from Evaporator		
Process Conditions and Specifications		
Shell Side Information		
Inlet Conditions		
Inlet Process Temp, C	280	536
Pressure, psia	159.7	
Pressure, (barg)	10.00	
Outlet Conditions		
Outlet Process Temp, C	109	228.2
Pressure, psia	70.0	
Shell Side Design Pressure, barg	3.8	
Tube Side Information		
Inlet Conditions		
Inlet Cooling WaterTemp, F	87	
Inlet Cooling WaterTemp, C	30.56	
Outlet Conditions		
Outlet Steam Temp, F	120.0	
Outlet Steam Temp, C	48.9	
Design Specs		
Equipment Description		
Equipment Type	HEX	
Equipment Description	Tubular	
Tube Material	Stainless	
Shell Material	Stainless	
Tube Side	Cooling Water	
Shell Side	Process	
HEX TEMA Type	AES	
Equipment Description	Floating Head	
HEX Calculations		
Density of Cooling Water, (lb/m^3)	2195.1	.652/.688btu/lbF
Mass Flow Input Process Stream, (lb/day)	307794.1356	
Cp Steam, (btu/lbF)	1	Engineering Toolbox
Cp Diamine, (btu/lbF)	1.20237E-06	JCT Document
$X_{Diamine}$	0.23	Mass Balance Entering
X_{H2O}	0.77	Mass Balance Entering
Total Cp, (btu/lbF)	0.770000277	Calculated
Heat Flow (Qo), Btu/day	40527268	m*Cp*LMTD
Area of Heat Transfer (A0), m2	53.13726	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	
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	
Cost Correlation- HEX		
Purchase Cost, Cp	55405.91226	
Installed Cost, CBM	$ 148,570	
Equipment Purchase Cost, Cp0	$ 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*CBM
Fee, Cfee	4457.105167	0.03*CBM
2016 Costs		
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	
CTM	$ 241,551.90	CBM+Confengency+Fees

Reactor Sizing and Costing: Jacketed/Batch 2 (Ajitated)		
Process Conditions 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)	105884.23	
Mass Flow Nylon 6,6, (kg/day)	-	
Temperature, C	280	
Outlet Conditions		
Mass Flow HMDA, (kg/day)	0	
Mass Flow Adipic Acid, (kg/day)	0	
Mass Flow Water, (kg/day)	252.25	
Mass Flow Nylon Salt, (kg/day)	-	
Mass Flow Nylon 6,6, (kg/day)	105631.1	
Temperature, C	280	
Sizing of Equipment		
Total Mass Flow Out, (kg/hr)	4411.80625	
$X_{Nylon\ 66}$	0.99762	Mass Balance
X_{H2O}	0.00238	Mass Balance
Density Nylon 66, (kg/m3)	1139.999166	Literature
Density Water, (kg/m3)	999.997995	Literature
Density, (kg/m3)	1140	
Total Flow Rate, (kg/hr)	4411.842917	
(m^3/day)	3.871171957	Density/Mass Flow Rate
Time in Vessel, (hr)	-	Reaction Time
(day)		hr/24
Reaction Rate Constant, (kg/mol/s)		From Literature 95% Confidence
Volume, (m^3)	24	Levenspiel Plot
Diameter, (m)	2.2	
L/D	3	Heuristic
Pressure, (psia)	145	Pressure of Vessel-Literature
Design Pressure, (psia)	195	
(barg)	12.43	
Duty, (J/s)	0	Adiabatic
Cost Correlation- Jacketed/Batch Reactor (Ajitated)		
Purchase Cost, Cp	693474.0042	Cpo*Fp*Fm
Installed Cost, CBM	1438059.271	Cpo*FBM
Equipment Purchase Cost, Cp0	68947.71679	
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	24	
Presure Factor, FP	3.244506158	
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	20.85724281	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	215708.8906	0.15*CBM
Fee, Cfee	43141.77812	0.03*CBM
2016 Costs		
Chemical Engineering Plant Cost Index in 2016	547	
Chemical Engineering Plant Cost Index in 2012	397	
Purchase Cost, Cp	955491.89	Cp*($CEPCI_{2016}$/$CEPCI_{2012}$)
Installed Cost, CBM	1981406.602	CBM*($CEPCI_{2016}$/$CEPCI_{2012}$)
Total Contengency	297210.9903	
Total Fees	59442.19806	
CTM	$ 2,338,059.79	CBM+Confengency+Fees

Reactor Sizing and Costing: Extruder		
Process Conditions and Specifications		
Inlet Conditions		
Nylon 6,6 Flow Rates, (kg/day)	105,631	
kg/s	1.223	
Temperature, C	280	
kW	51.352	
Type of Extruder	Twin Screw	Peters and Timmerhause
Pressure, (barg)		
Cp based on Flow	$ 130,000.00	Top Price
CBM	532303.36	
CTM		
Fees	15969.1008	
Contengency	79845.504	
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
CTM	$ 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	
CTM	$ 29,210.08	

Spinnerett		
Pressure, (barg)		
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 Tank (Pellets)		
Process Conditions 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)	43141.78	
Total Flow, (kg/day)	105631.10	
Sizing 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)	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, (m^3)	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- Jacketed/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	2.25	Vertical Process Vessel
B2 from Table A.4	1.85	Vertical Process Vessel
Contingency, Ccont	104237.4751	0.15*CBM
Fee, Cfee	20847.49502	0.03*CBM
2016 Costs		
Chemical Engineering Plant Cost Index in 2016	547	
Chemical Engineering Plant Cost Index in 2012	397	
Purchase Cost, Cp	413024.548	$Cp*(CEPCI_{2016}/CEPCI_{2012})$
Installed Cost, CBM	$ 957,479.41	$CBM*(CEPCI_{2016}/CEPCI_{2012})$
Total Contengency	$ 143,621.91	
Total Fees	$ 28,724.38	
CTM	$ 1,129,825.70	CBM+Confengency+Fees

Pump 1: Evaporator to CSTR 2		
Design Specs		
Pressure Change, (barg)	2.43	
Flowrate, (lb/day)	105884	
Inlet flowrate, (lb/hr)	9726	
Hydraulic Power, hp	13.8	
Shaft Power, Brake hp	21.2	
Pump Efficiency	0.65	Set by Design Group
Purchased Power, hp	24.2	
Motor Efficiency	0.876	
Actual Purchase Power, hp	25	Set by Design Group
Actual Purchase Power, kW	18.64	
Pump pressure, barg	2.4	
Pump Type	Centrifugal	Set by Design Group
Pump Material	Carbon Steel	Set by Design Group
Cost Correlation- Pump		
Purchase Cost, Cp	7614.673536	
Installed Cost, CBM	21913.65356	
Equipment 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	
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	3287.048034	
Fee, Cfee	657.4096067	
2016 Costs		
Chemical Engineering Plant Cost Index in 2016	547	
Chemical Engineering Plant Cost Index in 2012	397	
Purchase Cost, Cp	$ 10,492	
Installed Cost, CBM	$ 30,193	
Total Contingency, Ccont	$ 4,529	
Total Fees, Cfee	$ 906	
Total Module Capital, CTM	$ 35,628	

Pump 2: Condenser to Flash Tank		
Design Specs		
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	
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	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	3.3892	
K2 from Table A.1	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	38	
Bare Module Factor, FBM	4.32	
B1 from Table A.4	1.89	
B2 from Table A.4	1.35	
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	
Purchase Cost, Cp	$ 5,126	
Installed Cost, CBM	$ 14,751	
Total Contingency, Ccont	$ 2,213	
Total Fees, Cfee	$ 443	
Total Module Capital, CTM	$ 17,406	

Pump 3: Flash to Storage Tank		
Design Specs		
Pressure Change, (barg)	0.165	
Flowrate, (lb/day)	8756	
Inlet flowrate, (lb/hr)	365	
Hydraulic Power, hp	0.0351	
Shaft Power, Brake hp	0.0540	
Pump Efficiency	0.65	Set by Design Group
Purchased Power, hp	0.0931	
Motor Efficiency	0.5801	
Actual Purchase Power, hp	0.5	Set by Design Group
Actual Purchase Power, kW	0.37	
Pump pressure, barg	0.165	
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	3.3892	
K2 from Table A.1	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	38	
Bare Module Factor, FBM	4.32	
B1 from Table A.4	1.89	
B2 from Table A.4	1.35	
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	
Purchase Cost, Cp	$ 5,126	
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		
Pressure Change, (barg)	17.570	Based on Extruder Pressure
Flowrate, (lb/day)	105631	
Inlet flowrate, (lb/hr)	4401	
Hydraulic Power, hp	45.0908	
Shaft Power, Brake hp	69.3705	
Pump Efficiency	0.65	Set by Design Group
Purchased Power, hp	76.1572	
Motor Efficiency	0.9109	
Actual Purchase Power, hp	15	Set by Design Group
Actual Purchase Power, kW	11.19	
Pump pressure, barg	17.570	
Pump Type	Centrifugal	Set by Design Group
Pump Material	Carbon Steel	Set by Design Group
Cost Correlation- Pump		
Purchase Cost, Cp	7694.565523	
Installed Cost, CBM	22143.56825	
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	1.25	
C1 from Table A.2	-0.39350	
C2 from Table A.2	0.39570	10<Pressure<100
C3 from Table A.3	-0.00226	
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	3321.535237	
Fee, Cfee	664.3070475	
2016 Costs		
Chemical Engineering Plant Cost Index in 2016	547	
Chemical Engineering Plant Cost Index in 2012	397	
Purchase Cost, Cp	$ 10,602	
Installed Cost, CBM	$ 30,510	
Total Contingency, Ccont	$ 4,577	
Total Fees, Cfee	$ 915	
Total Module Capital, CTM	$ 36,002	

Pump 5: Evaporator Pump		
Design Specs		
Pressure Change, (barg)	2.43	
Flowrate, (lb/day)	139265	From HYSYS
Inlet flowrate, (lb/hr)	5803	From HYSYS
Hydraulic Power, hp	8.2	
Shaft Power, hp	12.6	
Pump Efficiency	0.65	Set by Design Group
Purchased/Break Power, hp	14.7	
Motor Efficiency	0.859	
Actual Purchase Power, hp	30	Set by Design Group
Actual Purchase Power, kW	22.37	
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	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	

Utilities (Pelletized)			
Service Factor			
Service Factor		0.95	
Days/yr		365	
Hours/ day		24	
Operation Hours/yr		8322	
Pump Electricity			
Total kW		153.95	
Total kW-hr		1281169.403	
Pice per kW-hr	$	0.0545	Calvert City, KS
Total Price/yr	$	69,823.73	
Reactor Electricity (stiring)			
Total kW		108.69	
Total kW-hr		904541.8547	
Pice per kW-hr	$	0.0545	Calvert City, KS
Total Price/yr	$	49,297.53	
Reactor Heating (Steam Jacket)			
Duty (J/s)		1291116458	
(Btu/h)		4405289355	
Flow Rate, (lb/h)		4738398.79	
1000 lb		4738.39879	
Cost/1000 lb		4.75	
Cost	$	22,507.39	
Cooling Water			
Condenser 1			
Price/1000 gal	$	120.00	Phillips
Inlet CW Flow,			
Flow Rate, lb/hr		1228099.042	
gpm		2465.591757	
Total Price/yr	$	295,871.01	
Density of Water,		1	
Heat Flow, Btu/hr		40527268	
Specific Heat (Water), Btu/lbF		1	
CW out Temp, C		120.0	
CW in Temp, C		87.00	
Temp Difference		33.0	
Hot Oil			
Volume, gal		110.00	
Cost	$	4,079.90	DME

Utilities (Spun)			
Service Factor			
Service Factor		0.95	
Days/yr		365	
Hours/ day		24	
Operation Hours/yr		8322	
Pump Electricity			
Total kW		153.95	
Total kW-hr		1281169.403	
Pice per kW-hr	$	0.0545	Calvert City, KS
Total Price/yr	$	69,823.73	
Reactor Electricity (stiring)			
Total kW		158.35	
Total kW-hr		1317754.121	
Pice per kW-hr	$	0.0545	Calvert City, KS
Total Price/yr	$	71,817.60	
Reactor Heating (Steam Jacket)			
Duty (J/s)		1291116458	
(Btu/h)		4405289355	
Flow Rate, (lb/h)		4738398.79	
1000 lb		4738.39879	
Cost/1000 lb		4.75	
Cost	$	22,507.39	
Cooling Water			
Condenser 1			
Price/1000 gal	$	120.00	Phillips
Inlet CW Flow,			
Flow Rate, lb/hr		1228099.042	
gpm		2465.591757	
Total Price/yr	$	295,871.01	
Density of Water,		1	
Heat Flow, Btu/hr		40527268	
Specific Heat (Water), Btu/lbF		1	
CW out Temp, C		120.0	
CW in Temp, C		87.00	
Temp Difference		33.0	
Hot Oil			
Volume, gal		110.00	
Cost	$	4,079.90	DME

67% Capacity Production Process

Reactor Sizing and Costing: Jacketed/CSTR 1 (Ajitated)		
Process Conditions and Specifications		
Inlet Conditions		
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	
Outlet Conditions		
Mass Flow HMDA, (kg/day)	-	
Mass Flow Adipic Acid, (kg/day)	-	
Mass Flow Water, (kg/day)	5633.58	
Mass Flow Nylon Salt, (kg/day)	82039.83	
Mass Flow Nylon 6,6, (kg/day)	-	
Temperature, C	255	
Sizing of Equipment		
Total Mass Flow Out, (kg/day)	87673.41	
X_{ADA}	0.52	Mass Balance
X_{HMDA}	0.41	Mass Balance
X_{H2O}	0.06	Mass Balance
Density ADA, (kg/m^3)	1359.998997	Literature
Density HMDA, (kg/m^3)	840052384	Literature
Density Water, (kg/m^3)	999.997995	Literature
Density, (kg/m^3)	344422245	
Total Flow Rate, (kg/hr)	3653.074167	
(m^3/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- Jacketed/Batch Reactor (Ajitated)		
Purchase Cost, Cp	171753.0126	Cpo*Fp*Fm
Installed Cost, CBM	379070.5887	Cpo*FBM
Equipment Purchase Cost, Cp0	27256.6735	
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	4.18	
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*CBM
Fee, Cfee	11372.11766	0.03*CBM
2016 Costs		
Chemical Engineering Plant Cost Index in 2017	547	
Chemical Engineering Plant Cost Index in 2012	397	
Purchase Cost, Cp	236647.098	Cp*($CEPCI_{2016}$/$CEPCI_{2012}$)
Installed Cost, CBM	522296.252	CBM*($CEPCI_{2016}$/$CEPCI_{2012}$)
Total Contengency	78344.4378	
Total Fees	15668.88756	
CTM	$ 616,309.58	CBM+Confengency+Fees

Reactor Sizing and Costing: Evaporator		
Process Conditions and Specifications		
Inlet Conditions		
Mass Flow HMDA, (kg/day)	-	
Mass Flow Adipic Acid, (kg/day)	-	
Mass Flow Water, (kg/day)	5633.58	
Mass Flow Nylon Salt, (kg/day)	82039.83	
Mass Flow Nylon 6,6, (kg/day)	-	
Temperature, C	250	338.5C= BP at 1 atm
Pressure, (barg)	10.00	
Total Flow, (kg/day)	87673.41	
Outlet Conditions		
Mass Flow HMDA, (kg/day)	-	
Mass Flow Adipic Acid, (kg/day)	-	
Mass Flow Water, (kg/day)	16732	
Mass Flow Nylon Salt, (kg/day)	70942.43	
Mass Flow Diamine, (kg/day)	5866.67	
Temperature, C	280	338.5C= BP at 1 atm
F	536	
Pressure, (barg)	10.000	
Temperature of Hot Oil, F	599.000	Low Pressure Steam
C	315.000	
Total Flow, (kg/day)	93541	
Sizing of Equipment		
Volume, (ft^3)	859.402225	
m3	24.33553803	2013.56
Diameter, (ft)	7.144882854	
m	2.177760294	
Heat Flow (Qo), Btu/hr	1,391,998.55	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)	40.0940665	
m2	3.7248591	
Cost Correlation- Evaporator		
Purchase Cost, Cp	255855.7939	Cpo*Fp*Fm
Installed Cost, CBM	$ 651,252.12	Cpo*FBM
Equipment Purchase Cost, Cp0	$ 82,553.13	22162.75357
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	
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	1.82	Vertical Process Vessel
Contingency, Ccont	97687.81823	0.15*CBM
Fee, Cfee	19537.56365	0.03*CBM
2016 Costs		
Chemical Engineering Plant Cost Index in 2016	547	
Chemical Engineering Plant Cost Index in 2012	397	
Purchase Cost, Cp	410961.6392	Cp*($CEPCI_{2016}$/$CEPCI_{2012}$)
Installed Cost, CBM	$ 1,046,056.59	CBM*($CEPCI_{2016}$/$CEPCI_{2012}$)
Total Contengency	$ 156,908.49	
Total Fees	$ 31,381.70	
CTM	$ 1,234,346.78	CBM+Confengency+Fees

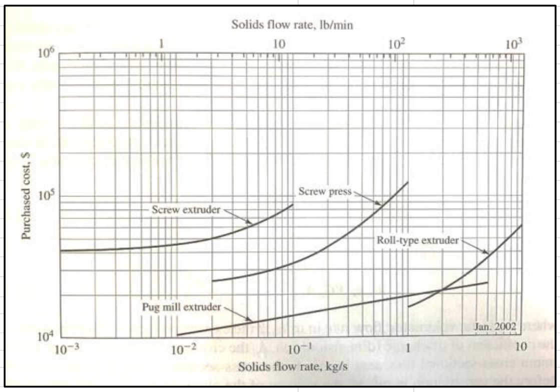
Reactor Sizing and Costing: Flash Drum		
Process Conditions and Specifications		
Inlet Conditions		
Mass Flow HMDA, (kg/day)	-	
Mass Flow Adipic Acid, (kg/day)	-	
Mass Flow Water, (kg/day)	16732	
Mass Flow Nylon Salt, (kg/day)	-	
Mass Flow Nylon 6,6, (kg/day)	-	
Mas Flow Diamine, (kg/day)	5866.67	342C= BP at 20 psia
Temperature, C	109	
Pressure, (barg)	3.812	55.3
Total Flow, (kg/day)	22598.41	
Outlet Conditions		
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 Equipment		
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/m^3)	0.0407	
(ft^3/day)	2.257028728	Density/Mass Flow Rate
(m^3/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- 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	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
B2 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	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 Tank (Diamine)		
Process Conditions 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)	-	
Mas Flow Diamine, (kg/day)	5866.67	
Temperature, C	255	338.5C= BP at 1 atm
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	
(m^3/day)	10.42905264	Density/Mass Flow Rate
(m^3/week)	73.00336849	
Time in Vessel, (hr)	168	Store for a Week
(day)	7	hr/24
Reaction Rate, ()		
Volume, (m^3)	73.00336849	
Diameter, (m)	3.1	
L/D	3	Heuristic
Orientation		Vertical
Pressure, (psia)	145	Pressure of Vessel-Literature
Design Pressure, (psia)	195	
(barg)	12.43	
Cost Correlation- Jacketed/Batch Reactor (Ajitated)		
Purchase Cost, Cp	227484.6077	Cpo*Fp*Fm
Installed Cost, CBM	535184.2713	Cpo*FBM
Equipment Purchase Cost, Cp0	50816.7765	
K1 from Table A.1	3.4974	Volume Min: 0.1 m^3 Max: 35 m^3
K2 from Table A.1	0.4485	Volume Min: 0.1 m^3 Max: 35 m^3
K3 from Table A.1	0.1074	Volume Min: 0.1 m^3 Max: 35 m^3
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*CBM
Fee, Cfee	16055.52814	0.03*CBM
2016 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	110609.243	
Total Fees	22121.8486	
CTM	$ 870,126.04	CBM+Confengency+Fees

Reactor Sizing and Costing: Condenser from Evaporator		
Process Conditions and Specifications		
Shell Side Information		
Inlet Conditions		
Inlet Process Temp, C	280	536
Pressure, psia	159.7	
Pressure, (barg)	10.00	
Outlet Conditions		
Outlet Process Temp, C	109	228.2
Pressure, psia	70.0	
Shell Side Design Pressure, barg	3.8	
Tube Side Information		
Inlet Conditions		
Inlet Cooling WaterTemp, F	87	
Inlet Cooling WaterTemp, C	30.56	
Outlet Conditions		
Outlet Steam Temp, F	120.0	
Outlet Steam Temp, C	48.9	
Design Specs		
Equipment Description		
Equipment Type	HEX	
Equipment Description	Tubular	
Tube Material	Stainless	
Shell Material	Stainless	
Tube Side	Cooling Water	
Shell Side	Process	
HEX TEMA Type	AES	
Equipment Description	Floating Head	
HEX Calculations		
Density of Cooling Water, (lb/m^3)	2195.1	.652/.688btu/lbF
Mass Flow Input Process Stream, (lb/day)	206222.4201	
Cp Steam, (btu/lbF)	1	Engineering Toolbox
Cp Diamine, (btu/lbF)	1.20237E-06	JCT Document
$X_{Diamine}$	0.23	Mass Balance Entering
X_{H2O}	0.77	Mass Balance Entering
Total Cp, (btu/lbF)	0.770000277	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), $Btu/hrft^2F$	1200.0	
$Btu/dayft^2F$	28800.0	
$Btu/daym^2F$	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	
Cost Correlation- HEX		
Purchase Cost, Cp	51275.77263	
Installed Cost, CBM	$ 137,495	
Equipment Purchase Cost, Cp0	$ 18,949	
K1 from Table A.1	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	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	20624.28916	0.15*CBM
Fee, Cfee	4124.857833	0.03*CBM
2016 Costs		
Chemical Engineering Plant Cost Index in 2016	547	
Chemical Engineering Plant Cost Index in 2012	397	
Purchase Cost, Cp	$ 70,649.49	$Cp*(CEPCI_{2016}/CEPCI_{2012})$
Installed Cost, CBM	189445.6116	$CBM*(CEPCI_{2016}/CEPCI_{2012})$
Total Contengency	28416.84174	
Total Fees	5683.368349	
CTM	$ 223,545.82	CBM+Confengency+Fees

Reactor Sizing and Costing: Jacketed/CSTR 2 (Ajitated)		
Process Conditions 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)	70942.43	
Mass Flow Nylon 6,6, (kg/day)	-	
Temperature, C	280	
Outlet 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	280	
Sizing of Equipment		
Total Mass Flow Out, (kg/hr)	2955.910417	
$X_{Nylon\ 66}$	0.99762	Mass Balance
X_{H2O}	0.00238	Mass Balance
Density Nylon 66, (kg/m3)	1139.999166	Literature
Density Water, (kg/m3)	999.997995	Literature
Density, (kg/m3)	1140	
Total Flow Rate, (kg/hr)	2955.934583	
(m^3/day)	2.593685061	Density/Mass Flow Rate
Time in Vessel, (hr)	-	Reaction Time
(day)		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	Adiabatic
Cost Correlation- Jacketed/Batch Reactor (Ajitated)		
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*CBM
Fee, Cfee	18726.60781	0.03*CBM
2016 Costs		
Chemical Engineering Plant Cost Index in 2016	547	
Chemical Engineering Plant Cost Index in 2012	397	
Purchase Cost, Cp	399883.4697	$Cp*(CEPCI_{2016}/CEPCI_{2012})$
Installed Cost, CBM	860071.744	$CBM*(CEPCI_{2016}/CEPCI_{2012})$
Total Contengency	129010.7616	
Total Fees	25802.15232	
CTM	$ 1,014,884.66	CBM+Confengency+Fees

Reactor Sizing and Costing: Extruder		
Process Conditions and Specifications		
Inlet Conditions		
Nylon 6,6 Flow Rates, (kg/day)	70,773	
kg/s	0.819	
Temperature, C	280	
kW	51.352	
Type of Extruder	Twin Screw	Peters and Timmerhause
Pressure, (barg)		
Cp based on Flow	$ 130,000.00	Top Price
CBM	532303.36	
CTM		
Fees	15969.1008	
Contengency	79845.504	
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
CTM	$ 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	
CTM	$ 29,210.08	

Spinnerett		
Pressure, (barg)		
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 Tank (Pellets)		
Process Conditions 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	
Mas Flow Diamine, (kg/day)	0.00	
Temperature, C	290	338.5C= BP at 1 atm
Pressure, (barg)	18726.61	
Total Flow, (kg/day)	105631.00	
Sizing of Equipment		
$X_{Diamine}$	0.23	Mass Balance
Density Nylon 6,6, (kg/m^3)	1140.000	Literature
Total Flow Rate, (kg/day)	105631.00	
(m^3/day)	92.65877193	Density/Mass Flow Rate
(m^3/week)	92.65877193	
Time in Vessel, (hr)	168	Store for a Week
(day)	7	hr/24
Reaction Rate, ()		
Volume, (m^3)	92.65877193	
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- Jacketed/Batch Reactor (Ajitated)		
Purchase Cost, Cp	299763.3711	Cpo*Fp*Fm
Installed Cost, CBM	694915.7708	Cpo*FBM
Equipment Purchase Cost, Cp0	62379.34855	
K1 from Table A.1	3.4974	
K2 from Table A.1	0.4485	
K3 from Table A.1	0.1074	
Volume,m3	92.65877193	
Presure Factor, FP	4.805490569	
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	11.14015755	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, Ccont	104237.3656	0.15*CBM
Fee, Cfee	20847.47312	0.03*CBM
2016 Costs		
Chemical Engineering Plant Cost Index in 2016	547	
Chemical Engineering Plant Cost Index in 2012	397	
Purchase Cost, Cp	413024.0907	Cp*($CEPCI_{2016}$/$CEPCI_{2012}$)
Installed Cost, CBM	$ 957,478.40	CBM*($CEPCI_{2016}$/$CEPCI_{2012}$)
Total Contengency	$ 143,621.76	
Total Fees	$ 28,724.35	
CTM	$ 1,129,824.52	CBM+Confengency+Fees

Pump 1: Evaporator to CSTR 2		
Design Specs		
Pressure Change, (barg)	2.43	
Flowrate, (lb/day)	70942	
Inlet flowrate, (lb/hr)	9726	
Hydraulic Power, hp	13.8	
Shaft Power, Brake hp	21.2	
Pump Efficiency	0.65	Set by Design Group
Purchased Power, hp	24.2	
Motor Efficiency	0.876	
Actual Purchase Power, hp	25	Set by Design Group
Actual Purchase Power, kW	18.64	
Pump pressure, barg	2.4	
Pump Type	Centrifugal	Set by Design Group
Pump Material	Carbon Steel	Set by Design Group
Cost Correlation- Pump		
Purchase Cost, Cp	7614.673536	
Installed Cost, CBM	21913.65356	
Equipment 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	
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	3287.048034	
Fee, Cfee	657.4096067	
2016 Costs		
Chemical Engineering Plant Cost Index in 2016	547	
Chemical Engineering Plant Cost Index in 2012	397	
Purchase Cost, Cp	$ 10,492	
Installed Cost, CBM	$ 30,193	
Total Contingency, Ccont	$ 4,529	
Total Fees, Cfee	$ 906	
Total Module Capital, CTM	$ 35,628	

Pump 2: Condenser to Flash Tank		
Design Specs		
Pressure Change, (barg)	0.20	
Flowrate, (lb/day)	22598	
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	0.6522	
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	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	3.3892	
K2 from Table A.1	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	38	
Bare Module Factor, FBM	4.32	
B1 from Table A.4	1.89	
B2 from Table A.4	1.35	
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	
Purchase Cost, Cp	$ 5,126	
Installed Cost, CBM	$ 14,751	
Total Contingency, Ccont	$ 2,213	
Total Fees, Cfee	$ 443	
Total Module Capital, CTM	$ 17,406	

Pump 3: Flash to Storage Tank		
Design Specs		
Pressure Change, (barg)	0.165	
Flowrate, (lb/day)	8756	
Inlet flowrate, (lb/hr)	365	
Hydraulic Power, hp	0.0351	
Shaft Power, Brake hp	0.0540	
Pump Efficiency	0.65	Set by Design Group
Purchased Power, hp	0.0931	
Motor Efficiency	0.5801	
Actual Purchase Power, hp	0.5	Set by Design Group
Actual Purchase Power, kW	0.37	
Pump pressure, barg	0.165	
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	3.3892	
K2 from Table A.1	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	38	
Bare Module Factor, FBM	4.32	
B1 from Table A.4	1.89	
B2 from Table A.4	1.35	
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	
Purchase Cost, Cp	$ 5,126	
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		
Pressure Change, (barg)	17.570	Based on Extruder Pressure
Flowrate, (lb/day)	70773	
Inlet flowrate, (lb/hr)	2949	
Hydraulic Power, hp	30.2109	
Shaft Power, Brake hp	46.4782	
Pump Efficiency	0.65	Set by Design Group
Purchased Power, hp	51.6403	
Motor Efficiency	0.9000	
Actual Purchase Power, hp	55	Set by Design Group
Actual Purchase Power, kW	41.01	
Pump pressure, barg	17.570	
Pump Type	Centrifugal	Set by Design Group
Pump Material	Carbon Steel	Set by Design Group
Cost Correlation- Pump		
Purchase Cost, Cp	16759.20905	
Installed Cost, CBM	48229.97325	
Equipment Purchase Cost, Cp0	8966.188094	
K1 from Table A.1	3.3892	
K2 from Table A.1	0.0536	
K3 from Table A.1	0.1538	
Shaft Power, KW	55.9	
Presure Factor, FP	1.25	
C1 from Table A.2	-0.39350	
C2 from Table A.2	0.39570	10<Pressure<100
C3 from Table A.3	-0.00226	
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	7234.495987	
Fee, Cfee	1446.899197	
2016 Costs		
Chemical Engineering Plant Cost Index in 2016	547	
Chemical Engineering Plant Cost Index in 2012	397	
Purchase Cost, Cp	$ 23,091	
Installed Cost, CBM	$ 66,453	
Total Contingency, Ccont	$ 9,968	
Total Fees, Cfee	$ 1,994	
Total Module Capital, CTM	$ 78,414	

Pump 5: Evaporator 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	

Utilities (Pelletized)		
Service Factor		
Service Factor	0.95	
Days/yr	365	
Hours/ day	24	
Operation Hours/yr	8322	
Pump Electricity		
Total kW	168.86	
Total kW-hr	1405283.711	
Pice per kW-hr	$ 0.0545	Calvert City, KS
Total Price/yr	$ 76,587.96	
Reactor Electricity (stiring)		
Total kW	63.64	
Total kW-hr	529570.47	
Pice per kW-hr	$ 0.0545	Calvert City, KS
Total Price/yr	$ 28,861.59	
Reactor Heating (Steam Jacket)		
Duty (J/s)	1291116458	
(Btu/h)	4405289355	
Flow Rate, (lb/h)	4738398.79	
1000 lb	4738.39879	
Cost/1000 lb	4.75	
Cost	$ 22,507.39	
Cooling Water		
Condenser 1		
Price/1000 gal	$ 120.00	Phillips
Inlet CW Flow,		
Flow Rate, lb/hr	822827.7519	
gpm	1651.949275	
Total Price/yr	$ 198,233.91	
Density of Water,	1	
Heat Flow, Btu/hr	27153316	
Specific Heat (Water), Btu/lbF	1	
CW out Temp, C	120.0	
CW in Temp, C	87.00	
Temp Difference	33.0	
Hot Oil		
Volume, gal	110.00	
Cost	$ 4,079.90	DME

Utilities (Spun)		
Service Factor		
Service Factor	0.95	
Days/yr	365	
Hours/ day	24	
Operation Hours/yr	8322	
Pump Electricity		
Total kW	168.86	
Total kW-hr	1405283.711	
Pice per kW-hr	$ 0.0545	Calvert City, KS
Total Price/yr	$ 76,587.96	
Reactor Electricity (stiring)		
Total kW	113.29	
Total kW-hr	942782.736	
Pice per kW-hr	$ 0.0545	Calvert City, KS
Total Price/yr	$ 51,381.66	
Reactor Heating (Steam Jacket)		
Duty (J/s)	1291116458	
(Btu/h)	4405289355	
Flow Rate, (lb/h)	4738398.79	
1000 lb	4738.39879	
Cost/1000 lb	4.75	
Cost	$ 22,507.39	
Cooling Water		
Condenser 1		
Price/1000 gal	$ 120.00	Phillips
Inlet CW Flow,		
Flow Rate, lb/hr	822827.7519	
gpm	1651.949275	
Total Price/yr	$ 198,233.91	
Density of Water,	1	
Heat Flow, Btu/hr	27153316	
Specific Heat (Water), Btu/lbF	1	
CW out Temp, C	120.0	
CW in Temp, C	87.00	
Temp Difference	33.0	
Hot Oil		
Volume, gal	110.00	
Cost	$ 4,079.90	DME

Optimized Continuous Process, T=260											
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		(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 ($P/F_{i,n}$)	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, T = 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 (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		(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 ($P/F_{i,n}$)	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

Continuous Process, Pellet											
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		(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 ($P/F_{i,n}$)	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	(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

Oprimization 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 (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		(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 ($P/F_{i,n}$)	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	(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 ($P/F_{i,n}$)	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	(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

Storage Tank (Diamine)		
Process Conditions 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)	-	
Mas Flow Diamine, (kg/day)	8756.22	
Temperature, C	110	338.5C= BP at 1 atm
Pressure, (barg)	3.80	
Total Flow, (kg/day)	8756.22	
Sizing of Equipment		
$X_{Diamine}$	0.23	Mass Balance
Density Diamine, (kg/m^3)	839.599	Literature
Total Flow Rate, (kg/day)	8756.22	
(m^3/day)	10.42905264	Density/Mass Flow Rate
(m^3/week)	73.00336849	
Time in Vessel, (hr)	168	Store for a Week
(day)	7	hr/24
Reaction Rate, ()		
Volume, (m^3)	73.00336849	Fixed roof
Diameter, (m)	3.1	
L/D	3	Heuristic
Orientation		Vertical
Pressure, (psia)	145	Pressure of Vessel-Literature
Design Pressure, (psia)	195	
(barg)	12.43	
Cost Correlation- Jacketed/Batch Reactor (Ajitated)		
Purchase Cost, Cp	227484.6077	Cpo*Fp*Fm
Installed Cost, CBM	535184.2713	Cpo*FBM
Equipment Purchase Cost, Cp0	50816.7765	
K1 from Table A.1	3.4974	Volume Min: 0.1 m^3 Max: 35 m^3
K2 from Table A.1	0.4485	Volume Min: 0.1 m^3 Max: 35 m^3
K3 from Table A.1	0.1074	Volume Min: 0.1 m^3 Max: 35 m^3
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*CBM
Fee, Cfee	16055.52814	0.03*CBM
2016 Costs		
Chemical Engineering Plant Cost Index in 2016	547	
Chemical Engineering Plant Cost Index in 2012	397	
Purchase Cost, Cp	$ 313,435.97	$Cp*(CEPCI_{2016}/CEPCI_{2012})$
Installed Cost, CBM	737394.9532	$CBM*(CEPCI_{2016}/CEPCI_{2012})$
Total Contengency	110609.243	
Total Fees	22121.8486	
CTM	$ 870,126.04	CBM+Confengency+Fees

Storage Tank (Pellets)		
Process Conditions 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	
Sizing 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)	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, (m^3)	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- Jacketed/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	2.25	Vertical Process Vessel
B2 from Table A.4	1.85	Vertical Process Vessel
Contingency, Ccont	104237.4751	0.15*CBM
Fee, Cfee	20847.49502	0.03*CBM
2016 Costs		
Chemical Engineering Plant Cost Index in 2016	547	
Chemical Engineering Plant Cost Index in 2012	397	
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	
Total Fees	$ 28,724.38	
CTM	$ 1,129,825.70	CBM+Confengency+Fees

Reactor Sizing and Costing: Flash Drum		
Process Conditions and Specifications		
Inlet Conditions		
Mass Flow HMDA, (kg/day)	-	
Mass Flow Adipic Acid, (kg/day)	-	
Mass Flow Water, (kg/day)	24973	
Mass Flow Nylon Salt, (kg/day)	-	
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 Conditions		
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 Equipment		
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/m^3)	0.0407	
(ft^3/day)	2.257028728	Density/Mass Flow Rate
(m^3/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- 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	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
B2 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	
CTM	$ 370,669.94	CBM+Confengency+Fees

Appendix E: MSDS

GPS Safety Summary | Contacts

Hexamethylenediamine

Chemical Identity

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

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.

Regulatory information and certifications

Classification and labelling

EU regulation (EC) 1272/2008 (CLP)

Acute toxicity, Oral, Cat. 4	H302 Harmful if swallowed
Acute toxicity, Dermal, Cat. 4	H312 Harmful in contact with skin
Skin Corrosion, Cat. 1B	H314 Causes severe skin burns and eye damage
STOT, single exposure, Cat. 3	H335 May cause respiratory irritation

Danger

Registration and certification

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

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 Oral/inhalation/dermal	Harmful if swallowed or in contact with skin. No reliable data available by inhalation. Moreover, since the substance is corrosive, no further tests are required.
Irritation / corrosion Skin/eye/respiratory tract	Causes severe skin burns and eye damage. 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 Oral/inhalation/dermal	May cause an irritation of the upper respiratory tract after repeated 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
Biodegradation	Readily biodegradable
Bioaccumulation potential	Not potentially bioaccumulative (Log Kow = 0.4)
PBT / vPvB conclusion	Not considered to be either PBT nor vPvB

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 on-site 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 under:	EU regulation (EC) 1907/2006 (REACH)
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	H302 Harmful if swallowed.
Acute toxicity, Dermal, Category 4	H312 Harmful in contact with skin.
Skin corrosion, Category 1B	H314 Causes severe skin burns and eye damage.
Specific target organ toxicity - single exposure, Category 3	H335 May cause respiratory irritation.

Labelling

Pictogram:

Signal word: Danger

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

ScienceLab.com
Chemicals & Laboratory Equipment

Health	2
Fire	1
Reactivity	0
Personal Protection	E

Material Safety Data Sheet
Adipic acid MSDS

Section 1: Chemical Product and Company Identification

Product Name: Adipic acid

Catalog Codes: SLA3658

CAS#: 124-04-9

RTECS: AU8400000

TSCA: TSCA 8(b) inventory: Adipic acid

CI#: Not available.

Synonym: Hexanedioic acid; 1,4-Butane Dicarboxylic Acid

Chemical Name: Adipic Acid

Chemical Formula: HOOC(CH2)4COOH

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

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, CO_2).

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.

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

EDINBURG PLASTICS, Inc.

Revision -1 on 10-02-07

Nylon-66 Thermoplastic Resin

Material Safety Data Sheet

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

Product Grades: DGAXXX, DTGXXX, DTTXXX, DGGXX, DOGXXX, DOAXXX, 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
Cornelius, NC 28031-7989 USA
Phone# (518) 438-7656 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	Mica	014808-60-7
<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, OSHA, or ACGIA as a carcinogen.

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.

For processing fume inhalation irritation, leave contaminated area and breathe fresh air. If coughing, difficult breathing or any other symptoms develop, seek medical attention at once, even if symptoms develop at a later time.

For skin contact with fume condensate, immediately wash thoroughly with soap and water. If irritation develops, seek medical attention.

FIRE FIGHTING MEASURES

Fire Fighting: Keep personnel removed and upwind of fire. Wear self-contained breathing apparatus.

Extinguishing Media: Water, Foam, Dry Chemical, CO_2

Hazardous Combustion Products: Hazardous gases/vapors produced in fire are: ammonia, carbon monoxide; small amounts of hydrogen cyanide and aldehydes.

Flash Point: >700°F (371°C)

ACCIDENTAL RELEASE MEASURES

General: Review FIRE FIGHTING MEASURES and HANDLING Sections.

HANDLING AND STORAGE

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.

EXPOSURE CONTROLS/PERSONAL 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.

PHYSICAL 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

STABILITY AND REACTIVITY

Stability: Stable

Polymerization: Polymerization will not occur

Conditions To Avoid: Expoxure to open flame or temperatures >570°F for pro-longed time.

Incompatabilities: Other Materials

Hazardous Decomposition: Hazardous gases or vapors can be released, including: hydrogen cyanide, carbon monoxide, ammonia.

ECOLOGICAL INFORMATION

AQUATIC TOXICITY: No information is available. Toxicity is expected to be low based on insolubility in water.

DISPOSAL INFORMATION

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.

TRANSPORTATION INFORMATION

DOT Hazard Class: Not Regulated
Proper Shipping Name: Not Regulated
Identification Number: Not Listed

REGULATORY INFORMATION

Federal Regulations

TSCA Status: In compliance with TSCA Inventory requirements for commercial purposes.

WHMIS Classification: Not a controlled product.

This product does not contain reportable quantities of substances subject to supplier notification.

State Regulations

Chemical Name	CAS number	State RTK
Polycaprolactam	025038-54-4	MA, NJ, PA
Titanium dioxide	013463-67-7	MA, NJ, PA

OTHER

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 with applicable hazard communication standards and regulations.

ScienceLab.com
Chemicals & Laboratory Equipment

Health	3
Fire	2
Reactivity	0
Personal Protection	J

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

CI#: Not available.

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

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, CO_2), nitrogen oxides (NO, NO_2...).

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.

Ionicity (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 more realistic range is −20 to +30%

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