MANUFACTURING FACILITY FOR NYLON 6,6

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Abstract

In the case of constructing a Nylon 6,6 manufacturing facility in Calvert City, Kentucky, a continuous process that produces pellets was chosen. This process proved to be safer and more economically attractive than batch processes or processes that produced fibers. This was done by simulating the process in Aspen Plus to determine required reactor volumes, heat duties, and the product composition.

The process was found to have a net present value of $61,500,000 and a discounted cash flow rate of return of 27%, greater than the assumed hurdle rate of 15%, and a payback period of 4.17 years. An initial capital investment of $37,000,000 is required, along with annual operating costs of $2,000,000.

Based on the preliminary design, it is suggested that this process should be continued onto the detailed design phase.

Introduction

The objective of this project was to complete an economic analysis on the construction of a grass roots plant to produce 85 million pounds per year (MM lb/yr) of Nylon 6, 6 in Calvert City, Kentucky. The economic analysis was based on the net present value (NPV) and discounted cash flow rate of return (DFROR) for the process. In addition to economics, safety and environmental factors were considered in the design of the process.

Nylon 6, 6 is produced from the step-growth polymerization of Adipic Acid and Hexamethylene diamine. This reaction occurs via the removal of water from a nylon salt that has a 1:1 ratio of Adipic Acid and Hexamethylene diamine. The polymerization can either occur continuously or in batches [1].

In 2011 2 million tons of Nylon 6, 6 were produced worldwide. Nylon 6, 6 can be produced as either fibers or pellets, each accounted for about 50% of the total amount produced. Nylon 6,6 is chosen because of its strength, heat and chemical resistance. The fibers are commonly used in the textile industry. Applications include: luggage, carpets, and airbags. Pellets can be used to make 3D structural objects via injection molding [2].

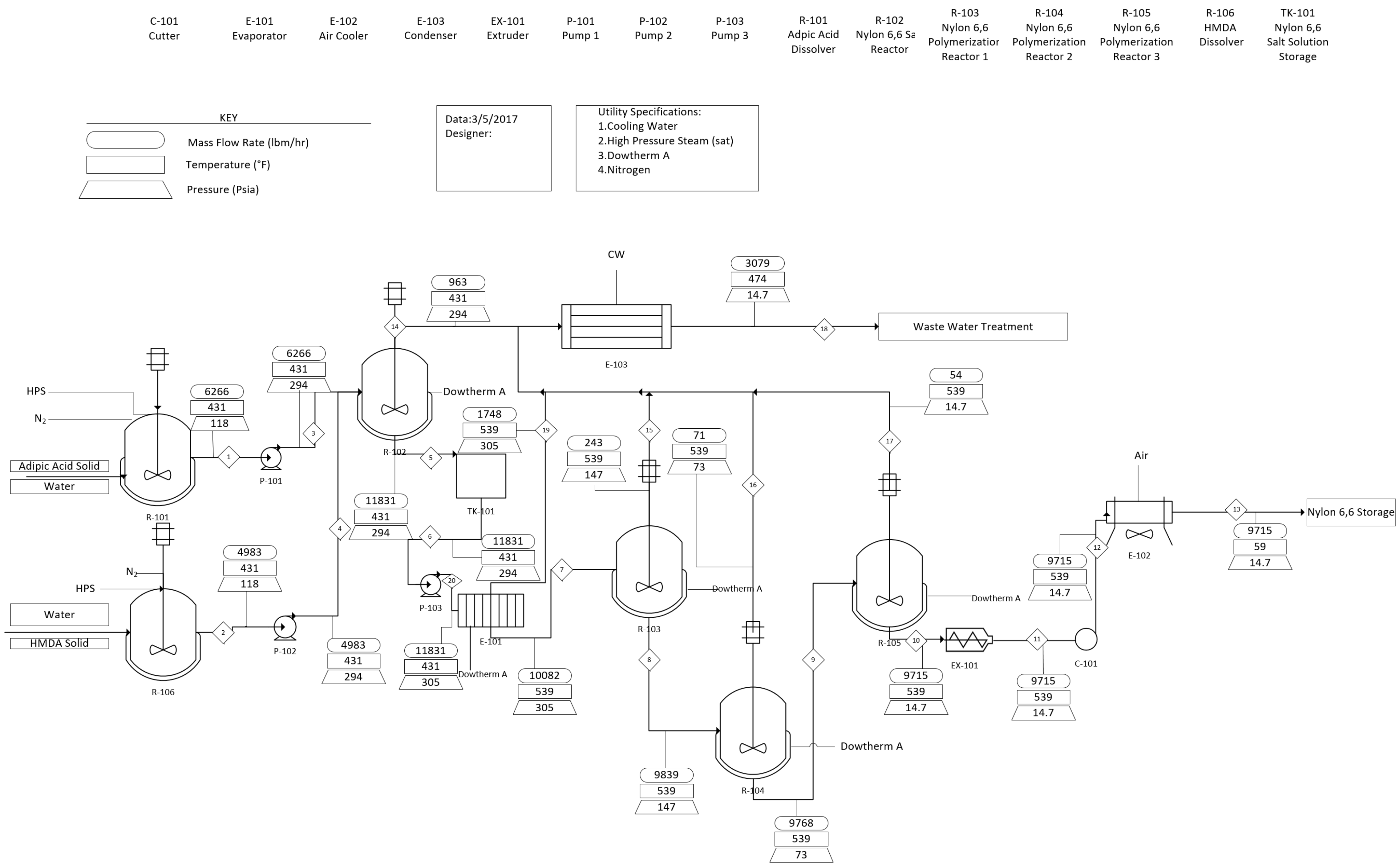

Figure 1: PFD for Nylon 6,6 Manufacturing Facility

Table 1: Stream Summary Table

Stream Number	1	2	3	4	5	6	7	8	9	10
Stream Label	ADA Feed Stream	HMDA Feed Stream	ADA Feed Stream After Pumping up to the Reactor	HMDA Feed Stream After Pumping up to the Reactor	Stream Coming Out of the Nylon 66 Salt Reactor	Stream Coming Out of the Nylon 66 Salt Storage Tank	Stream Coming Out of the Evaporator	Stream Coming out of the Polymerization Reactor 1	Stream Coming out of the Polymerization Reactor 2	Stream Coming out of R-105
Phase	Liquid	Liquid	Liquid	Liquid	Liquid	Liquid	Liquid	Liquid	Liquid	Liquid
Pressure (psia)	118	118	294	294	294	294	305	147	73	73
Temperature (°F)	431	431	431	431	431	431	539	539	539	539
Mass Flowrate (lbm/hr)	6266	4983	6266	4983	11831	11831	10082	9839	9768	9715
Molar Flowrate(lbmol/hr)	76	74	43	43	157	157	60	50	46	43
Component Molar Flowrate (lbmol/hr)										
Adipic Acid	38	0	38	0	1.22E-01	1.22E-01	1.18E-01	7.50E-03	3.64E-03	8.48E-04
HMDA	0	37	0	37	1.22E-01	1.22E-01	7.13E-02	6.11E-03	2.72E-03	4.36E-04
H2O	38	37	38	37	114	114	17.0	6.8	3.2	0.6
Nylon 66	0	0	0	0	37	37	37	37	37	37

Table 2: Stream Summary Table cont'd

Stream Number	11	12	13	14	15	16	17	18	19	20
Stream Label	Stream Coming out of the Extruder	Stream Coming out of the Cutter	Stream Coming out of the Air Cooler	Vapor Stream of CSTR 1	Vapor Stream of CSTR 2	Vapor Stream of CSTR 3	Vapor Stream of CSTR 4	Waste Water Treatment Stream	Vapor Stream Coming out of the Evaporator	Stream Leaving Pump 3
Phase	Liquid	Liquid	Solid	Vapor	Vapor	Vapor	Vapor	Liquid	Vapor	Liquid
Pressure (Pisa)	73	73	14.7	294	147	73	14.7	14.7	305	305
Temperature (°°F)	539	539	59	431	539	539	539	60	539	431
Mass Flowrate (lbm/hr)	9715	9715	9715	963	243	71	54	3079	1748	11831
Molar Flowrate(lbmol/hr)	43	43	43	53	13	4	3	171	97	157
Component Molar Flowrate (lbmol/hr)										
Adipic Acid	3.64E-03	3.64E-03	8.49E-04	9.93E-05	7.57E-05	2.14E-05	1.88E-05	4.17E-03	3.95E-03	1.22E-01
HMDA	2.72E-03	2.72E-03	4.88E-04	5.78E-03	9.52E-05	3.54E-04	2.16E-04	5.82E-02	5.05E-02	1.22E-01
H2O	3.2	3.2	0.6	53.4	13.5	3.9	3.0	170.5	96.7	114
Nylon 66	37	37	37	0	0	0	0	0	0	37

Process Description:

Aspen Plus using a Polymer template was used to simulate the process. A basic simulation example of Nylon 6,6 from Seavey and Liu's "Step-Growth Polymerization Process Modeling and Design" was used to start the design [3]. Figure 2 shows the BFD for the process outlying the steps where separation and major chemical reactions occur.

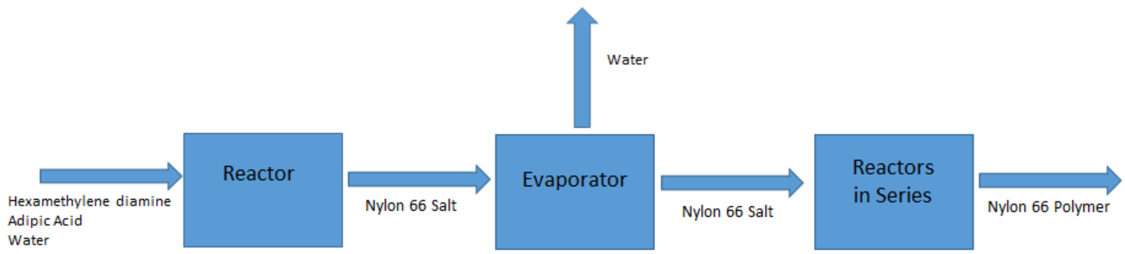

Figure 2: BFD for Nylon 6,6 Manufacturing Facility

$HOOC\text{-}(CH_2)_4\text{-}COOH + n\ H_2N\text{-}(CH_2)_6\text{-}NH2 \rightarrow [\text{-}OC\text{-}(CH_2)_4\text{-}CO\text{-}NH\text{-}(CH_2)_6\text{-}NH\text{-}]_n + 2H_2O$ (Reaction 1)

$$r_1 = 7 \cdot [NH_2][COOH] \cdot e^{\frac{-2.5\times10^6\ J/kmol}{RT}} \quad \text{(Equation 1)}$$

$$r_2 = 0.014 \cdot [H_2O] \cdot e^{\frac{-2.5\times10^6\ J/kmol}{RT}} \quad \text{(Equation 2)}$$

$\text{-}NH_2 + \text{-}COOH = \text{-}NH_3^+ + \text{-}COO\text{-}$ (Reaction 2)

$\text{-}NH_2 + \text{-}COOH = \text{-}CONH\text{-} + H_2O$ (Reaction 3)

$\text{-}COOH + H_20 = \text{-}COO\text{-} + H_30^+$ (Reaction 4)

$2H_20 = H_30^+ + OH^-$ (Reaction 5)

$\text{-}COOH + H_30^+ = \text{-}C\text{+}(OH)_2 + H_20$ (Reaction 6)

$\text{-}C\text{+}(OH)_2 + \text{-}NH_2 = \text{-}CONH\text{-} + H$ (Reaction 7)

The overall reaction for the first reactor in Figure 2 is a polycondensation reaction shown in Reaction 1 which uses equimolar Hexamethylene diamine (HMDA) and Adipic Acid (ADA) and reacts them with equimolar DI water [4], so the molar concentration is 25:25:50 ADA, HMDA and water respectively. These all react to form an aqueous solution of nylon salt and water. The reaction rates used from literature are shown as Equation 1 and 2. Equation 1 represents the forward polycondensation reaction while Equation 2 represents the reverse condensation reaction. Reactions 2-7 show the basic reactions taking place in this process [5]. An amine group from HMDA or electrophilic group reacts with the Carboxylic Acid group in ADA or nucleophilic group to create a segment of Nylon 6,6. The salt solution is then sent to an evaporator to remove most of the water before the solution is sent to the polymerization reactors so that a reverse condensation reaction does not slow down the polymerization reaction. Water is also removed as a vapor stream from all reactors to further reduce the water content. The Nylon 6,6 salt is then polymerized in the series of reactors in Figure 2 until sufficient polymerization of the salt solution has occurred.

The first decision towards designing the process was whether designing a continuous or batch process would be more profitable. A continuous process was chosen based on research that if the process is producing more than 1 MM lb/year, a continuous process should be used [6], and the process given runs at 85 MM lb/year [1]. A continuous process would also be inherently safer since the reaction isn't taking as long. There is also overall more innovative and up to date research on continuous processes. Another decision that needed to be made was whether to sell the final product as pellets or as a fiber. Pellets were chosen after looking at the selling price of pellets vs fiber and finding that pellets would sell for substantially more per pound, with little difference in the capital cost [7, 8]. Furthermore, Nylon 66 pellet market is predicted to grow in the coming years, as the Nylon 66 Fibre market is expected shrink [9]. The inlet flowrate was found by setting up the simulation in Aspen Plus and estimating flowrates for HMDA and ADA until the desired outlet flowrate was acquired.

The process for making Nylon 6,6 starts with preparation of the reactants. HMDA storage is shown on Figure 1 as R-106, which is an agitated jacketed continuous flow stirred tank reactor (CSTR). A reactor is used so that the solid crystal HMDA can be dissolved in equimolar water and heated with high pressure steam to 431°F so that it is ready for the first reactor. An inert Nitrogen gas blanket is used to protect the reactant from air and contaminants, as well as a release to reduce pressure without actually releasing the reactant. Nitrogen is an inert gas so there would be no concern with it reacting with the components. ADA is also stored in an agitated jacketed CSTR, R-101 on Figure 1. This is because ADA is has low solubility in water, so crystal ADA and water are added to the reactor where it is constantly stirred and heated by high pressure steam into an aqueous solution. R-101 also uses a Nitrogen blanket to protect the solution from air or other contaminants.

Both reactants are then pumped from their respective reactors to R-102 at a pressure of 294 psia and temperature of 431 °F [3]. The pressure was increased from the pressure given in the simulation example to remove more water from R-102 by vapor stream. A jacketed agitated CSTR was chosen to model this reactor because it needed to be constantly stirred for the reactants to mix and the reaction to proceed, as well as the need for Dowtherm A to keep the reactor at 431 °F for the reaction. Dowtherm A was used as a utility because 431 °F was higher than the temperature that high pressure steam could provide [4]. The HMDA and ADA react to form Nylon salt as a 32 mol% aqueous solution with water.

The salt solution leaving R-102 is then sent to E-101, which is an evaporator. The evaporator was modeled as a flash drum heated with Dowtherm A to separate the majority of the water as a vapor stream from the liquid nylon salt stream. Dowtherm A was used as a heating element instead of steam because of the high temperature the reaction needs to polymerize is greater than high pressure steam can provide [4]. The nylon salt stream is preheated to temperature of 539 °F and a pressure of 305 psia to reduce the possibility for the unreacted reactants to go out the vapor stream in the next reactor [4].

The next step is for the nylon salt stream to go to the polymerization reactors. Agitated CSTRs were chosen because the solution needs to be constantly stirred for optimum polymerization. It was decided to use three reactors in series because the volume for one was too large to be considered safe and three gave the minimum number of CSTRs in series without going too far over the maximum volume from heuristics [10]. Pressure was decreased from 147 psia in R-103 to 14.7 psia in R-105 to remove more water and bring the mass water composition in the product below the acceptable amount of 0.2% [11]. Temperature is held at the incoming stream's temperature of 539 °F for all three polymerization reactors because this is the temperature necessary for the polymerization reaction [3]. Water is removed from the reactors as overhead vapor streams that are sent to the condenser.

The stream from the third polymerization reactor R-105 is a molten polymer that is sent to the extruder, EX-101, where it is pushed through pellet sized holes and cut by a rotating blade, C-101, which both run off an electric pump. The pellets are then sent to an air-cooled dryer, E-102, which is powered by an electric fan. The pellets move through the condenser by electric conveyor belt until they are completely solidified and cooled to 59 °F and can be stored in a cool dry environment in closed tight containers to prevent moisture accumulation [12]. Too much moisture can degrade the final product.

The vapor streams from each reactor and evaporator are sent overhead to a condenser, E-103. The condenser is modeled as a shell and tube heat exchanger and uses cooling water to condense the incoming water vapor stream to a liquid at standard conditions of 60 °F and 14.7 psia before it is sent to the plant's waste water treatment facility.

Energy Balance and Utility Requirements

Table 3: Energy Balances

Equipment ID	Energy Requirement	Units	Demand	Source	Utility Mass Flowrate	Units
R-101	1.398E+05	Btu/hr	Raise temperature of water and adipic acid from 60°F to 431°F	HPS	1.921E+02	lbm/hr
R-102	3.420E+06	Btu/hr	Maintain Reactor Temperature of 431°F	Dowtherm A	2.541E+04	lbm/hr
R-103	2.447E+06	Btu/hr	Maintain Reactor Temperature of 539°F	Dowtherm A	1.818E+04	lbm/hr
R-104	5.650E+04	Btu/hr	Maintain Reactor Temperature of 539°F	Dowtherm A	4.198E+02	lbm/hr
R-105	4.554E+04	Btu/hr	Maintain Reactor Temperature of 539°F	Dowtherm A	3.384E+02	lbm/hr
R-106	1.398E+05	Btu/hr	Raise temperature of water and HMDA from 60°F to 431°F	HPS	1.921E+02	lbm/hr
P-101	2.983	kWh	Raise pressure of Stream 1 from 14.7 psia to 294 psia	Electricity	-	-
P-102	2.237	kWh	Raise pressure of Stream 2 from 14.7 psia to 294 psia	Electricity	-	-
P-103	0.3729	kWh	Raise pressure of Stream from 294 psia to 305 psia	Electricity	-	-
E-101	2.199E+06	Btu/hr	Remove water from stream 6 and raise temperature from 431°F to 539°F	Dowtherm A	1.634E+04	lbm/hr
E-102	3.832E+06	Btu/hr	Condense streams from reactors	Cooling Water	3.843E+06	lbm/hr
E-103	2.673E+06	Btu/hr	Lower temperatuer of stream 12 from 539°F to 59°F	Air	1.114E+07	lbm/hr

The energy balance table is shown in Table 3. The heat duties of each stream are obtained from Aspen Plus. The utilities that will be used in this process are cooling water, electricity, Dowtherm A, and high pressure steam. Cooling water is used to condense overhead vapors from the evaporator and polymerization reactors. The cooling water will be recycled through the cooling tower. The electricity demand for this process is mainly determined by the work required for pumps and air cooler. The power required will be purchased from Calvert City, Kentucky [13]. Dowtherm A is chosen to be the heat transfer fluid for the evaporator and reactors to reach the high-temperature heating requirement for this process. Dowtherm A is a mixture of 26.5 wt% diphenyl in diphenyl oxide [14]. It is thermally stable and easily recyclable throughout the process. High pressure steam is demanded for providing heat for the ADA and HMDA preparation. Steam is one of the most widely-used heat sources in chemical plants due to its high heat output per pound of utility at constant temperature.

Unit Descriptions – Primary Equipment

Condenser

E-103 is the condenser used on the vapors that come off the Nylon 6, 6 salt reactor, the evaporator and the three step-polymerization reactors. It is chosen as a fixed tube sheet to maximize countercurrent flow of the process fluid and the cooling water. The overall heat transfer coefficient was determined by having the process fluid, a heavy organic, on the shell side of the condenser and cooling water on the tube side. All tubes were said to be 3/4" outer diameter 14 BWG. Heat transfer coefficients and fouling factors were taken from the Handbook of Energy Systems Engineering [15].

The overall heat duty required to cool the product stream was taken from Aspen Plus and the final area of the condenser was obtained using Equation (3) below.

$$A = \frac{Q}{U_O LMTD} \quad \text{(Equation 3)}$$

Where:

- A is the heat transfer area, ft
- Q is the heat duty, Btu/hr
- U_O is the overall heat transfer coefficient, Btu/hr ft^2 °F
- LMTD is the log mean temperature difference, °F

Calculations for the dryer are shown in the appendix in Table 27 and a specification sheet is provided in Table 14 in the next section.

Cutter

The Cutter is used for separating the extruding pellets off of the extruder on the end of the product process for its final form before selling. The type of cutter will be Rotary type. There is no sizing necessary for cutters as the models are one size fits all, and models offer different setting speeds for different pellet and cut-off sizes. It will be considered to be an additional 5% of the total Extruder cost.

Dryer

E-102 is the dryer used to remove excess water from the molten nylon and bring it down to room temperature. The dryer was sized as a rotary, gas fired dryer because it can be operated continuously and remove the high moisture content of our product. The dryer was assumed to operate in a similar fashion to a heat exchanger. The overall heat transfer coefficient was estimated using the method for a shell and tube heat exchanger. The fluid said to be inside the tubes was molten nylon, estimated as a heavy organic, and air was said to be on the outside. Heat transfer coefficients and fouling factors were taken from the Handbook of Energy Systems Engineering [15].

The overall heat duty required to cool the product stream was taken from Aspen Plus and the final area of the dryer was obtained using Equation (3) above.

Calculations for the dryer are shown in the appendix in Table 28 and a specification sheet is provided in Table 13 in the next section.

Electric Drive Motor

The electric drive motor is an enclosed motor used for operating the extruder and cutter on the extrusion process. Each motor is sized correlating to the intake capacity size determined for the extruder. For the extruder design in this process, the intake capacity size of 55 L required a 75 kW motor [16].

Evaporator

E-101 is the evaporator used to remove water from the feed stream and raise its temperature before it enters the polymerization reactors. The evaporator chosen for the process is a short tube evaporator because it was the smallest evaporator that could provide the required heat transfer area. The evaporator was sized as a shell and tube heat exchanger that is in a vertical orientation. The overall heat transfer coefficient was calculated by condensing Dowtherm A, a light organic, on the shell side and vaporizing the water with some of the process fluid, a heavy organic, on the tube side. All tubes were said to be 3/4" outer diameter 14 BWG. Heat transfer coefficients and fouling factors were taken from the Handbook of Energy Systems Engineering [15].

The overall heat duty required to heat the stream and remove water was taken from Aspen Plus, and the final area of the evaporator was obtained using Equation (3) above.

Calculations for the evaporator are shown in the appendix in Table 29 and a specification sheet is provided in Table 12 in the next section.

Extruder

The Extruder in this process is part of the final stage of the product process as it forms the product into its final form as pellets. The extruder modeled in this process is a stainless steel Pelletizing Extruder, however, limited information on how to size them is available. Therefore, the sizing correlation was done using a Dispersion Kneader Extruder, which is very similar to a Pelletizing Extruder.

Sizing of the extruder is based on the capacity intake levels, as specified for extruders [17]. For sizing, a holdup time of 45 seconds was assumed. Taking into account the flowrate of the product, its density, and hold up time, the hold-up volume required can be determined, which can be sized up to capacity intake sizes that are pre-determined for extruders. In regards to the extruder vendor being considered, pre-determined sizing thresholds have been placed for extruders. These thresholds specify certain intake capacities for sizing the extruder. The intake capacity for the pre-determined extruder sizes has attached a bulk volume for the extruders [18]. The bulk volume, along with the MOC density and the cost rate for MOC, is plugged into the equation below to determine the cost of the unit [19]. When considering T (thickest wall section) and t (thinnest wall section) of the extruders, a 5:1 ratio is assumed.

$$\text{Cost} = M(1+0.1T/t) = 1.5M \qquad \text{(Equation 4)}$$

Where:

- M is the total cost of bulk volume of materials ($) [19, 20]
- T is the thickest wall section in the extruder
- t is the thinnest wall section in the extruder
- T:t is assumed to be 5:1

Pump

P-101 is the 2 stage centrifugal pump that raises the pressure of the stream coming from the ADA dissolver to the Nylon 6, 6 salt reactor. The pump was sized using two parameters: the pressure differential across the pump and the capacity of the pump. The pressure differential was used to determine the head the pump would have to provide, shown in Equation 5 below:

$$H = 2.31\left(\frac{\Delta P}{SG}\right) \quad \text{(Equation 5)}$$

Where:

- H is the head of the pump, ft
- ΔP is the pressure differential across the pump, psi
- SG is the specific gravity of the process fluid

Since the head of the pump exceeded the 500 ft limit heuristic provided in Turton et al. [10] a multistage pump was chosen instead of a single stage pump.

The capacity of the pump was used to determine the break horsepower of the pump, show in Equation 6 below.

$$BHP = \frac{QHSG}{3960\eta_{pump}} \quad \text{(Equation 6)}$$

Where:

- BHP is the break horsepower of the pump, hp
- Q is the capacity of the pump, gpm
- H is the head of the pump, ft
- SG is the specific gravity of the process fluid
- η_{pump} is the pump efficiency, %

The purchased horsepower is then determined by dividing the break horsepower by the pump efficiency. The motor is then selected from a list of standard motor sizes. The list of motor sizes and efficiencies are provided in pump handout provided by Dr. Ramsey [16].

P-102 is the single stage centrifugal pump that raises the pressure of the stream coming from the HMDA storage tank to the Nylon 6, 6 salt reactor. It is sized the same way as P-101 was sized above.

P-103 is the single stage centrifugal pump that raises the pressure of the stream coming from the Nylon 6,6 salt storage tank to the evaporator. It is sized the same way as P-101 was sized above.

Due to their relatively low costs and importance to keeping the process running, a spare pump would be purchased alongside each pump.

Calculations for the pumps are shown in Tables 30-32 in the appendix and specification sheets are shown in the next section in Tables 15-17.

Reactor

R-101 is the vessel that creates an ADA solution from solid ADA and DI water. It is a jacketed agitated vessel to ensure proper mixing during the dissolving process and to maintain the proper operating temperature. The volume of the vessel was chosen so that it could hold one day's worth of product.

R-106 is the vessel that creates a HMDA solution from solid HMDA and DI water. It is a jacketed agitated vessel to ensure proper mixing during the dissolving process and to maintain the proper operating temperature. The volume of the vessel was chosen so that it could hold one day's worth of product.

R-102 is the vessel that creates the nylon 6, 6 salt from ADA and HMDA. It is a jacketed agitated vessel to ensure proper mixing occurs during the reaction and to maintain the proper operating temperature. The volume of the vessel was determined using Aspen Plus and a residence time in the reactor of 20 minutes [21].

R-103, R-104, and R-105 are the vessels in which the step-growth polymerization of Nylon 6, 6 occurs. They are jacketed agitated vessels to ensure proper mixing occurs during the reaction and to maintain the proper operating temperature. The volume of the vessel was determined using Aspen Plus and a residence time of 20 minutes for each reactor [21].

Calculations for the reactors are shown in Tables 33-38 in the appendix and specification sheets are shown in the next section in Tables 5-10.

Tank

TK-101 is the intermediate storage tank for Nylon 6, 6 salt. The volume of the tank was chosen so that it could hold one day's worth or reactant at half full.

Calculations for the tank is shown in Table 38 in the appendix and the specification sheet is shown in the next section in Table 18.

The material of construction for all process equipment is stainless steel. Stainless steel was chose due to the corrosive nature of all of our reactants [10].

Unit Descriptions – Utilities

Cooling Tower

The Cooling Tower is the utility equipment that continuously reduces the temperature of the cooling water stream running through the process. The cooling tower for this process was modelled as an air cooled heat exchanger. To size the air cooler, the heat duty necessary to reduce the cooling water from 113 °F (45 °C) to 86 °F (30 °C) [10] was modelled, as shown in the equation below:

$$A = \frac{Q}{U_O LMTD} \qquad \text{(Equation 7)}$$

Where:

- A is the heat transfer area, ft
- Q is the heat duty, Btu/hr
- U_O is the overall heat transfer coefficient, Btu/hr ft^2 °F

- LMTD is the log mean temperature difference, °F

The MOC of the air cooler is stainless steel in order to prevent corrosion from water.

Nonreactive Heater

Dowtherm A is used for heating in the evaporator and all the reactors except the raw material mixers in the beginning of the process. In order to reheat the Dowtherm A for recycle, a nonreactive heater is used to reheat the Dowtherm A after each cycle. The heater is sized based on the heat duty that is required to reheat the Dowtherm A for reuse. For this process, a heuristic of 80% efficiency is considered for sizing the heater [10]. The equation for sizing can be seen below:

$$Q_{Heater-Size} = \frac{Q_{Dowtherm}}{E_0} \qquad \text{(Equation 8)}$$

Where:

- $Q_{Heater-Size}$ is the Heat Duty required for the heater, its sizing factor.
- $Q_{Dowtherm}$ is the Heat Duty required for the Dowtherm A to be reusable.
- E_0 is the efficiency of the process.

The MOC of the Nonreactive heater considered is Stainless Steel.

Steam Boiler

The Steam Boiler is used for reheating High Pressure Steam as it cycles through and heats the beginning dissolving reactors. The Steam Boiler is sized based off of the heat duty required to reheat the used steam flow back to High Pressure Steam physical qualifications. For this process, much like the Dowtherm A heater, an efficiency of 80% is considered for sizing. The equation for sizing can be seen below:

$$Q_{Boiler-Size} = \frac{Q_{HPS}}{E_0} \qquad \text{(Equation 9)}$$

Where:

- $Q_{Boiler-Size}$ is the Heat Duty required for the boiler, its sizing factor.
- Q_{HPS} is the Heat Duty required for the High Pressure Steam to be reusable.
- E_0 is the efficiency of the process.

The MOC of the Steam Boiler is Stainless Steel in order to deal with the fouling nature of steam.

Waste Water Treatment

After the process water used for dissolution of the raw materials is evaporated out of the nylon salt solution, it is run through waste water treatment, along with the cooling water used in the condenser. This is done in order to clean and reuse the water for this process. The Waste Water Treatment facility is needed to neutralize and clean out unreacted raw materials, as well as to deionize the water for reuse in dissolution of raw materials at the beginning of the process. The process for doing waste water treatment requires four stages: Primary Sludge Removal, Filtration, Chemical Neutralization (Secondary

Sludge Removal), and Deionization. Each stage requires a certain piece or pieces of equipment, along with pumps in between each stage [22, 23]

For the first stage, all process water is pumped into a fixed head tank. The tank has two stationary screens which remove sludge and unreacted materials as the process moves from one side of the tank to the other. At the other end of the tank, the water is pumped to the top of a gravity filter for the second stage of the process.

The second stage, gravity filtration, lets water filter through a vertical filter. This both filters out smaller materials as well as chemically treats the water and other reagents within it. At the bottom of the filter, the water is pumped to the second tank for the third stage of the process.

The third stage of the process requires chemically treating the remaining non-water reactants held in the stream. As they are treated, their physical composition changes in regard to density and phase, so that they can be collected in the stationary screen at this process. After running through the stationary screen the water is pumped to the top of the second gravity filter unit, the fourth stage of the process.

The fourth stage of the process involves only deionizing the process water through a gravity filtration system. The filter is colluded with solid ionic compounds in order to fully deionize the process water completely. At the end of the process, the deionized water is either sent back to the dissolving reactors or is sent to the cooling tower if it is to be used for heat transfer.

The entire treatment process requires four pumps, three stationary screens, two gravity filters, and two tanks. The pumps were sized, based on the requirements needed for the largest pump. The tanks were designed in consideration of a three minute hold time of the water in the system. The stationary screens were sized based off the diameter of the tank and its total height. The gravity filter units were sized in order to provide for a three minute gravity cycle with only a 7-ft height; the area was the variable in this case [10].

Table 4: Equipment List and Cost

Cutter	Cutter Type			MOC		Purchased Equipment Cost	Bare Module Cost	
C-101	Rotary			SS		$ 27,914	$ 32,938	
Extruder and motor	Extruder Type			MOC		Purchased Equipment Cost	Bare Module Cost	
EX-101	Pelletizing			SS		$ 581,602	$ 693,756	
Exchangers	Exchanger Type	Shell Pressure (barg)	Tube Pressure (barg)	MOC	Area (m^2)	Purchased Equipment Cost	Bare Module Cost	
E-101	Short Tube	23	2	SS	78	$ 239,094	$ 973,345	
E-102	Rotary, gas fired	1.01	1.01	SS	34	$ 162,459	$ 203,074	
E-103	Fixed Tube	7	3.45	SS	8	$ 58,535	$ 131,121	
Pumps	Pump Type	Power (kW)	# Spares	MOC	Discharge Presssure (barg)	Purchased Equipment Cost	Bare Module Cost	
P-101	2 Stage Centrifugal Pump	3	1	SS	33	$ 43,158	$ 84,323	
P-102	1 Stage Centrifugal Pump	2.23	1	SS	26	$ 24,722	$ 47,133	
P-103	1 Stage Centrifugal Pump	0.37	1	SS	0.758	$ 23,201	$ 44,094	
Reactors	Reactor Type	Design Pressure (barg)	Volume (m^3)	MOC	Height (m)	Diameter (m)	Purchased Equipment Cost	Bare Module Cost
R-101	Jacketed Agitated	11	48.5	SS	8.22	2.74	$ 1,500,180	$ 3,042,827
R-102	Jacketed Agitated	24	20.3	SS	6.15	2.05	$ 1,415,868	$ 2,770,267
R-103	Jacketed Agitated	14	77.2	SS	9.6	3.2	$ 2,653,089	$ 5,221,415
R-104	Jacketed Agitated	9	8.27	SS	4.56	1.52	$ 307,688	$ 680,087
R-105	Jacketed Agitated	4	25.4	SS	6.63	2.21	$ 489,866	$ 1,109,522
R-106	Jacketed Agitated	11	66.9	SS	9.15	3.05	$ 1,881,419	$ 3,781,474
Tanks	Tank Type	Design Pressure (barg)	Volume (m^3)	MOC	Height (m)	Diameter (m)	Purchased Equipment Cost	Bare Module Cost
TK-101	Horizontal	7	237	SS	45.75	15.25	$ 1,428,231	$ 2,320,732
							Total Purchased Cost	$ 10,837,026
							Total Bare Module Cost	$ 21,136,107

Table 5: Utility Equipment Cost Summary

Cooling Water	Type	No. Required	MOC	Pressure Range	Purchased Equipment Cost	Bare Module Cost
Cooling Tower	Air Cooler	1	SS	P<10 barg	$ 288,396	$ 1,295,819
Waste Water Treatment Facility	Type	No. Required	MOC	Power (kWh)	Purchased Equipment Cost	Bare Module Cost
Pumps	Centrifugal	4	SS	40	$ 29,640	$ 231,673
	Type	No. Required	MOC	Area (m^2)	Purchased Equipment Cost	Bare Module Cost
Screens	Stationary	3	SS	5	$ 53,473	$ 71,654
Filters	Gravity	2	SS	40	$ 210,771	$ 347,772
Tanks	Fixed Roof	2	SS	100	$ 86,165	$ 267,111
High Pressure steam	Type	No. Required	MOC	Duty (kW)	Purchased Equipment Cost	Bare Module Cost
Heaters	Steam boiler	1	SS	628	$ 171,549	$ 526,819
Dowtherm A	Type	No. Required	MOC	Duty (kW)	Purchased Equipment Cost	Bare Module Cost
Furnace	Nonreactive Fired Heater	1	SS	806	$ 414,955	$ 1,078,883
				Total Purchased Cost		**$ 1,254,949**
				Total Bare Module Cost		**$ 3,819,731**

Table 5: Equipment Specification Sheet 1

ADA Dissolver				
Identifications:	Item	Dissolver		Date: 9 March,2017
	Item No.	R-101		By
	No. Required	1		
Function:	Dissolve ADA with Water			
Operation:	Continuous			
Materials Handled:	Solid ADA	Water	Solution	
Quantity (lb/hr)	5553	713	6266	
Temperature (°F):	60	60	431	
Pressure (psia):	14.7	14.7	118	
Design Data:	Diameter (ft)	9		
	Length (ft)	27		
	Volume (ft^3)	1718		
	Materials of Construction:	Stainless Steel		
Utilities:	High Pressure Steam at 1.921E+2 lbm/hr			
	N2 at 2.91 lbm/hr			
Controls	Pressure Controller			
	Temperature Controller			
Tolerances:				
Comments and Drawings:	See Process Flow Sheet, Figure 1			

Table 6: Equipment Specification 2

HMDA Dissolver				
Identifications:	Item	Dissolver		Date: 9 March,2017
	Item No.	R-106		By
	No. Required	1		
Function:	Dissolve HMDA with Water			
Operation:	Continuous			
Materials Handled:	Solid HMDA	Water	Solution	
Quantity (lb/hr)	4300	683	4983	
Temperature (°F):	60	60	431	
Pressure (psia):	14.7	14.7	118	
Design Data:	Diameter (ft)	10		
	Length (ft)	30		
	Volume (ft^3)	2356		
	Materials of Construction:	Stainless Steel		
Utilities:	High Pressure Steam at 1.921E+2 lbm/hr			
Controls	Pressure Controller			
	Temperature Controller			
Tolerances:				
Comments and Drawings:	See Process Flow Sheet, Figure 1			

Table 7: Equipment Specification Sheet 3

CSTR 1				
Identifications:	Item	CSTR 1		Date: 9 March,2017
	Item No.	R-102		By:
	No. Required	1		
Function:	Nylon 66 Salt Reactor			
Operation:	Continuous			
Materials Handled:	Feed	Stream Outlet	Vapor Outlet	
Quantity (lb/hr)	12794	11831	963	
Composition(mass fraction):				
HMDA	0.39	0.0012	6.97E-04	
ADA	0.49	0.0015	1.51E-05	
H_2O	0.12	0.824	0.999	
Nylon 66	0	0.173	0	
Temperature (°F):	431	431	431	
Pressure (psia):	118	294	118	
Design Data:	Diameter (ft)	6.75		
	Length (ft)	20.25		
	Volume (ft^3)	725		
	Materials of Construction:	Stainless Steel		
	Residence Time (min)	20		
Utilities:	Dowtherm A at 2.541E+4 lbm/hr			
Controls:	Pressure Controller			
	Temperature Controller			
Tolerances:				
Comments and Drawings:	See Process Flow Sheet, Figure 1			

Table 8: Equipment Specification Sheet 4

CSTR 2			
Identifications:	Item	CSTR 2	Date: 9 March,2017
	Item No.	R-103	By:
	No. Required	1	
Function:	Nylon 66 Polymerization Reactor 1		
Operation:	Continuous		
Materials Handled:	Feed	Stream Outlet	Vapor Outlet
Quantity (lb/hr)	10082	9839	243
Composition(mass fraction):			
HMDA	8.22E-04	7.22E-05	6.46E-04
ADA	0.0017	1.11E-04	4.60E-05
H_2O	0.031	0.0124	0.999
Nylon 66	0.967	0.987	0
Temperature (°F):	539	539	539
Pressure (psia):	305	147	147
Design Data:	Diameter (ft)	10.5	
	Length (ft)	31.5	
	Volume (ft^3)	2728	
	Materials of Construction:	Stainless Steel	
	Residence Time (min)	20	
Utilities:	Dowtherm A at 1.818E+4 lbm/hr		
Controls:	Pressure Controller		
	Temperature Controller		
Tolerances:			
Comments and Drawings:	See Process Flow Sheet, Figure 1		

Table 9: Equipment Specification Sheet 5

CSTR 3			
Identifications:	Item	CSTR 3	Date: 9 March,2017
	Item No.	R-104	By:
	No. Required	1	
Function:	Nylon 66 Polymerization Reactor 2		
Operation:	Continuous		
Materials Handled:	Feed	Stream Outlet	Vapor Outlet
Quantity (lb/hr)	9839	9768	71
Composition(mass fraction):			
HMDA	7.22E-05	3.23E-05	5.80E-04
ADA	1.11E-04	5.44E-05	4.40E-05
H_2O	0.0124	0.0058	0.998
Nylon 66	0.987	0.994	0
Temperature (°F):	539	539	539
Pressure (psia):	147	73.5	73.5
Design Data:	Diameter (ft)	5	
	Length (ft)	15	
	Volume (ft^3)	295	
	Materials of Construction:	Stainless Steel	
	Residence Time (min)	20	
Utilities:	Dowtherm A at 4.198E+2 lbm/hr		
Controls:	Pressure Controller		
	Temperature Controller		
Tolerances:			
Comments and Drawings:	See Process Flow Sheet, Figure 1		

Table 10: Equipment Specification Sheet 6

CSTR 4			
Identifications:	Item	CSTR 4	Date: 9 March,2017
	Item No.	R-105	By:
	No. Required	1	
Function:	Nylon 66 Polymerization Reactor 1		
Operation:	Continuous		
Materials Handled:	Feed	Stream Outlet	Vapor Outlet
Quantity (lb/hr)	9768	9715	53.6
Composition(mass fraction):			
HMDA	3.23E-05	5.23E-06	4.69E-04
ADA	5.44E-05	1.28E-05	5.12E-05
H_2O	0.0058	0.0011	0.999
Nylon 66	0.994	0.999	0
Temperature (°F):	539	539	539
Pressure (psia):	73.5	14.7	14.7
Design Data:	Diameter (ft)	7.25	
	Length (ft)	21.75	
	Volume (ft^3)	898	
	Materials of Construction:	Stainless Steel	
	Residence Time(min)	20	
Utilities:	Dowtherm A at 3.384E+2 lbm/hr		
Controls:	Pressure Controller		
	Temperature Controller		
Tolerances:			
Comments and Drawings:	See Process Flow Sheet, Figure 1		

Table 11: Equipment Specification Sheet 7

Extruder			
Identifications:	Item	Extruder	Date: 9 March,2017
	Item No.	EX-101	By
	No. Required	1	
Function:	Shape the Melt Nylon 66		
Operation:	Continuous		
Materials Handled:	Condition		
Quantity (lb/hr)	9715		
Temperature (°F):	539		
Pressure (psia):	14.7		
Design Data:	Volume (ft^3)	670.5	
	Materials of Construction:	Stainless Steel	
Utilities:			
Controls			
Tolerances:			
Comments and Drawings:	See Process Flow Sheet, Figure 1		

Table 12: Equipment Specification Sheet 8

Evaporator				
Identifications:	Item	Evaporator	Date: 9 March,2017	
	Item No.	E-101	By	
	No. Required	1		
Function:	Remove Water from the Nylon 66 Salt and Heat up the Stream			
Operation:	Continuous			
Materials Handled:	Feed	Stream Outlet	Vapor Outlet	
Quantity (lb/hr)	11831	10082	1748	
Composition(mass fraction):				
HMDA	0.0012	8.22E-04	3.35E-03	
ADA	0.0015	0.0017	3.30E-04	
H_2O	0.824	0.031	0.996	
Nylon 66	0.173	0.967	0	
Temperature (°F):	431	539	539	
Pressure (psia):	294	305	305	
Design Data:	Area (ft^2)	836		
	Heat Duty (Btu/hr)	2.20E+06		
	Design Pressure (psia)	354.7		
	Materials of Construction:	Stainless Steel		
Utilities:	Dowtherm A at 1.634E+4 lbm/hr			
Controls:	Temperature Controller			
Tolerances:				
Comments and Drawings:	See Process Flow Sheet, Figure 1			

Table 13: Equipment Specification Sheet 9

Air Cooler				
Identifications:	Item		Air Cooler	Date: 9 March,2017
	Item No.		E-102	By
	No. Required		1	
Function:	Cool Down the Nylon 66 Pellets			
Operation:	Continuous			
Materials Handled:	Feed		Polymer Stream	
Quantity (lb/hr)		9715	9715	
Composition(mass fraction):				
HMDA		5.23E-06	5.23E-06	
ADA		1.28E-05	1.28E-05	
H_2O		0.0011	0.0011	
Nylon 66		0.999	0.999	
Temperature (°F):		539	59	
Pressure (psia):		14.7	14.7	
Design Data:	Area (ft^2)		358	
	Heat Duty (Btu/hr)		-2.67E+06	
	Design Pressure (psia)		64.7	
	Materials of Construction:		Stainless Steel	
Utilities:	Air at 1.114E+7 lbm/hr			
Controls:				
Tolerances:				
Comments and Drawings:	See Process Flow Sheet, Figure 1			

Table 14: Equipment Specification Sheet 11

Condenser				
Identifications:	Item		Condenser	Date: 9 March,2017
	Item No.		E-103	By
	No. Required		1	
Function:	Condense the Vapor Streams			
Operation:	Continuous			
Materials Handled:	Feed		Polymer Stream	
Quantity (lb/hr)		1017	1017	
Composition(mass fraction):				
HMDA		6.85E-04	6.85E-04	
ADA		1.70E-05	1.70E-05	
H_2O		0.999	0.999	
Nylon 66		0	0	
Temperature (°F):		400	60	
Pressure (psia):		14.7	14.7	
Design Data:	Area (ft^2)		85	
	Heat Duty (Btu/hr)		-1.23E+06	
	Design Pressure (psia)		64.7	
	Materials of Construction:		Stainless Steel	
Utilities:	Cooling water at 3.843E+6 lbm/hr			
Controls:	Temperature Controller			
Tolerances:				
Comments and Drawings:	See Process Flow Sheet, Figure 1			

Table 15: Equipment Specification Sheet 12

Pump 1			
Identifications:	Item	Pump	Date: 9 March,2017
	Item No.	P-101	By
	No. Required	2	
Function:	Pump the Adipic Acid Solution to the Reactor		
Operation:	Centrifugal		
Materials Handled:	Inlet	Outlet	
Quantity (lb/hr)	6266	6266	
Temperature (°F):	431	431	
Pressure (psia):	118	294	
Design Data:	Discharge Pressure (psia)	279	
	Head (ft)	7.68E+02	
	Capacity(gpm)	11.85	
	Efficiency of Pump	0.65	
	Efficiency of Motor	0.82	
	Purchased Horsepower (HP)	2	
	Materials of Construction:	Stainless Steel	
Utilities:	Electricity of 2.983 kWh		
Controls:			
Tolerances:			
Comments and Drawings:	See Process Flow Sheet, Figure 1		

Table 16: Equipment Specification Sheet 13

	Pump 2			
Identifications:	Item		Pump	Date: 9 March,2017
	Item No.		P-102	By
	No. Required		2	
Function:	Pump the HMDA Solution to the Reactor			
Operation:	Centrifugal			
Materials Handled:	Inlet		Outlet	
Quantity (lb/hr)		4983	4983	
Temperature (°F):		431	431	
Pressure (psia):		118	294	
Design Data:	Discharge Pressure (psia)		294	
	Head (ft)		4.99E+02	
	Capacity(gpm)		9.2	
	Efficiency of Pump		0.65	
	Efficiency of Motor		0.83	
	Purchased Horsepower (HP)		3	
	Materials of Construction:		Stainless Steel	
Utilities:	Electricity of 2.237 kWh			
Controls:				
Tolerances:				
Comments and Drawings:	See Process Flow Sheet, Figure 1			

Table 17: Equipment Specification Sheet 14

Pump 3			
Identifications:	Item	Pump	Date: 9 March,2017
	Item No.	P-103	By
	No. Required	2	
Function:	Pump the HMDA Solution to the Reactor		
Operation:	Centrifugal		
Materials Handled:	Inlet	Outlet	
Quantity (lb/hr)	11831	11831	
Temperature (°F):	431	431	
Pressure (psia):	294	305	
Design Data:	Discharge Pressure (psia)	305	
	Head (ft)	2.30E+01	
	Capacity(gpm)	23.63	
	Efficiency of Pump	0.65	
	Efficiency of Motor	0.8	
	Purchased Horsepower (HP)	0.5	
	Materials of Construction:	Stainless Steel	
Utilities:	Electricity of 0.373 kWh		
Controls:			
Tolerances:			
Comments and Drawings:	See Process Flow Sheet, Figure 1		

Table 18: Equipment Specification Sheet 15

	Nylon 66 Salt Storage Tank		
Identifications:	Item Item No. No.Required	Tank TK-101 1	Date: 9 March,2017 By
Function:	Storage Nylon 66 Salt Solution		
Operation:	Continuous		
Materials Handled:	Condition		
Quantity (lb/hr)	11831		
Temperature (°F):	431		
Pressure (psia):	294		
Desgin Data:	Diameter (ft)	15.25	
	Length (ft)	45.75	
	Volume (ft^3)	8356	
	Materials of Construction:	Stainless Steel	
	Design Pressure (psia):	114.7	
	Materials of Construction:	Stainless Steel	
Utilities:	N2 at		
Controls	Level Controller		
Tolerances:			
Comments and Drawings:	See Process Flow Sheet, Figure 1		

Fixed Capital Investment Summary

The Total Fixed Capital Investment will be the total cost for constructing the Nylon 6,6 plant. It will include all primary equipment necessary as well as utility equipment, land purchase, and land development. The majority of all costs are known and correlated with built-in contingency for the specific piece of equipment attached to it. However, certain costs for complete construction of a plant simply can't be foreseen and require a certain level of contingency built into the total cost of the plant. Based off equipment sizing costs, with material factors considered, the base cost for the specific Nylon 6,6 synthesis operation can be used to size-up the total cost of the operation in order to get an accurate appraisal of the capital necessary for completion of the facility.

For each piece of equipment in the primary operation of the synthesis, a bare module cost is derived based on the materials of construction used and the pressure of the operation the piece of equipment undergoes. Using the correlations from Turton et al.[10] for purchase cost and bare module cost, the correlation for Total Module cost will be costed using the equation below:

$$C_{TM} = 1.18 \sum_{i=1}^{n} C_{BM} \qquad \text{(Equation 10)}$$

Where:

- CBM is bare module cost
- Ctm is Total Module cost
- n is total pieces of primary equipment

The value above is considered as the bare module with 18% contingency cost associated with it. The Total Module cost is otherwise referred to as the installed cost. It considers such factors as concrete setting, piping, transportation, and others, on top of the basic purchase cost of equipment. The Total Module cost as well deals with added contingency that could be associated with installation. For this project, the Total Module cost will be considered over a total sum for Bare Module cost of all equipment sized. The Total Module cost will be a significant value into the finalized capital cost of the plant. As this will be a grass root facility, the complete fixed investment for the plant will encompass all utility implementations on top of the complete cost for the primary equipment. The correlation considered for this is shown below:

$$C_{Gr} = C_{TM} + C_{Land} + 0.25 \sum_{i}^{n} C_{BM} \qquad \text{(Equation 11)}$$

Where:

- C_{Gr} is the grass roots capital cost
- C_{TM} is the total module cost
- C_{Land} is the cost of land
- CBM is the bare module cost
- n is the total pieces of equipment

Since all other possible costs associated with the fixed capital total were variable and minor in comparison to the cost of all primary and secondary pieces of equipment, a contingency factor of 25% is assessed against the total bare module cost of all equipment. The summary for all costs considered for this project is listed below:

Table 19: Fixed Capital Cost Summary

Costing Consideration	Cost ($MM)	Type of Cost
Primary Equipment	21.092	Bare Module
Utilities	3.820	Bare Module
Total	24.912	Bare Module
All Equipment	29.396	Total Module
Land	1.00	Total Module
Fixed Capital Cost	36.624	Grass Roots

The final Fixed Capital Cost is rounded up to the nearest million for accounting purposes. This will be the final cost used in the economic evaluation of the project.

Safety

All major safety concerns were covered in the HAZOP in Table 19. Most concerns came from reading the MSDS sheets for HMDA, ADA and Nylon 6,6. The intermediates of the reaction are so small in outgoing streams that they were not included in the safety analysis. The only byproduct is water, which is not hazardous. One concern with HMDA and ADA was how corrosive they are. It is recommended that stainless steel be used for the process equipment to prevent corrosion, which could lead to a leak in pipes or process equipment. Another concern with ADA is that if solid ADA forms a dust cloud, it can become explosive, so it is recommended to store solid ADA in sealed containers.

Another area that was looked at for safety hazards was the actual process by looking at the PFD. A major hazard found in the PFD was a pressure increase in the process vessels that could lead to an explosion. This could be due to an increase in incoming flow to the vessel or backflow from another vessel. To mitigate this fail close control valves can be put before vessels and fail open control valves after vessels. Also there can be a pressure controller input to alert the operator of an over-pressurized vessel as well as change the flow rate coming out of the tank. It is also necessary to have a surge vessel between the first reactor and second set of polymerization reactors to reduce the possibility of backflow. An increase in temperature is another concern that could lead to release of volatile gas and a possible explosion. This can be mitigated by installing a temperature controller on all vessels with a utility that is connected to a control valve on the incoming utility line so that the temperature can be controlled by changing the flowrate of the utility. Another concern for the process is low liquid levels in the surge tank, which could cavitate the pump. A level controller can be installed on the tank that is connected to the control valve leaving the tank to keep the liquid at an appropriate level.

Health

The only real health concern from the MSDS sheets for HMDA and ADA are that they are both highly corrosive. Workers need to be wearing gloves, goggles and gas masks if loading or whenever handling the solid crystal HMDA and ADA. They can cause severe skin burns, eye damage and can cause irritation to the upper respiratory tract [24,25]. The end product, Nylon 6,6, does not have any major health concerns.

Environment

The major pollutants from this process come from the vapor streams off of the reactors and the evaporator. These streams all go to the condenser to condense into a liquid and are brought down to standard conditions of 60 °F and 14.7 psia before being sent to water treatment. Since there is a very minimal amount of leftover ADA and HMDA in the stream and both are biodegradable in water [24,25] there is no need for further separation before the water treatment facility. The sludge generated will be taken to a landfill. Since all of the vapor condenses there is no need for a flare or incinerator to release the gas to the atmosphere.

Other Important Considerations

Table 20: HAZOP

Hazard and Operability Analysis Activity: Creating Nylon 6,6 Pellets from Adipic Acid and HMDA						
NO	HAZARD	HAZARD EFFECT	SEVERITY	PROBABILITY	RISK	MINIMISE RISK BY
1	Solid Adipic Acid dust cloud	Explosion	H	L	H	Storing solid adipic acid in closed containers and being careful if ever handling
2	Increased pressure in process vessels	Explosion	H	L	H	Install fail closed control valves on lines leading to the tank, and fail open on lines leading from tank. Install alarm to alert operator of high pressure in tank, as well as pressure relief valves on pressurized process vessels
3	Low liquid level in process vessels	Inadequate NPSH leading to cavitation of pumps	L	M	M	Install a level alarm in process vessels
4	Back flow from downstream process vessels	Product contamination and over	H	L	H	Install a surge vessel before downstream

		pressured vessels which could lead to explosion				polymerization reactors.
5	Corrosivity of HMDA and ADA	Release of chemicals from a corrosion leak and possible hazard to employees in area since ADA and HMDA are corrosive to skin	M	L	M	Use stainless steel for entire process
6	Fire	Release of toxic gases like from degradation of HMDA, ADA and nylon 6,6	H	L	H	Install fire protection like smoke alarms and sprinklers
7	Pump Breaks	System goes down, liquid backs up into reactors	M	L	M	Install spare pumps within process to be used if one pump goes down
FINAL ASSESSMENT:						

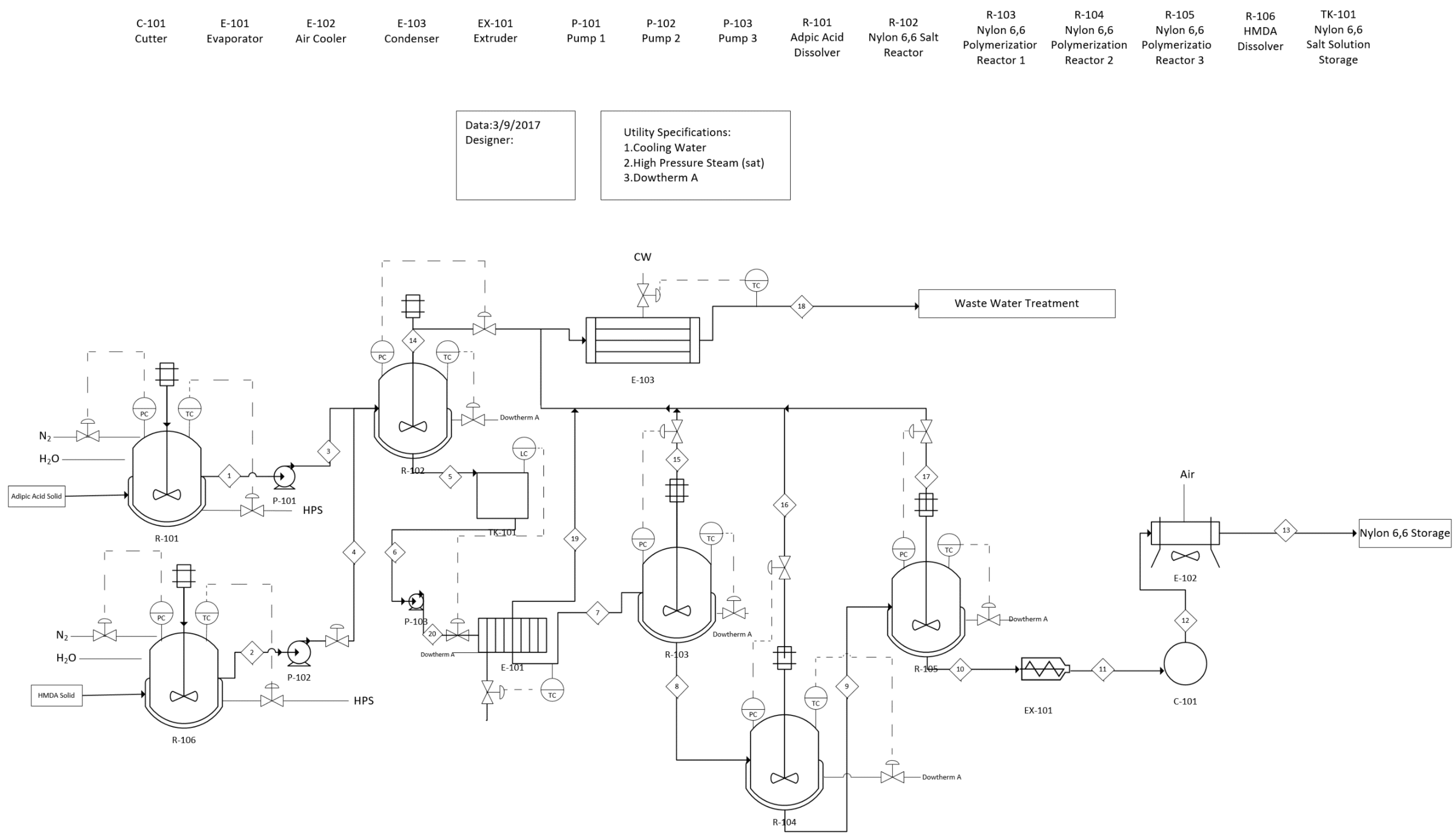

Figure 3: Control Strategy for Nylon 6,6 Manufacturing Process

Control Strategy

R-101

This reactor uses a pressure controller connected to a control valve on the Nitrogen gas stream before the tank to change the pressure in the tank by changing the flowrate of the incoming solid ADA stream. There is also a temperature controller attached to a control valve for the incoming Dowtherm A stream to change the Temperature in the tank by changing the flowrate of Dowtherm A coming in.

R-106

This reactor is similar to R-101. It uses a pressure controller connected to a control valve on the Nitrogen gas stream before the tank to change the pressure in the tank by changing the flowrate of the incoming solid HMDA stream. There is also a temperature controller attached to a control valve for the incoming Dowtherm A stream to change the Temperature in the tank by changing the flowrate of Dowtherm A coming in.

R-102

This reactor uses a pressure controller connected to a control valve on the vapor stream coming out of the reactor, Stream 14, to change the pressure in the tank by changing the flowrate of the outgoing vapor stream. There is also a temperature controller attached to a control valve for the incoming Dowtherm stream to change the Temperature in the tank by changing the flowrate of Dowtherm A coming in.

E-101

The evaporator uses a temperature controller attached to a control valve on the Dowtherm A stream to control the temperature of the liquid outlet stream to the polymerization reactors.

R-103

This reactor uses a pressure controller connected to a control valve on the vapor stream coming out of the reactor, Stream 15, to change the pressure in the tank by changing the flowrate of the outgoing vapor stream. There is also a temperature controller attached to a control valve for the incoming Dowtherm A stream to change the Temperature in the tank by changing the flowrate of Dowtherm A coming in.

R-104

This reactor uses a pressure controller connected to a control valve on the vapor stream coming out of the reactor, Stream 16, to change the pressure in the tank by changing the flowrate of the outgoing vapor stream. There is also a temperature controller attached to a control valve for the incoming Dowtherm A stream to change the Temperature in the tank by changing the flowrate of Dowtherm A coming in.

R-105

This reactor uses a pressure controller connected to a control valve on the vapor stream coming out of the reactor, Stream 17, to change the pressure in the tank by changing the flowrate of the outgoing vapor stream. There is also a temperature controller attached to a control valve for the incoming

Dowtherm A stream to change the Temperature in the tank by changing the flowrate of Dowtherm A coming in.

E-103

The condenser uses a temperature controller connected to the control valve on the cooling water stream coming in to change the temperature in the condenser by changing the flowrate of the cooling water.

Manufacturing Costs

Manufacturing costs indicate the complete costs for operation of the Nylon 6,6 plant during production. This will include all considerations from raw materials needed to for the synthesis of Nylon 6,6, as well as the operation costs surrounding the reactors and other pieces of equipment.

Raw materials

The two chemical components needed to synthesize Nylon 6,6 are ADA, a distant derivative of butadiene, as well as HMDA, synthesized from adiponitrile, which is as well a distant derivative of butadiene [23]. These two components, because of their price fluctuation due to the oil market volatility, are usually synthesized from a host component (Butadiene) [23]. In consideration of minimizing an already considerable Fixed Capital Investment that comes attached to a grassroots design, this preliminary design suggests buying these two components from other vendors, while considering adding the processes for synthesizing ADA and HMDA down the line of the life of the plant.

The ratio for raw material to product is considered 1:1, without considering the conversion of the reaction. In this manner, for every pound of HMDA reacted with ADA, a pound of Nylon 6,6 is theoretically synthesized.

Electricity

The Process Plant will run off electricity for most of its operations. On account of this, the plant will buy electricity from Calvert City [13]. The utility for all operations will be costed based on KwH usage annually. The process itself will be considered to be the largest consumer of electricity. The electrical usage for all other minor considerations of the plant will be deemed negligible as their usage is too small to be determined and because of the cost of electricity is very inexpensive for industrial process use. All electricity considered is based off of all production operations, including utilities. Safety Valves and other process safety control features are included under this usage blanket.

Process Required Water

Both ADA and HMDA need to be dissolved in water before beginning the polymerization process. The water used in this process needs to be deionized, as both products are reactive in nature to subtle ionic characteristics in the solute fluid [27]. This water will be recycled through a wastewater treatment process in the plant, which will deionize them for reuse. The cost going into this process will include only the cost of treating the process stream in order for it to be recycled back into the process as a deionized water per unit volume [10]. The waste water treatment will have its own cost, as deionizing water is a smaller subsection of the waste water treatment process.

Cooling Water

During the process, a condenser is used to cool the vapor streams that come off the evaporator. All process water within the system is considered to go through a cooling tower in order to have a very operationally sized cooling tower and cooling water stream. The cooling water will be recycled through a cooling tower, which uses an air cooler system. The cost associated with this process will be a blanket cost per unit volume of reducing the duty of the cooling water stream [10].

Dowtherm A

After the synthesis of the Nylon salt within the water solution between both components, the aqueous water needs to be evaporated out of the process. Dowtherm A is easily recyclable throughout the process [28]. To reheat the Dowtherm A for each use, it will be run through a nonreactive heater, which will increase its duty to the desired level. To cost this utility, a blanket value for thermally reheating will be used at 80% efficiency [10]. This will include the price for the fuel gas necessary to reheat the fluid at an 80% efficiency set point. This will be applied to sizing the nonreactive heater and it will also be used for costing the thermal system desired, which specifies the cost per GJ of energy needed to heat a system. The cost for this can be seen in the table at the bottom of this section.

Waste Water Treatment

A waste water treatment utility cost is assessed for cleaning the used deionized water after being evaporated out of the nylon salt solution. This stream will contain small amounts of ADA and HMDA and a trace amount of Nylon 6,6. The cooling water used in the condenser will be added in as well. For this reason, the treatment will include filtration, sludge removal, and will also be chemically treated. This cost will be by unit volume [10]. The cost for deionizing the water for reuse will be included with the deionized water utility cost, and not with this cost.

Waste Disposal

The waste disposal considered in this process are the unreacted components that come out of the used deionized water stream during waste water treatment. While it will have been chemically treated and neutralized, for safety purposes, the waste will be labelled as a hazardous material in order to safely dispose of it. The cost associated with disposal will be by tonne disposed of [10].

Nitrogen

In order to prevent contamination in the ADA and HMDA dissolvers, nitrogen blanketing will be used for its inert characteristics to discourage undesired reactions from taking place [29]. While it can be considered a completely recycled process with no treatment, small amounts of nitrogen are assumed to be lost into the atmosphere during this blanketing process. For this reason, the nitrogen stream will be considered to be completely replaced daily in order to cost it effectively [30].

Acetic Acid

In the explicit polymerization reaction of the process, a 0.5% acetic acid solution will be used to stabilize the reaction, in order to prevent a reverse reaction from taking place [4]. The acetic acid is considered non-recyclable and will be sent through wastewater treatment and disposal. This material will be cost by the pound. A one to two ratio of acetic acid to Nylon 6,6 is considered for costing, since the acetic acid solution has potential for becoming a large utility factor due to its high cost. In this manner, 1 lb of 0.5% acetic acid solution is considered for 2lbs raw materials solution.

Labor

The labor for this plant will be determined by a costing correlation regularly used for process plants [10]. This correlation will consider which pieces of equipment require how many labor shifts, a rule of thumb for how many workers are needed to fill the shifts required, and a base salary for process plant workers. This will encompass the annual cost of labor. The equation for costing labor is based upon the number of shifts necessary, and the total amount of laborers needed to accomplish these shifts. The equation for this can be seen below:

$$N_{OL} = (6.29 + 31.7P^2 + 0.23N_{NP})^{0.5} \quad \text{(Equation 12)}$$

Where:

- NOL is the of operators per shift
- P is the number of particulate steps, of which require physical handling of product or material
- NNP is the number of non-particulate steps, such as ones carried out by equipment.

Once the number of operators per shift is determined, a rule of thumb used for determining the necessary amount of full-time workers is employed to determine the total labor cost of the plant:

$$Operating\ Labor = 4.5N_{OL} \quad \text{(Equation 13)}$$

Where Operating Labor is the total number of full time workers necessary for annual operation of the plant.

The Operating Labor is multiplied by the salary, in order to account for the total cost of labor. The salary used was a base salary for systems operators in 2001. This value was brought forward to the year 2016 using the CEPCI. This value is the considered salary per each full-time employ.

High Pressure Steam

The first dissolution reactors require high pressure steam in order to efficiently dissolve the raw materials into the deionized process water stream. The High Pressure Steam (HPS) stream will be recycled throughout the operation in a steam boiler. The cost for continually reheating/boiling the HPS stream will be based on the amount of energy necessary to bring the stream back to its characteristic physical properties as HPS. This will be based off the duty. An 80% efficiency is considered in reheating the HPS stream back to HPS physical characterization [10]. The cost of this stream will be based off amount of GJ energy used annually, as specified.

Initial Start-Up

The initial start-up of the plant will involve costing the raw materials, required process and cooling water, Dowtherm A, nitrogen, acetic acid, and high pressure steam, as well as labor for start-up. All these costs will be included in the Working Capital Costs, which by heuristic will be about 20% of the Fixed Capital Investment [10]. The Working Capital Cost is the amount cost necessary for preliminary startup of the plant, on top of in between construction and operation costs that may accumulate. Spare equipment is also considered in this value.

Manufacturing Costs Summary Table

The table below summarizes the cost for each utility, based on the unit it is most easily costed by. All streams are considered during a 100% production year (85 MM Nylon 6,6 produced).

Table 21: Utility Costs Summary

Component	Price ($) for Unit	Unit	Annual Amount
HMDA	$1.15	Lb.	98,837,209
AAD	$0.69	Lb.	98,837,209
Electricity	$0.055	KwH	45,272
Deionized Water (Recycle)	$41.00	1000 m^3	29.94
Cooling Water (Recycle)	$0.354	Giga-Joule	31,607.25
Dowtherm (Recycle)(80%)	$13.88	Giga-Joule	21,511.02
Waste Water Treatment	$56	1000 m^3	119.76
Waste Disposal	$36	Tonne (1000 kg)	1.20
Nitrogen	$0.07	100 L.	414,840.76
Acetic Acid (0.5% soln)	$0.19	100 lb	988,372.09
High Pressure Steam	$17.70	Giga-Joule	15,824
Labor Salary	$81,176	Full-Time Workers	14

Economic Analysis

For consideration of economic analysis, an NPV-DCFROR approach was assessed as it fits with a product producing project. In considering NPV and DCFROR, a maximized revenue-profit stream is the objective.

Revenue Considerations

Revenue was listed as the end of the year total product sold at a certain price. As no information was specified for contractual pricing of Nylon 6,6, a researched market price of $2.57 per pound was used for analyzing the economic situation of the facility over a 10-year period life [31].

As specified, an annual product stream of 85MM pounds was produced and sold. All economic considerations are made surrounding this specification. Detailed calculations are shown in Table X of the appendix. The process is found to have a NPV of $61.5 MM, a DCFROR of 27%, and a payback period of 4.17 years.

Table 22: Cash Flow Time Chart

		i*		Nylon 6,6 ($/lb)	HMDA ($/lb)	Adipic Acid ($/lb)	Conversion %		Capital Costs		Year 2018 Operation Time	
		0.15		$ 2.57	$ 1.15	$ 0.69	0.86		$ 37,000,000.00		0.25	
		2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Units	**End of Year**	0	1	2	3	4	5	6	7	8	9	10
$/lbs	Production "Units" Nylon 6,6		21,250,000	85,000,000	85,000,000	85,000,000	85,000,000	85,000,000	85,000,000	85,000,000	85,000,000	85,000,000
	Sales Nylon 6,6(+)		$ 54,612,500.00	$ 218,450,000.00	$ 218,450,000.00	$ 218,450,000.00	$ 218,450,000.00	$ 218,450,000.00	$ 218,450,000.00	$ 218,450,000.00	$ 218,450,000.00	$ 218,450,000.00
	Sales Revenue		$ 54,612,500.00	$ 218,450,000.00	$ 218,450,000.00	$ 218,450,000.00	$ 218,450,000.00	$ 218,450,000.00	$ 218,450,000.00	$ 218,450,000.00	$ 218,450,000.00	$ 218,450,000.00
	Salvage Value(+)											
	Royalties(-)											
	Net Revenue		$ 54,612,500.00	$ 218,450,000.00	$ 218,450,000.00	$ 218,450,000.00	$ 218,450,000.00	$ 218,450,000.00	$ 218,450,000.00	$ 218,450,000.00	$ 218,450,000.00	$ 218,450,000.00
Reagent ($/lbs)	Raw Materials, Adipic Acid "Units"		24,709,302	98,837,209	98,837,209	98,837,209	98,837,209	98,837,209	98,837,209	98,837,209	98,837,209	98,837,209
	Raw Materials, Adipic Acid Costs (-)		$ (17,049,418.60)	$ (68,197,674.42)	$ (68,197,674.42)	$ (68,197,674.42)	$ (68,197,674.42)	$ (68,197,674.42)	$ (68,197,674.42)	$ (68,197,674.42)	$ (68,197,674.42)	$ (68,197,674.42)
Reagent ($/lbs)	Raw Materials, HMD "Units"		24,709,302	98,837,209	98,837,209	98,837,209	98,837,209	98,837,209	98,837,209	98,837,209	98,837,209	98,837,209
	Raw Materials, HMD Costs (-)		$ (28,416,265.99)	$ (113,665,063.95)	$ (113,665,063.95)	$ (113,665,063.95)	$ (113,665,063.95)	$ (113,665,063.95)	$ (113,665,063.95)	$ (113,665,063.95)	$ (113,665,063.95)	$ (113,665,063.95)
KwH/unit	Op. Cost Electricity "Units"		11,318.00	45,272.00	45,272.00	45,272.00	45,272.00	45,272.00	45,272.00	45,272.00	45,272.00	45,272.00
	Op. Cost Electricity (-)		$ (622.49)	$ (2,489.96)	$ (2,489.96)	$ (2,489.96)	$ (2,489.96)	$ (2,489.96)	$ (2,489.96)	$ (2,489.96)	$ (2,489.96)	$ (2,489.96)
1000kgs/unit	Op. Cost High Press. Steam "Units"		3,956.00	15,824.00	15,824.00	15,824.00	15,824.00	15,824.00	15,824.00	15,824.00	15,824.00	15,824.00
	Op. Cost HP Steam (-)		$ (70,021.20)	$ (280,084.80)	$ (280,084.80)	$ (280,084.80)	$ (280,084.80)	$ (280,084.80)	$ (280,084.80)	$ (280,084.80)	$ (280,084.80)	$ (280,084.80)
1000m^3/unit	Op. Cost Deionized Water "Units"		29.94	119.76	119.76	119.76	119.76	119.76	119.76	119.76	119.76	119.76
	Op. Cost Deionized Water (-)		$ (1,227.59)	$ (4,910.34)	$ (4,910.34)	$ (4,910.34)	$ (4,910.34)	$ (4,910.34)	$ (4,910.34)	$ (4,910.34)	$ (4,910.34)	$ (4,910.34)
1000kgs/unit	Op. Cost Low Press. Steam "Units"											
	Op. Cost LP Steam (-)		$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
1000kgs/unit	Op. Cost Boiler Feed Water "Units"											
	Op. Cost Boiler Feed Water (-)		$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
GJ/unit	Op. Cost Thermal System "Units"		5,377.75	21,511.02	21,511.02	21,511.02	21,511.02	21,511.02	21,511.02	21,511.02	21,511.02	21,511.02
	Op. Cost Thermal System (-)		$ (74,643.23)	$ (298,572.92)	$ (298,572.92)	$ (298,572.92)	$ (298,572.92)	$ (298,572.92)	$ (298,572.92)	$ (298,572.92)	$ (298,572.92)	$ (298,572.92)
GJ/unit	Op. Cost Cooling Water "Units"		7,901.81	31,607.25	31,607.25	31,607.25	31,607.25	31,607.25	31,607.25	31,607.25	31,607.25	31,607.25
	Op. Cost Cooling Water (-)		$ (2,797.24)	$ (11,188.97)	$ (11,188.97)	$ (11,188.97)	$ (11,188.97)	$ (11,188.97)	$ (11,188.97)	$ (11,188.97)	$ (11,188.97)	$ (11,188.97)
1000m^3/unit	Op. Cost Wastewater Treatment "Units"		$ 29.94	$ 119.76	$ 119.76	$ 119.76	$ 119.76	$ 119.76	$ 119.76	$ 119.76	$ 119.76	$ 119.76
	Op. Cost Wastewater Treatment (-)		$ (1,676.70)	$ (6,706.81)	$ (6,706.81)	$ (6,706.81)	$ (6,706.81)	$ (6,706.81)	$ (6,706.81)	$ (6,706.81)	$ (6,706.81)	$ (6,706.81)
100L/unit	Op. Cost Nitrogen Blanket "Units"		$ 103,710.19	$ 414,840.76	$ 414,840.76	$ 414,840.76	$ 414,840.76	$ 414,840.76	$ 414,840.76	$ 414,840.76	$ 414,840.76	$ 414,840.76
	Op. Cost Nitrogen Blanket (-)		$ (7,259.71)	$ (29,038.85)	$ (29,038.85)	$ (29,038.85)	$ (29,038.85)	$ (29,038.85)	$ (29,038.85)	$ (29,038.85)	$ (29,038.85)	$ (29,038.85)
lb/unit	Op. Cost Acetic Acid "Units"		$ 24,709,302.33	$ 98,837,209.30	$ 98,837,209.30	$ 98,837,209.30	$ 98,837,209.30	$ 98,837,209.30	$ 98,837,209.30	$ 98,837,209.30	$ 98,837,209.30	$ 98,837,209.30
	Op. Cost Acetic Acid (-)		$ (46,947.67)	$ (187,790.70)	$ (187,790.70)	$ (187,790.70)	$ (187,790.70)	$ (187,790.70)	$ (187,790.70)	$ (187,790.70)	$ (187,790.70)	$ (187,790.70)
tonne/unit	Op. Cost Waste Disposal "Units"		$ 0.30	$ 1.20	$ 1.20	$ 1.20	$ 1.20	$ 1.20	$ 1.20	$ 1.20	$ 1.20	$ 1.20
	Op. Cost Waste Disposal (-)		$ (299.30)	$ (1,197.18)	$ (1,197.18)	$ (1,197.18)	$ (1,197.18)	$ (1,197.18)	$ (1,197.18)	$ (1,197.18)	$ (1,197.18)	$ (1,197.18)
	Op. Labor Costs (-)		$ (283,645.00)	$ (1,134,580.00)	$ (1,134,580.00)	$ (1,134,580.00)	$ (1,134,580.00)	$ (1,134,580.00)	$ (1,134,580.00)	$ (1,134,580.00)	$ (1,134,580.00)	$ (1,134,580.00)
	Sum Op. Costs (-)		$ (489,140.13)	$ (1,956,560.53)	$ (1,956,560.53)	$ (1,956,560.53)	$ (1,956,560.53)	$ (1,956,560.53)	$ (1,956,560.53)	$ (1,956,560.53)	$ (1,956,560.53)	$ (1,956,560.53)
MACRS	Depreciation (-)		$ (2,220,000.00)	$ (5,476,000.00)	$ (5,860,800.00)	$ (4,688,640.00)	$ (3,751,800.00)	$ (3,000,700.00)	$ (2,544,860.00)	$ (2,423,500.00)	$ (2,425,720.00)	$ (2,424,980.00)
	Amortization (-)											
	Depletion (-)											
	Loss Forward (-)											
	Writeoff (-)											$ (2,183,000.00)
	Taxable Income		$ 6,437,675.27	$ 31,111,261.63	$ 30,726,461.63	$ 31,898,621.63	$ 32,835,461.63	$ 33,586,561.63	$ 34,042,401.63	$ 34,163,761.63	$ 34,161,541.63	$ 31,979,281.63
	Tax @ 40%		$ (2,575,070.11)	$ (12,444,504.65)	$ (12,290,584.65)	$ (12,759,448.65)	$ (13,134,184.65)	$ (13,434,624.65)	$ (13,616,960.65)	$ (13,665,504.65)	$ (13,664,616.65)	$ (12,791,712.65)
	Net Income		$ 3,862,605.16	$ 18,666,756.98	$ 18,435,876.98	$ 19,139,172.98	$ 19,701,276.98	$ 20,151,936.98	$ 20,425,440.98	$ 20,498,256.98	$ 20,496,924.98	$ 19,187,568.98
	Depreciation (+)		$ 2,220,000.00	$ 5,476,000.00	$ 5,860,800.00	$ 4,688,640.00	$ 3,751,800.00	$ 3,000,700.00	$ 2,544,860.00	$ 2,423,500.00	$ 2,425,720.00	$ 2,424,980.00
	Amortization (+)		0	0	0	0	0	0	0	0	0	0
	Depletion (+)		0	0	0	0	0	0	0	0	0	0
	Loss Forward (+)		0	0	0	0	0	0	0	0	0	0
	Writeoff (+)											$ 2,183,000.00
Spares/Unspecified	Working Capital (-)	$ (2,220,000.00)	$ (5,180,000.00)									
In-Use Equipment	Fixed Capital (-)	$ (22,200,000.00)	$ (14,800,000.00)									
	Cash Flow	$ (24,420,000.00)	$ (13,897,394.84)	$ 24,142,756.98	$ 24,296,676.98	$ 23,827,812.98	$ 23,453,076.98	$ 23,152,636.98	$ 22,970,300.98	$ 22,921,756.98	$ 22,922,644.98	$ 23,795,548.98
	Discounted Factor (P/Fi,n)	1	0.869565217	0.756143667	0.657516232	0.571753246	0.497176735	0.432327596	0.37593704	0.326901774	0.284262412	0.247184706
	Discounted Cash Flow	$ (24,420,000.00)	$ (12,084,691.16)	$ 18,255,392.80	$ 15,975,459.51	$ 13,623,629.40	$ 11,660,324.24	$ 10,009,523.88	$ 8,635,386.96	$ 7,493,163.02	$ 6,516,046.35	$ 5,881,895.78
	NPV @ i* =	$ 61,546,130.78										
	DCFROR =	27%										
	PWC	$ (36,504,691.16)										
	Payback Period											

Sensitivity Analysis

The sensitivity analysis for this project was considered using a DCFROR Analysis as well as an NPV analysis in order to determine the economic situation with shifts in certain variables. The variables considered in these analyses were Product Price, Raw Material Cost, Fixed Capital Cost, and Conversion Rate. Table 21 summarizes the variability considerations for each factor [10].

Table 23: Sensitivity Analysis Variables

Variable	Analyzed Change
Product Price	-50% to +20%
Raw Material Cost	-25% to +50%
Fixed Capital Cost	-10% to +25%
Conversion Rate	-5% to +5%

For the first economic consideration, Net Present Value (NPV), the following Tornado Chart depicts the magnitude each variable affects the NPV.

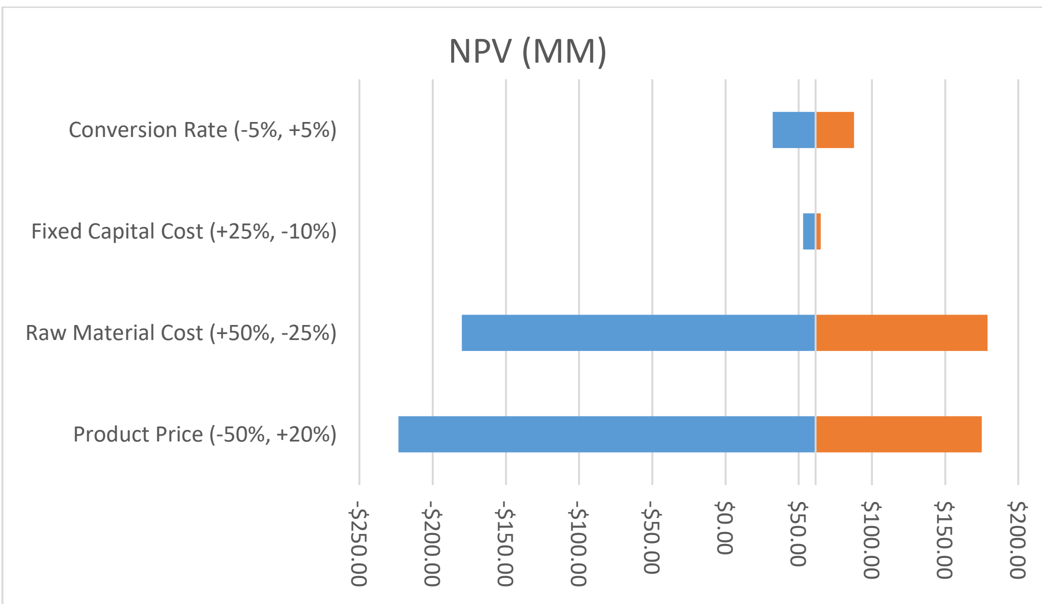

Figure 4: NPV Sensitivity Analysis

As can be seen, the NPV is most positively impacted by a decreased Raw Material Cost, while it is most negatively impacted by a decreased price in product, Nylon 6,6. The effects of these two factors dwarf those of the other two. The second economic consideration, Discounted Cash Flow Rate of Return (DCFROR), is depicted below and how each variable affects it.

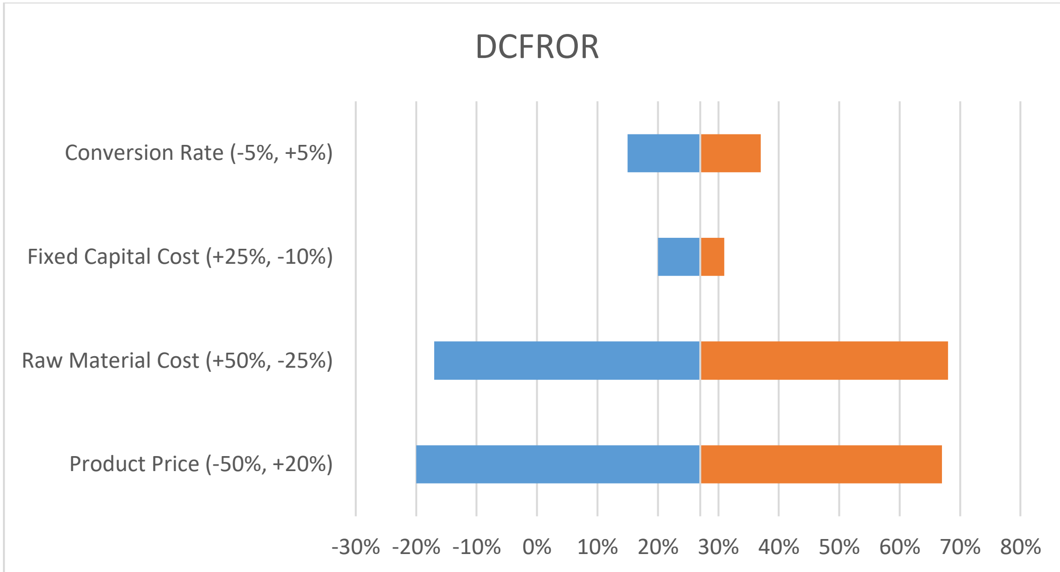

Figure 5: DCFROR Sensitivity Analysis

The effects of the conversion rate and the fixed capital cost have larger magnitudes of effect on the DCFROR than they did on the NPV previously. However, similar to the Tornado Chart for NPV, the largest affects towards the DCFROR are in regards to sale price of Nylon 6,6 and costs for raw materials.

As can be seen from both the tornado charts for the NPV Sensitivity Analysis and the DCFROR Sensitivity Analysis, the factors with the most effect on the NPV and the DCFROR are the cost of raw materials and the price of Nylon 6,6. These two factors, as they are considered mutually dependent on each other, are usually very proportional in price with each other, even with volatility in the market. Below is a summary table of all sensitivity analysis details.

Table 24: Sensitivity Analysis Summary

Variable Considered	**Reduced Variable**	**Increased Variable**
Price of Nylon 6,6	**-50%**	**+20%**
NPV ($MM)	-223.51	175.12
DCFROR (%)	-20	67
Cost of Raw Materials	**-25%**	**+50%**
NPV ($MM)	178.94	-180.14
DCFROR (%)	68	-17
Conversion Rate	**-5%**	**+5%**
NPV ($MM)	32.13	87.73
DCFROR (%)	15%	37%

Fixed Capital Cost	-10%	+25%
NPV ($MM)	64.95	53.03
DCFROR (%)	31%	20%

Breakeven

While holding all other costs constant and just considering the price of Nylon 6,6, a breakeven cost may be determined. Breakeven cost is the cost of product (Nylon 6,6) when the NPV is equal to zero. For this project, the breakeven cost was determined to be $2.29 per pound. The table below summarizes this investigation.

Table 25: Breakeven Cost Summary

Product	Original Selling Price	Breakeven Price (NPV = 0)	Percentage change
Nylon 6,6	$2.57	$2.29	-10.9%

Turndown Analysis

A turndown characteristic was specified in order to reduce Nylon production due to market demands. The specific turndown specification is 67%. The economic ramifications for this turn down over a variety of time specifications are as follows.

Table 26: Turndown Summary

Considered Variable	NPV ($MM)	DCFROR (%)
100% Nylon Production	61.5	27
67% Nylon Production Year 2	56.1	24
67% Nylon Production Year 10	59.8	27
67% Nylon Production Years 2-6	40.4	18
67% Nylon Production Years 6-10	49.4	25
67% Nylon Production 10-Year Period	31.5	16

For this analysis, all years except year 0 and year 1 were considered, as those years attain less or no production of Nylon. From the summary table, as can be assumed, the turndown of plant production of Nylon 6,6 reduces the Net Present Value and the attached Discounted Cash Flow Rate of Return. Along with this, it can be noticed that a turndown later in the plant life has less affect than a turndown early on in the life of the plant. In the case of a total turndown of production over the 10-year life of the plant, the operation will still be a profitable enterprise.

Conclusion and Recommendations

A continuous process was chosen for the Nylon 6,6 manufacturing facility, because the specified product flow rate given was greater than the maximum flow rate specified for batch processes. Also, a continuous process would be inherently safer because the reaction and storage time would be shorter. Pellets were chosen over fiber because from pricing information, it was found pellets would sell more per pound than fiber would, without having to change major pieces of equipment. A simulation with three polymerization reactors that decreased pressure to atmospheric was found to give the product within design specifications for product flowrate and moisture composition. After sizing and economics, the NPV was determined to be $61.5 MM and the process had a DCFROR of 27% for the 100% case. We also found that it would be more beneficial for the turndown case to happen towards the end of the plant life than beginning, but even if turndown occurred over the entire process life there would still be a positive NPV and DCFROR.

It is recommended to go forward with the current plan since both the NPV and DCFROR are positive. For further analysis, it is recommended to consider adding on processes for making HMDA and ADA in house. This would drive down the cost of raw materials and potentially increase the NPV of the process. Also, more research should be done on more specific equipment sizing for the extruder and air dryer, which would give a more accurate capital cost. More research should also be done on stabilizing the polymerization reaction using acetic acid, which would drive down the material cost of acetic acid.

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Appendix

Table 27: Condenser Calculations

Countercurrent Flow	
T prodcut,o (°F)	90
T prodcut,i (°F)	400.37
T water,o (°F)	104
T water,i (°F)	86
LMTD	68

q (Btu/hr)	1.2023E+06
U_o (Btu / hr ft2 °F)	208
A_o (ft^2)	85

$c_{p\ water}$ (Btu / lb_m)	0.997
m_h (lbm/hr)	66995.4
q (gpm)	134
q (m^3/yr)	267317

K1	4.3247
K2	-0.303
K3	0.1634
A (ft^2)	85.20011716
A (m^2)	7.915357552
logCp0	4.184367964
Cp0	15288.60865

C1	0.03881
C2	-0.11272
C3	0.08138
P operating (psi)	64.7
P Design (barg)	6.93
logFp	0.00156347
Fp	1.003606509

Tubes: 3/4" OD 14 BWG	
Thickness (in)	0.083
OD (in)	0.75
ID (in)	0.584
x_w/k_w (hr ft^2 °F / Btu)	0.0007

Condensing Fluid on Shell Side	
h_i (Btu / hr ft2 °F)	1200
h_o (Btu / hr ft2 °F)	2500
R_{fi} (hr ft2 °F / Btu)	0.0005
R_{fo} (hr ft2 °F / Btu)	0.002

Purchase Cost:

Identification Number	1
Fm	2.8
Cp (2001)	$42,962
Cp (2016)	$58,535

Installed Cost:

Fm	1
B1	1.63
B2	1.66
Cbm (2001)	$96,238
Cbm (2016)	$131,121

Installation Cost	$72,586

Table 28: Dryer Calculations

Countercurrent Flow	
T prodcut,o (°F)	75
T prodcut,i (°F)	539.33
T Air,o (°F)	59
T Air,i (°F)	59
LMTD	136

q (Btu/hr)	2.6726E+06
U_o (Btu / hr ft2 °F)	17
A_o (ft^2)	1174

Tubes: 3/4" OD 14 BWG	
Thickness (in)	0.083
OD (in)	0.75
ID (in)	0.584
x_w/k_w (hr ft^2 °F / Btu)	0.0007

Condensing Fluid on Shell Side	
h_i (Btu / hr ft2 °F)	100
h_o (Btu / hr ft2 °F)	25
R_{fi} (hr ft2 °F / Btu)	0.005
R_{fo} (hr ft2 °F / Btu)	0

Area (m^2)	33.24398	
Rotary, Gas Fired		
K1	K2	K3
3.5645	1.1118	-0.0777
Cp0	$ 162,459.11	
FBM	1.25	
CBM	$ 203,073.89	

Table 29: Evaporator Calculations

Short Tube ()				
K1	K2	K3	Cp0	
5.2366	-0.6572	0.35	$	239,093.52
FM		CBM (P<10)	CBM (P>10)	
CS	2.2	$ 526,005.74	$	542,116.10
Cu Alloy	2.8	$ 669,461.85	$	689,965.95
SS	3.95	$ 944,419.39	$	973,344.82
Ni Alloy	7.5	$ 1,793,201.37	$	1,848,123.07
Ti	11.28	$ 2,696,974.87	$	2,779,577.10

Countercurrent Flow	
T prodcut,o (°F)	539.33
T prodcut,i (°F)	431.33
T Heating Fluid,o (°F)	560
T Heating Fluid,i (°F)	560
LMTD	59

Tubes: 3/4" OD 14 BWG	
Thickness (in)	0.083
OD (in)	0.75
ID (in)	0.584
x_w/k_w (hr ft^2 °F / Btu)	0.0007

q (Btu/hr)	2.1987E+06
U_o (Btu / hr ft2 °F)	45
A_o (ft^2)	836

Condensing Fluid on Shell Side	
h_i (Btu / hr ft2 °F)	100
h_o (Btu / hr ft2 °F)	500
R_{fi} (hr ft2 °F / Btu)	0.005
R_{fo} (hr ft2 °F / Btu)	0.0005

$m_{product}$ (lbm/hr)	0.000E+00
$\lambda_{fg\ heating\ fluid}$ (Btu / lb_m)	1.1980E+02
m_h (lbm/hr)	1.8353E+04
q (gpm)	37
q (m^3/yr)	73231

Area (m^2)	Pressure (barg)	Fp
78	23.4422	1.030627737

C1	C2	C3
0.1578	-0.2992	0.1413

Table 30: Pump 1 1st Stage Calculations

Head (delta P is known)	
P out (barg)	16.56
ΔP (psi)	139.6115
Density (lb/ft3)	52.44
SG	0.840
Head (ft)	383.8

Brake Horsepower	
Capacity (gpm)	11.85
Head (ft)	383.8
Efficiency of Pump	0.65
Efficiency of Motor	0.82
BHP	1.5
PHP	1.8
Buying PHP	2

(Centrifugal)	
K1	3.3892
K2	0.0536
K3	0.1538
Power (hp)	2
Power (kW)	1.4914
logCp0	3.403139397
Cp0	$2,530
C1	-0.3935
C2	0.3957
C3	-0.00226
P (psig)	204.30
P Design (barg)	17.53333609
logFp	0.10
Fp	1.25
Purchase Cost:	
Identification Number	39
Fm	2.3
Cp (2001)	$7,245
Cp (2016)	$9,872
Cp (2016) 1+spare	$19,744
Installed Cost:	
Fm	2.3
B1	1.89
B2	1.35
Cbm (2001)	$14,563
Cbm (2016)	$19,842
Cbm (2016) 1+spare	$39,684.13
Installation Cost	$19,941

Table 31: Pump 2nd Stage Calculations

Head (delta P is known)	
P out (barg)	16.56
ΔP (psi)	139.6115
Density (lb/ft3)	52.44
SG	0.840
Head (ft)	383.8

Brake Horsepower	
Capacity (gpm)	11.85
Head (ft)	383.8
Efficiency of Pump	0.65
Efficiency of Motor	0.82
BHP	1.5
PHP	1.8
Buying PHP	2

(Centrifugal)	
K1	3.3892
K2	0.0536
K3	0.1538
Power (hp)	2
Power (kW)	1.4914
logCp0	3.4031394
Cp0	$2,530
C1	-0.3935
C2	0.3957
C3	-0.00226
P (psig)	343.91
P Design (barg)	27.159089
logFp	0.17
Fp	1.48
Purchase Cost:	
Identification Number	39
Fm	2.3
Cp (2001)	$8,593
Cp (2016)	$11,707
Cp (2016) 1+spare	$23,414
Installed Cost:	
Fm	2.3
B1	1.89
B2	1.35
Cbm (2001)	$16,382
Cbm (2016)	$22,320
Cbm (2016) 1+spare	$44,639.41
Installation Cost	$21,225

Table 32: Pump 2 Calculations

Head (delta P is known)	
P out (barg)	27.20
ΔP (psi)	293.923
Density (lb/ft3)	84.9
SG	1.361
Head (ft)	499.0

Brake Horsepower	
Capacity (gpm)	9.2
Head (ft)	499.0
Efficiency of Pump	0.65
Efficiency of Motor	0.83
BHP	2.4
PHP	2.9
Buying PHP	3

(Centrifugal)	
K1	3.3892
K2	0.0536
K3	0.1538
Power (hp)	3
Power (kW)	2.2371
logCp0	3.426749782
Cp0	$2,671
C1	-0.3935
C2	0.3957
C3	-0.00226
P (psig)	343.91
P Design (barg)	27.15908934
logFp	0.17
Fp	1.48
Purchase Cost:	
Identification Number	39
Fm	2.3
Cp (2001)	$9,073
Cp (2016)	$12,361
Cp (2016) 1+spare	$24,722
Installed Cost:	
Fm	2.3
B1	1.89
B2	1.35
Cbm (2001)	$17,297
Cbm (2016)	$23,567
Cbm (2016) 1+spare	$47,133
Installation Cost	$22,411

Table 33: Reactor 1 Calculations

D (ft)	9
H (ft)	27
V (ft^3)	1717.665783
V (m^3)	50.15894118
$P_{operating}$ (psig)	103.3
Pdesign (barg)	10.56964382

K_1	4.1052
K_2	0.532
K_3	-0.0005
$\log C_p^o$	5.008339735
C_p^o	101938.8513

D (m)	2.74
F_P	3.484299751

Purchase Cost:

Identification Number	20
Fm	3.1
Cp (2001)	1101075.094
Cp (2016)	$ 1,500,180

Installed Cost:

B_1	2.25
B_2	1.82
F_{bm}	21.9084192
C_{bm} (2001)	2233319.086
C_{bm} (2016)	**$ 3,042,827**

Table 34: Reactor 2 Calculations

D (ft)	6.75
H (ft)	20.25
V (ft^3)	724.6402524
V (m^3)	18.85
$P_{operating}$ (psig)	293.9
Pdesign (barg)	23.71102745

K_1	4.1052
K_2	0.532
K_3	-0.0005
$\log C_p^o$	4.799920744
C_p^o	63084.22095

D (m)	2.05
F_P	5.31390454
Volume (M3)	20.29891006

Purchase Cost:

Identification Number	20
Fm	3.1
Cp (2001)	$ 1,039,193
Cp (2016)	$ 1,415,868

Installed Cost:

B_1	2.25
B_2	1.82
F_{bm}	32.23104942
C_{bm} (2001)	2033270.643
C_{bm} (2016)	**$ 2,770,267**

q(Btu/hr)	3.42E+06
$\lambda_{fg\ heating\ fluid}$ (Btu / lb_m)	1.3460E+02
m_h (lbm/hr)	25406
q (gpm)	51
q (m^3/yr)	101371

Table 35: Reactor 3 Calculations

D (ft)	10.5
H (ft)	31.5
V (ft^3)	2727.589647
V (m^3)	75.8
$P_{operating}$ (psig)	147
Pdesign (barg)	13.58264731

K_1	4.1052
K_2	0.532
K_3	-0.0005
$\log C_p^o$	5.107654058
C_p^o	128130.9534

D (m)	3.2
F_P	4.902410297
Volume (M3)	77.20778105

Purchase Cost:

Identification Number	20
Fm	3.1
Cp (2001)	$ 1,947,267
Cp (2016)	$ 2,653,089

Installed Cost:

B_1	2.25
B_2	1.82
F_{bm}	29.9093989
C_{bm} (2001)	3832319.796
C_{bm} (2016)	**$ 5,221,415**

q(Btu/hr)	2.32E+05
$\lambda_{fg\ heating\ fluid}$ (Btu / lb_m)	1.3240E+02
m_h (lbm/hr)	1755
q (gpm)	4
q (m^3/yr)	7003

Table 36: Reactor 4 Calculations

D (ft)	5
H (ft)	15
V (ft^3)	294.5243113
V (m^3)	7.95
$P_{operating}$ (psig)	73.5
Pdesign (barg)	8.515009859

K_1	4.1052
K_2	0.532
K_3	-0.0005
$\log C_p^o$	4.593017566
C_p^o	39175.7722

D (m)	1.52
F_P	1.859534174
Volume (M3)	8.27450266

Purchase Cost:

Identification Number	20
Fm	3.1
Cp (2001)	$ 225,831
Cp (2016)	$ 307,688

Installed Cost:

B_1	2.25
B_2	1.82
F_{bm}	12.74149181
C_{bm} (2001)	499157.7806
C_{bm} (2016)	**$ 680,087**

q(Btu/hr)	5.64E+04
$\lambda_{fg\ heating\ fluid}$ (Btu / lb_m)	1.3240E+02
m_h (lbm/hr)	426
q (gpm)	1
q (m^3/yr)	1700

Table 37: Reactor 5 Calculations

D (ft)	7.25
H (ft)	21.75
V (ft^3)	897.8941785
V (m^3)	25.1
$P_{operating}$ (psig)	14.7
Pdesign (barg)	4.460899902

K_1	4.1052
K_2	0.532
K_3	-0.0005
$\log C_p^o$	4.851878836
C_p^o	71101.51188

D (m)	2.21
F_P	1.631212907
Volume (M3)	25.43243582

Purchase Cost:

Identification Number	20
Fm	3.1
Cp (2001)	$ 359,543
Cp (2016)	$ 489,866

Installed Cost:

B_1	2.25
B_2	1.82
F_{bm}	11.45330322
C_{bm} (2001)	814347.1751
C_{bm} (2016)	**$ 1,109,522**

q(Btu/hr)	4.55E+04
$\lambda_{fg\ heating\ fluid}$ (Btu / lb_m)	1.3240E+02
m_h (lbm/hr)	343
q (gpm)	1
q (m^3/yr)	1370

Table 38: Reactor 6 Calculations

D (ft)	10
H (ft)	30
V (ft^3)	2356.19449
V (m^3)	64.57428571
$P_{operating}$ (psig)	103.3
Pdesign (barg)	10.56964382

K_1	4.1052
K_2	0.532
K_3	-0.0005
$\log C_p^o$	5.066513555
C_p^o	116550.3428

D (m)	3.05
F_P	3.821939504

Purchase Cost:

Identification Number	20
Fm	3.1
Cp (2001)	1380889.914
Cp (2016)	$ 1,881,419

Installed Cost:

B_1	2.25
B_2	1.82
F_{bm}	23.81338268
C_{bm} (2001)	2775457.914
C_{bm} (2016)	**$ 3,781,474**

Table 39: Salt Tank Calculations

Diameter (ft)	15.25
Diameter (m)	4.65
Length (ft)	45.75
Length (m)	13.94
Volume (m^3)	236.63
Pressure (psia)	64.70
Pressure (barg)	6.89
MOC	SS

CEPCI	2001	397
	2016	540.9

Mass flow (kg/h)	5366.26
density (kg/m^3)	1115.734
Volume (m^3/day)	115.431
Volume (m^3)	230.862
Volume (ft^3)	8152.822
Diameter (ft)	15.13

Cost	
K1	3.5565
K2	0.3376
K3	0.0905
Fp	3.945571452
Fm	3.6
B1	1.49
B2	1.52
$\log_{10}C_P^0$(2001)	4.868059478
C_p^0 (2001)	$ 73,801
C_p^0(2016)	$ 100,551
C_{BM} (2001)	$ 1,703,329
C_p(2016)	$ 1,428,231
C_{BM} (2016)	$ 2,320,732

Table 40: Extruder and Related Equipment

Material Costs ($/lb)(SS)	Bulk Volume (ft^3)	Material Density (lb/ft^3)	Thickest Wall (in)	Thinnest Wall (in)
1.04	671	500	3	0.5
Material by Unit	$ 348,920.00			
		Motor (Electric/Enclosed)		(75-2600 kW)
Cp0 (Extruder)	$ 558,272.00	kW		75
Cp0 (Cutter)	$ 27,913.60			
CBM (Extruder)	$ 658,760.96	K1		1.956
CBM (Cutter)	$ 32,938.05	K2		1.7142
CBM (Motor)	$ 34,994.78	K3		-0.2282
		Cp0		$ 23,329.85
Ctm	$ 857,498.67	CBM		$ 34,994.78
CBM,total	$ 726,693.78			

Table 41: Utility Equipment Costing

Cooling Tower	
	Air Cooler
Area (m^2)	3140
K1	4.0336
K2	0.2341
K3	0.0497
Cp0	$ 288,395.53
CBM	$ 1,295,818.79
Ctm	$ 1,529,066.17

	Screens (stationary)
Area	5
K1	3.8219
K2	1.0368
K3	-0.605
Cp0	$ 17,824.36
CBM	$ 23,884.64

	Tank1 (SS)
Volume	100
K1	4.8509
K2	-0.3973
K3	0.1445
Cp0	$ 43,082.41
CBM	$ 133,555.47

	Tank2 (SS)
Volume	100
K1	4.8509
K2	-0.3973
K3	0.1445
Cp0	$ 43,082.41
CBM	$ 133,555.47

	Steam Boiler
Duty	P
1200	25
K1	6.9617
K2	-1.48
K3	0.3161
Cp0	$ 252,097.62
CBM	$ 774,181.37
Ctm	$ 913,534.01

Dutyi	628
Cp0	$ 171,548.75
CBM	$ 526,819.12
Ctm	$ 621,646.56

	Non Reactive Furnace
Duty (kW)	1000
K1	7.3488
K2	-1.1666
K3	0.2028
Cp0	$ 472,280.48
CBM	$ 1,227,929.26

Size (kW)	806
Cp0	$ 414,955.02
CBM	$ 1,078,883.05

BTU/hr	2,200,000.00
kW	644.76
kW'	805.95

	Cp0	CBM
Furnace	$ 414,955.02	$ 1,078,883.05
Steam Boiler	$ 171,548.75	$ 526,819.12
Wastewater/Deionizer	$ 380,048.16	$ 918,209.39
Cooling Tower	$ 288,395.53	$ 1,295,818.79
Total	$ 1,254,947.45	$ 3,819,730.34

Table 42: Total Equipment Summary

	CBM
Primary Equipment	$ 21,092,014.78
Utilities	$ 3,819,730.34
Total	$ 24,911,745.12
CTM	$ 29,395,859.25
Land	$1,000,000
Cgr	$ 36,623,795.53

Aspen Report

ASPEN PLUS   PLAT: WINDOWS   VER: 34.0   03/06/2017 PAGE 1

RUN CONTROL SECTION

RUN CONTROL INFORMATION

THIS COPY OF ASPEN PLUS LICENSED TO OKLAHOMA STATE UNIVERSIT

TYPE OF RUN: NEW

INPUT FILE NAME: _4157zgx.inm

OUTPUT PROBLEM DATA FILE NAME: _4157zgx
LOCATED IN:

PDF SIZE USED FOR INPUT TRANSLATION:
  NUMBER OF FILE RECORDS (PSIZE) =   0
  NUMBER OF IN-CORE RECORDS   =   256
PSIZE NEEDED FOR SIMULATION   =   256

CALLING PROGRAM NAME: apmain
LOCATED IN: C:\Program Files (x86)\AspenTech\Aspen Plus V8.8\Engine\\xeq

SIMULATION REQUESTED FOR ENTIRE FLOWSHEET

DESCRIPTION

Polymers Simulation with Metric Units : K, atm, kg/hr, kmol/hr,
cal/sec, l/min. Property Method: None Flow basis for input: Mass
Stream report composition: Mass flow

FLOWSHEET SECTION

FLOWSHEET CONNECTIVITY BY STREAMS

STREAM	SOURCE	DEST	STREAM	SOURCE	DEST
FEED	----	CSTR1	VAPOR1	CSTR1	MIXER
S34	CSTR1	EVAPORAT	S1	CSTR2	CSTR3
VAPOR2	CSTR2	MIXER	S4	CSTR3	CSTR4
VAPOR3	CSTR3	MIXER	VAPOR4	CSTR4	MIXER
S35	CSTR4	DRYER	S25	MIXER	B10
PRODUCT	B10	----	S33	EVAPORAT	MIXER
S32	EVAPORAT	CSTR2	POLYMER	DRYER	----

FLOWSHEET CONNECTIVITY BY BLOCKS

BLOCK	INLETS	OUTLETS
CSTR1	FEED	VAPOR1 S34
CSTR2	S32	S1 VAPOR2
CSTR3	S1	S4 VAPOR3
CSTR4	S4	VAPOR4 S35
MIXER	VAPOR1 VAPOR4 VAPOR3 S33 VAPOR2	S25
B10	S25	PRODUCT
EVAPORAT	S34	S33 S32
DRYER	S35	POLYMER

COMPUTATIONAL SEQUENCE

SEQUENCE USED WAS:
CSTR1 EVAPORAT CSTR2 CSTR3 CSTR4 DRYER MIXER B10

OVERALL FLOWSHEET BALANCE

*** MASS AND ENERGY BALANCE ***

	IN	OUT	GENERATION	RELATIVE DIFF.
CONVENTIONAL COMPONENTS				
(KMOL/HR)				
HMDA	19.4490	0.265777E-01	-19.4224	-0.148061E-16
ADA	19.4490	0.227518E-02	-19.4467	0.255539E-15
H2O	38.8980	77.6197	38.7216	-0.677408E-14
NYLON-66	0.00000	19.4479	19.4479	0.275844E-13
TOTAL BALANCE				

```
 MOLE(KMOL/HR )       77.7961       97.0965       19.3004       0.00000
 MASS(KG/HR   )       5803.20       5803.20                 0.241353E-13
 ENTHALPY(CAL/SEC )   -0.193942E+07 -0.197805E+07              0.195309E-01
```

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FLOWSHEET SECTION

OVERALL FLOWSHEET BALANCE (CONTINUED)

```
             ***  CO2 EQUIVALENT SUMMARY ***
  FEED STREAMS CO2E           0.00000      KG/HR
  PRODUCT STREAMS CO2E        0.00000      KG/HR
  NET STREAMS CO2E PRODUCTION   0.00000      KG/HR
  UTILITIES CO2E PRODUCTION     0.00000      KG/HR
  TOTAL CO2E PRODUCTION        0.00000      KG/HR
```

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PHYSICAL PROPERTIES SECTION

COMPONENTS

```
 ID      TYPE  ALIAS         NAME
 HMDA     C    C6H16N2       HEXAMETHYLENEDIAMINE
 ADA      C    C6H10O4-D1    ADIPIC-ACID
 H2O      C    H2O           WATER
 HMDA-E   C    C6H15N2-E     HEXAMETHYLENE-DIAMINE-E
 ADA-E    C    C6H9O3-E      ADIPIC-ACID-E
 HMDA-R   C    C6H14N2-R     HEXAMETHYLENE-DIAMINE-R
 ADA-R    C    C6H8O2-R      ADIPIC-ACID-R
 NYLON-66 C    NYLON66       NYLON-66

 ID           ATTRIBUTE TYPES
 NYLON-66      SFRAC SFLOW EFRAC ZMOM FMOM DPN MWN
```

REACTION SECTION

REACTION: R-1 TYPE: STEP-GROWTH

Unit operations referencing this reaction model:

Reactor Name	Block Type	Reactor Name	Block Type
CSTR1	RCSTR	CSTR2	RCSTR
CSTR3	RCSTR	CSTR4	RCSTR

The polymer being produced is: NYLON-66

Reactions generated by this Step Growth Model

```
 1) HMDA     + ADA      -> H2O      + HMDA-E   + ADA-E
 2) HMDA     + ADA-E    -> H2O      + HMDA-E   + ADA-R
 3) HMDA     + ADA-E    + HMDA-R   -> HMDA-E   + ADA-E    + HMDA-E
 4) HMDA     + ADA-R    + HMDA-R   -> HMDA-E   + ADA-R    + HMDA-E
 5) H2O      + ADA-E    + HMDA-E   -> ADA      + HMDA
 6) H2O      + ADA-E    + HMDA-R   -> ADA      + HMDA-E
 7) H2O      + ADA-R    + HMDA-E   -> ADA-E    + HMDA
 8) H2O      + ADA-R    + HMDA-R   -> ADA-E    + HMDA-E
 9) HMDA-E   + ADA      -> H2O      + HMDA-R   + ADA-E
10) HMDA-E   + ADA-E    -> H2O      + HMDA-R   + ADA-R
11) HMDA-E   + ADA-E    + HMDA-E   -> HMDA-R   + ADA-E    + HMDA
12) HMDA-E   + ADA-R    + HMDA-E   -> HMDA-R   + ADA-R    + HMDA
```

U-O-S BLOCK SECTION

BLOCK: B10 MODEL: HEATER

INLET STREAM: S25
OUTLET STREAM: PRODUCT
PROPERTY OPTION SET: POLYNRTL POLYMER NRTL / REDLICH-KWONG

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(KMOL/HR)	77.3749	77.3749	0.00000
MASS(KG/HR)	1396.76	1396.76	0.00000
ENTHALPY(CAL/SEC)	-0.120237E+07	-0.147060E+07	0.182394

*** CO2 EQUIVALENT SUMMARY ***

FEED STREAMS CO2E	0.00000	KG/HR
PRODUCT STREAMS CO2E	0.00000	KG/HR
NET STREAMS CO2E PRODUCTION	0.00000	KG/HR
UTILITIES CO2E PRODUCTION	0.00000	KG/HR
TOTAL CO2E PRODUCTION	0.00000	KG/HR

*** INPUT DATA ***

TWO PHASE TP FLASH

SPECIFIED TEMPERATURE	K	288.706
SPECIFIED PRESSURE	ATM	1.00000
MAXIMUM NO. ITERATIONS		30
CONVERGENCE TOLERANCE		0.000100000

*** RESULTS ***

OUTLET TEMPERATURE	K	288.71
OUTLET PRESSURE	ATM	1.0000
HEAT DUTY	CAL/SEC	-0.26823E+06
OUTLET VAPOR FRACTION		0.0000

V-L PHASE EQUILIBRIUM :

COMP	F(I)	X(I)	Y(I)	K(I)
HMDA	0.34094E-03	0.34094E-03	0.62540E-05	0.32451E-03
ADA	0.24430E-04	0.24430E-04	0.49369E-12	0.35749E-09
H2O	0.99963	0.99963	0.99999	0.17697E-01

U-O-S BLOCK SECTION

BLOCK: CSTR1 MODEL: RCSTR

INLET STREAM: FEED
OUTLET STREAMS: VAPOR1 S34
PROPERTY OPTION SET: POLYNRTL POLYMER NRTL / REDLICH-KWONG

*** MASS AND ENERGY BALANCE ***

	IN	OUT	GENERATION	RELATIVE DIFF.
TOTAL BALANCE				
MOLE(KMOL/HR)	77.7961	95.4820	17.6859	0.00000
MASS(KG/HR)	5803.20	5803.20		0.517186E-14
ENTHALPY(CAL/SEC)	-0.193942E+07	-0.170005E+07		-0.123423

*** CO2 EQUIVALENT SUMMARY ***

FEED STREAMS CO2E 0.00000 KG/HR
PRODUCT STREAMS CO2E 0.00000 KG/HR
NET STREAMS CO2E PRODUCTION 0.00000 KG/HR
UTILITIES CO2E PRODUCTION 0.00000 KG/HR
TOTAL CO2E PRODUCTION 0.00000 KG/HR

*** INPUT DATA ***

REACTOR TYPE: TEMP SPEC TWO PHASE REACTOR

RESIDENCE TIME	HR	0.33333
REACTOR TEMPERATURE	K	495.00
REACTOR PRESSURE	ATM	20.000

*** RESULTS ***

REACTOR HEAT DUTY	CAL/SEC	0.23937E+06
REACTOR VOLUME	L	17321.
VAPOR PHASE VOLUME FRACTION		0.88075
VAPOR PHASE VOLUME	L	15255.
LIQUID PHASE VOLUME	L	2065.5

BLOCK: CSTR2 MODEL: RCSTR

INLET STREAM: S32
OUTLET STREAMS: S1 VAPOR2
PROPERTY OPTION SET: POLYNRTL POLYMER NRTL / REDLICH-KWONG

U-O-S BLOCK SECTION

BLOCK: CSTR2 MODEL: RCSTR (CONTINUED)

*** MASS AND ENERGY BALANCE ***

	IN	OUT	GENERATION	RELATIVE DIFF.
TOTAL BALANCE				
MOLE(KMOL/HR)	27.3575	28.6621	1.30461	0.00000
MASS(KG/HR)	4573.18	4573.18		0.00000
ENTHALPY(CAL/SEC)	-486873.	-470608.		-0.334080E-01

*** CO2 EQUIVALENT SUMMARY ***

FEED STREAMS CO2E 0.00000 KG/HR
PRODUCT STREAMS CO2E 0.00000 KG/HR
NET STREAMS CO2E PRODUCTION 0.00000 KG/HR
UTILITIES CO2E PRODUCTION 0.00000 KG/HR
TOTAL CO2E PRODUCTION 0.00000 KG/HR

*** INPUT DATA ***

REACTOR TYPE: TEMP SPEC TWO PHASE REACTOR

RESIDENCE TIME	HR	0.33333
REACTOR TEMPERATURE	K	555.00
REACTOR PRESSURE	ATM	10.000

*** RESULTS ***

REACTOR HEAT DUTY	CAL/SEC	16265.
REACTOR VOLUME	L	10792.
VAPOR PHASE VOLUME FRACTION		0.83923
VAPOR PHASE VOLUME	L	9057.1
LIQUID PHASE VOLUME	L	1735.1

BLOCK: CSTR3 MODEL: RCSTR

INLET STREAM: S1
OUTLET STREAMS: S4 VAPOR3
PROPERTY OPTION SET: POLYNRTL POLYMER NRTL / REDLICH-KWONG

*** MASS AND ENERGY BALANCE ***

	IN	OUT	GENERATION	RELATIVE DIFF.
TOTAL BALANCE				
MOLE(KMOL/HR)	22.5451	22.6850	0.139917	0.00000
MASS(KG/HR)	4462.91	4462.91		-0.611368E-15

ENTHALPY(CAL/SEC) -375948. -371999. -0.105060E-01

U-O-S BLOCK SECTION

BLOCK: CSTR3 MODEL: RCSTR (CONTINUED)

*** CO2 EQUIVALENT SUMMARY ***

FEED STREAMS CO2E	0.00000	KG/HR
PRODUCT STREAMS CO2E	0.00000	KG/HR
NET STREAMS CO2E PRODUCTION	0.00000	KG/HR
UTILITIES CO2E PRODUCTION	0.00000	KG/HR
TOTAL CO2E PRODUCTION	0.00000	KG/HR

*** INPUT DATA ***

REACTOR TYPE: TEMP SPEC TWO PHASE REACTOR

RESIDENCE TIME	HR	0.33333
REACTOR TEMPERATURE	K	555.00
REACTOR PRESSURE	ATM	5.0000

*** RESULTS ***

REACTOR HEAT DUTY	CAL/SEC	3949.7
REACTOR VOLUME	L	7071.5
VAPOR PHASE VOLUME FRACTION		0.75682
VAPOR PHASE VOLUME	L	5351.8
LIQUID PHASE VOLUME	L	1719.6

BLOCK: CSTR4 MODEL: RCSTR

INLET STREAM: S4
OUTLET STREAMS: VAPOR4 S35
PROPERTY OPTION SET: POLYNRTL POLYMER NRTL / REDLICH-KWONG

*** MASS AND ENERGY BALANCE ***

	IN	OUT	GENERATION	RELATIVE DIFF.
TOTAL BALANCE				
MOLE(KMOL/HR)	20.9005	21.0704	0.169927	-0.168611E-15
MASS(KG/HR)	4430.75	4430.75		0.00000
ENTHALPY(CAL/SEC)	-344403.	-341220.		-0.923973E-02

*** CO2 EQUIVALENT SUMMARY ***

FEED STREAMS CO2E	0.00000	KG/HR
PRODUCT STREAMS CO2E	0.00000	KG/HR

NET STREAMS CO2E PRODUCTION 0.00000 KG/HR
UTILITIES CO2E PRODUCTION 0.00000 KG/HR
TOTAL CO2E PRODUCTION 0.00000 KG/HR

U-O-S BLOCK SECTION

BLOCK: CSTR4 MODEL: RCSTR (CONTINUED)

*** INPUT DATA ***

REACTOR TYPE: TEMP SPEC TWO PHASE REACTOR

RESIDENCE TIME	HR	0.33333
REACTOR TEMPERATURE	K	555.00
REACTOR PRESSURE	ATM	1.0000

*** RESULTS ***

REACTOR HEAT DUTY	CAL/SEC	3182.2
REACTOR VOLUME	L	22134.
VAPOR PHASE VOLUME FRACTION		0.92283
VAPOR PHASE VOLUME	L	20426.
LIQUID PHASE VOLUME	L	1708.1

BLOCK: DRYER MODEL: HEATER

INLET STREAM: S35
OUTLET STREAM: POLYMER
PROPERTY OPTION SET: POLYNRTL POLYMER NRTL / REDLICH-KWONG

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(KMOL/HR)	19.7216	19.7216	0.00000
MASS(KG/HR)	4406.44	4406.44	0.00000
ENTHALPY(CAL/SEC)	-320373.	-507453.	0.368665

*** CO2 EQUIVALENT SUMMARY ***
FEED STREAMS CO2E 0.00000 KG/HR
PRODUCT STREAMS CO2E 0.00000 KG/HR
NET STREAMS CO2E PRODUCTION 0.00000 KG/HR
UTILITIES CO2E PRODUCTION 0.00000 KG/HR
TOTAL CO2E PRODUCTION 0.00000 KG/HR

*** INPUT DATA ***

TWO PHASE TP FLASH
SPECIFIED TEMPERATURE K 288.150
SPECIFIED PRESSURE ATM 0.99975
MAXIMUM NO. ITERATIONS 30
CONVERGENCE TOLERANCE 0.000100000

U-O-S BLOCK SECTION

BLOCK: DRYER MODEL: HEATER (CONTINUED)

*** RESULTS ***

OUTLET TEMPERATURE	K	288.15
OUTLET PRESSURE	ATM	0.99975
HEAT DUTY	CAL/SEC	-0.18708E+06
OUTLET VAPOR FRACTION		0.0000

V-L PHASE EQUILIBRIUM :

COMP	F(I)	X(I)	Y(I)	K(I)
HMDA	0.10030E-04	0.10030E-04	0.13216E-04	0.42223E-03
ADA	0.19516E-04	0.19516E-04	0.27097E-10	0.44494E-09
H2O	0.13846E-01	0.13846E-01	0.99999	0.23143E-01
NYLON-66	0.98612	0.98612	0.91962E-76	0.29884E-79

BLOCK: EVAPORAT MODEL: FLASH2

INLET STREAM: S34
OUTLET VAPOR STREAM: S33
OUTLET LIQUID STREAM: S32
PROPERTY OPTION SET: POLYNRTL POLYMER NRTL / REDLICH-KWONG

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(KMOL/HR)	71.2428	71.2428	0.00000
MASS(KG/HR)	5366.26	5366.26	0.210160E-13
ENTHALPY(CAL/SEC)	-0.132076E+07	-0.116685E+07	-0.116530

*** CO2 EQUIVALENT SUMMARY ***

FEED STREAMS CO2E	0.00000	KG/HR
PRODUCT STREAMS CO2E	0.00000	KG/HR
NET STREAMS CO2E PRODUCTION	0.00000	KG/HR

UTILITIES CO2E PRODUCTION 0.00000 KG/HR
TOTAL CO2E PRODUCTION 0.00000 KG/HR

U-O-S BLOCK SECTION

BLOCK: EVAPORAT MODEL: FLASH2 (CONTINUED)

*** INPUT DATA ***

TWO PHASE TP FLASH	
SPECIFIED TEMPERATURE K	555.000
SPECIFIED PRESSURE ATM	20.7333
MAXIMUM NO. ITERATIONS	30
CONVERGENCE TOLERANCE	0.000100000

*** RESULTS ***

OUTLET TEMPERATURE K	555.00
OUTLET PRESSURE ATM	20.733
HEAT DUTY CAL/SEC	0.15391E+06
VAPOR FRACTION	0.61600

V-L PHASE EQUILIBRIUM :

COMP	F(I)	X(I)	Y(I)	K(I)
HMDA	0.77529E-03	0.11824E-02	0.52152E-03	0.44108
ADA	0.77904E-03	0.19632E-02	0.40850E-04	0.20808E-01
H2O	0.72417	0.28261	0.99944	3.5365
NYLON-66	0.27427	0.71425	0.55808E-81	0.78135E-81

BLOCK: MIXER MODEL: MIXER

INLET STREAMS: VAPOR1 VAPOR4 VAPOR3 S33 VAPOR2
OUTLET STREAM: S25
PROPERTY OPTION SET: POLYNRTL POLYMER NRTL / REDLICH-KWONG

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(KMOL/HR)	77.3749	77.3749	0.00000
MASS(KG/HR)	1396.76	1396.76	0.00000
ENTHALPY(CAL/SEC)	-0.120237E+07	-0.120237E+07	-0.193643E-15

*** CO2 EQUIVALENT SUMMARY ***
FEED STREAMS CO2E 0.00000 KG/HR
PRODUCT STREAMS CO2E 0.00000 KG/HR

NET STREAMS CO2E PRODUCTION 0.00000 KG/HR
UTILITIES CO2E PRODUCTION 0.00000 KG/HR
TOTAL CO2E PRODUCTION 0.00000 KG/HR

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U-O-S BLOCK SECTION

BLOCK: MIXER MODEL: MIXER (CONTINUED)

*** INPUT DATA ***

TWO PHASE FLASH
MAXIMUM NO. ITERATIONS 30
CONVERGENCE TOLERANCE 0.000100000
OUTLET PRESSURE: MINIMUM OF INLET STREAM PRESSURES

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STREAM SECTION

FEED POLYMER PRODUCT S1 S25

STREAM ID	FEED	POLYMER	PRODUCT	S1	S25
FROM :	----	DRYER	B10	CSTR2	MIXER
TO :	CSTR1	----	----	CSTR3	B10
SUBSTREAM: MIXED					
PHASE:	MIXED	LIQUID	LIQUID	LIQUID	VAPOR
COMPONENTS: KMOL/HR					
HMDA	19.4490	1.9781-04	2.6380-02	2.7733-03	2.6380-02
ADA	19.4490	3.8488-04	1.8903-03	3.4010-03	1.8903-03
H2O	38.8980	0.2731	77.3466	3.0671	77.3466
NYLON-66	0.0	19.4479	0.0	19.4718	0.0
COMPONENTS: KG/HR					
HMDA	2260.1029	2.2987-02	3.0655	0.3223	3.0655
ADA	2842.3381	5.6247-02	0.2763	0.4970	0.2763
H2O	700.7591	4.9194	1393.4208	55.2549	1393.4208
NYLON-66	0.0	4401.4387	0.0	4406.8389	0.0
TOTAL FLOW:					
KMOL/HR	77.7961	19.7216	77.3749	22.5451	77.3749
KG/HR	5803.2000	4406.4374	1396.7626	4462.9131	1396.7626
L/MIN	1913.1219	73.0987	23.2189	86.7549	5.4732+04
STATE VARIABLES:					
TEMP K	495.0000	288.1500	288.7056	555.0000	518.7407
PRES ATM	8.0000	0.9998	1.0000	10.0000	1.0000
VFRAC	0.2848	0.0	0.0	0.0	1.0000
LFRAC	0.7152	1.0000	1.0000	1.0000	0.0

SFRAC	0.0	0.0	0.0	0.0	0.0
ENTHALPY:					
CAL/MOL	-8.9746+04	-9.2631+04	-6.8422+04	-6.0031+04	-5.5942+04
CAL/GM	-1203.1113	-414.5823	-3790.2959	-303.2580	-3098.9692
CAL/SEC	-1.9394+06	-5.0745+05	-1.4706+06	-3.7595+05	-1.2024+06
ENTROPY:					
CAL/MOL-K	-91.0253	-326.7266	-39.5887	-216.4517	-6.1335
CAL/GM-K	-1.2203	-1.4623	-2.1930	-1.0934	-0.3398
DENSITY:					
MOL/CC	6.7774-04	4.4966-03	5.5540-02	4.3312-03	2.3562-05
GM/CC	5.0556-02	1.0047	1.0026	0.8574	4.2534-04
AVG MW	74.5950	223.4321	18.0519	197.9550	18.0519
COMPONENT ATTRIBUTES:					
NYLON-66 SFRAC					
HMDA-E	MISSING	3.1707-03	2.1880-02	1.1775-02	2.1880-02
ADA-E	MISSING	4.4212-03	2.2658-02	1.2991-02	2.2658-02
HMDA-R	MISSING	0.4965	0.4779	0.4879	0.4779
ADA-R	MISSING	0.4959	0.4775	0.4873	0.4775
SFLOW					
HMDA-E	MISSING	0.1232	0.0	0.4576	0.0
ADA-E	MISSING	0.1718	0.0	0.5049	0.0
HMDA-R	MISSING	19.2992	0.0	18.9625	0.0
ADA-R	MISSING	19.2749	0.0	18.9389	0.0
EFRAC					
HMDA-E	MISSING	0.4176	0.4913	0.4755	0.4913

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STREAM SECTION

FEED POLYMER PRODUCT S1 S25 (CONTINUED)

STREAM ID	FEED	POLYMER	PRODUCT	S1	S25
ADA-E	MISSING	0.5824	0.5087	0.5245	0.5087
ZMOM					
ZMOM	MISSING	0.1475	0.0	0.4812	0.0
FMOM					
FMOM	MISSING	38.8692	0.0	38.8639	0.0
DPN					
DPN	MISSING	263.4393	44.9050	80.7561	44.9050
MWN					
MWN	MISSING	2.9831+04	5099.7086	9157.0682	5099.7086

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STREAM SECTION

S32 S33 S34 S35 S4

STREAM ID	S32	S33	S34	S35	S4
FROM :	EVAPORAT	EVAPORAT	CSTR1	CSTR4	CSTR3
TO :	CSTR2	MIXER	EVAPORAT	DRYER	CSTR4
SUBSTREAM: MIXED					
PHASE:	LIQUID	VAPOR	LIQUID	LIQUID	LIQUID
COMPONENTS: KMOL/HR					
HMDA	3.2347-02	2.2887-02	5.5234-02	1.9781-04	1.2327-03
ADA	5.3708-02	1.7927-03	5.5501-02	3.8488-04	1.6503-03
H2O	7.7314	43.8606	51.5920	0.2731	1.4362
NYLON-66	19.5401	0.0	19.5401	19.4479	19.4614
COMPONENTS: KG/HR					
HMDA	3.7589	2.6596	6.4185	2.2987-02	0.1432
ADA	7.8491	0.2620	8.1111	5.6247-02	0.2412
H2O	139.2830	790.1610	929.4440	4.9194	25.8733
NYLON-66	4422.2865	0.0	4422.2865	4401.4387	4404.4899
TOTAL FLOW:					
KMOL/HR	27.3575	43.8853	71.2428	19.7216	20.9005
KG/HR	4573.1775	793.0826	5366.2601	4406.4374	4430.7476
L/MIN	89.3966	1522.6576	103.2760	85.4065	85.9822
STATE VARIABLES:					
TEMP K	555.0000	555.0000	495.0000	555.0000	555.0000
PRES ATM	20.7333	20.7333	20.0000	1.0000	5.0000
VFRAC	0.0	1.0000	0.0	0.0	0.0
LFRAC	1.0000	0.0	1.0000	1.0000	1.0000
SFRAC	0.0	0.0	0.0	0.0	0.0
ENTHALPY:					
CAL/MOL	-6.4068+04	-5.5780+04	-6.6740+04	-5.8481+04	-5.9322+04
CAL/GM	-383.2662	-3086.5832	-886.0415	-261.7402	-279.8284
CAL/SEC	-4.8687+05	-6.7998+05	-1.3208+06	-3.2037+05	-3.4440+05
ENTROPY:					
CAL/MOL-K	-183.1583	-11.7824	-92.7316	-244.1237	-231.6201
CAL/GM-K	-1.0957	-0.6520	-1.2311	-1.0926	-1.0926
DENSITY:					
MOL/CC	5.1004-03	4.8036-04	1.1497-02	3.8486-03	4.0513-03
GM/CC	0.8526	8.6809-03	0.8660	0.8599	0.8589
AVG MW	167.1636	18.0717	75.3236	223.4321	211.9925
COMPONENT ATTRIBUTES:					
NYLON-66 SFRAC					
HMDA-E	4.7746-02	4.7746-02	4.7746-02	3.1707-03	7.8980-03
ADA-E	4.7865-02	4.7865-02	4.7865-02	4.4212-03	9.1321-03

```
      HMDA-R       0.4522     0.4522     0.4522     0.4965     0.4918
      ADA-R        0.4522     0.4522     0.4522     0.4959     0.4912
    SFLOW
      HMDA-E       1.8518     0.0        1.8518     0.1232     0.3070
      ADA-E        1.8564     0.0        1.8564     0.1718     0.3549
      HMDA-R      17.5394     0.0       17.5394    19.2992    19.1145
      ADA-R       17.5370     0.0       17.5370    19.2749    19.0906
    EFRAC
      HMDA-E       0.4994     0.4994     0.4994     0.4176     0.4638

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                          STREAM SECTION

 S32 S33 S34 S35 S4 (CONTINUED)

 STREAM ID            S32       S33       S34       S35       S4

      ADA-E        0.5006     0.5006     0.5006     0.5824     0.5362
    ZMOM
      ZMOM         1.8541     0.0        1.8541     0.1475     0.3310
    FMOM
      FMOM        38.7846     0.0       38.7846    38.8692    38.8670
    DPN
      DPN        20.9181    20.9181    20.9181   263.4393   117.4393
    MWN
      MWN      2385.1128  2385.1128  2385.1128  2.9831+04  1.3308+04

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                          STREAM SECTION

 VAPOR1 VAPOR2 VAPOR3 VAPOR4
 ---------------------------

 STREAM ID            VAPOR1     VAPOR2     VAPOR3     VAPOR4
 FROM :               CSTR1      CSTR2      CSTR3      CSTR4
 TO   :               MIXER      MIXER      MIXER      MIXER

 SUBSTREAM: MIXED
 PHASE:               VAPOR      VAPOR      VAPOR      VAPOR
 COMPONENTS: KMOL/HR
   HMDA              2.6217-03  6.1250-04  1.6063-04  9.8138-05
   ADA               4.5058-05  3.4334-05  9.6935-06  8.5137-06
   H2O               24.2366     6.1164     1.7843     1.3487
   NYLON-66            0.0        0.0        0.0        0.0
 COMPONENTS: KG/HR
   HMDA                0.3047  7.1176-02  1.8666-02  1.1404-02
```

ADA	6.5850-03	5.0177-03	1.4166-03	1.2442-03
H2O	436.6287	110.1882	32.1455	24.2975
NYLON-66	0.0	0.0	0.0	0.0
TOTAL FLOW:				
KMOL/HR	24.2392	6.1170	1.7845	1.3488
KG/HR	436.9399	110.2644	32.1655	24.3102
L/MIN	762.7660	452.8564	267.5905	1021.3021
STATE VARIABLES:				
TEMP K	495.0000	555.0000	555.0000	555.0000
PRES ATM	20.0000	10.0000	5.0000	1.0000
VFRAC	1.0000	1.0000	1.0000	1.0000
LFRAC	0.0	0.0	0.0	0.0
SFRAC	0.0	0.0	0.0	0.0
ENTHALPY:				
CAL/MOL	-5.6332+04	-5.5709+04	-5.5671+04	-5.5642+04
CAL/GM	-3124.9992	-3090.5204	-3088.5918	-3087.2444
CAL/SEC	-3.7929+05	-9.4660+04	-2.7596+04	-2.0848+04
ENTROPY:				
CAL/MOL-K	-12.6824	-10.1742	-8.7516	-5.5184
CAL/GM-K	-0.7036	-0.5644	-0.4855	-0.3062
DENSITY:				
MOL/CC	5.2963-04	2.2513-04	1.1115-04	2.2012-05
GM/CC	9.5473-03	4.0581-03	2.0034-03	3.9672-04
AVG MW	18.0261	18.0258	18.0248	18.0232
COMPONENT ATTRIBUTES:				
NYLON-66 SFRAC				
HMDA-E	4.7746-02	1.1775-02	7.8980-03	3.1707-03
ADA-E	4.7865-02	1.2991-02	9.1321-03	4.4212-03
HMDA-R	0.4522	0.4879	0.4918	0.4965
ADA-R	0.4522	0.4873	0.4912	0.4959
SFLOW				
HMDA-E	0.0	0.0	0.0	0.0
ADA-E	0.0	0.0	0.0	0.0
HMDA-R	0.0	0.0	0.0	0.0
ADA-R	0.0	0.0	0.0	0.0
EFRAC				
HMDA-E	0.4994	0.4755	0.4638	0.4176

STREAM SECTION

VAPOR1 VAPOR2 VAPOR3 VAPOR4 (CONTINUED)

STREAM ID	VAPOR1	VAPOR2	VAPOR3	VAPOR4
ADA-E	0.5006	0.5245	0.5362	0.5824
ZMOM				

```
  ZMOM       0.0      0.0      0.0      0.0
 FMOM
  FMOM       0.0      0.0      0.0      0.0
 DPN
  DPN     20.9181    80.7561   117.4393   263.4393
 MWN
  MWN      2385.1128  9157.0682  1.3308+04  2.9831+04

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                  PROBLEM STATUS SECTION

 BLOCK STATUS
 ------------

 ****************************************************************************
 *                                                                          *
 * Calculations were completed normally                                     *
 *                                                                          *
 * All Unit Operation blocks were completed normally                        *
 *                                                                          *
 * All streams were flashed normally                                        *
 *                                                                          *
 ****************************************************************************
```

Figure 6: Aspen Plus Flowsheet