To: Whom it may concern
From: Design Report Group: Gavin Dolsky, Crandel Fenton, Jake Sessler, & Alec Thomits
Date: 9 March 2017
Subject: Grassroots Nylon 6, 6 Production Facility

This team was assigned with proposing a grassroots design for a Nylon 6,6 production facility in the Calvert City, Kentucky area. The chemicals hexamethylenediamine and adipic acid are continually processed through a tubular reactor and granulated into Nylon pellets for market. The accompanying report includes a design for full capacity of 85MM pounds per year of nylon production and reduced capacity at 67% of max capacity. Both a hazard analysis and a control strategy are included in the facility design as well as economic analyses, in order to determine the necessary capital investment and the amount of time until profits are realized.

Your consideration of the proposed design and the accompanying documents is greatly appreciated.

Thank You,

Gavin Dolsky, Crandel Fenton, Jake Sessler, & Alec Thomits

AIChE 2017 Student Design Competition

Manufacturing Facility for Nylon 6,6

Gavin Dolsky, Crandel Fenton, Jake Sessler, & Alec Thomits

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Abstract

A preliminary grass roots design was performed for a continuous nylon 6,6 polymerization process. The objective of this project was to create a safe and sustainable process for the polymerization of nylon 6,6 that produced 85 MM lbs/yr using Adipic Acid and HMDA as the constituents. Upon completing the design and economic evaluation, it is recommended that management consider moving forward with this process.

The initial investment for creating a grass roots plant for producing nylon 6,6 was determined to be $18,800,000. Upon completing the economic analysis, the net present value for the 100 percent production was determined to be $70,120,000 while the 67 percent production is $31,100,000. The payback period for the 100 percent production was found to be 2.25 years with a DCFROR of 69 percent.

Some key assumptions needed to be made while creating the economic analysis. With the economic evaluation, the assumption is made that all of the product made is sold and all raw material purchased is used. While another assumption is that all of the prices for raw material, utilities, and sales price remain the same throughout the entire life of the analysis. Although these will deviate, the NPV will still be much greater than zero while the DCFROR will stay above 15 percent. Therefore, it is recommended to begin moving forward with the creation of this plant and produce nylon 6,6 pellets.

Introduction

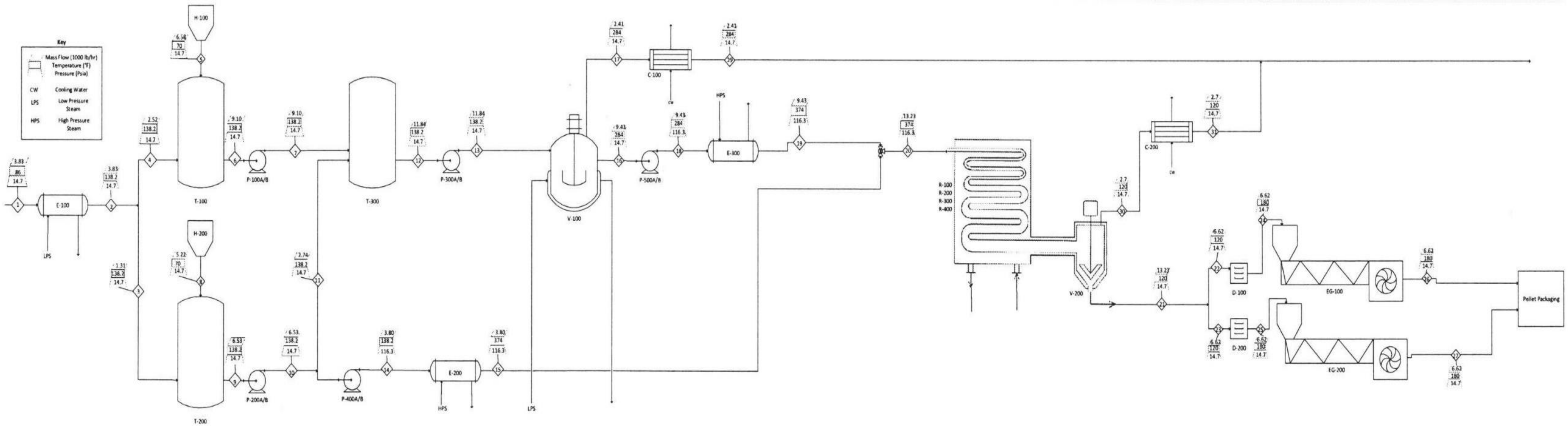
For this project, the objective was to design a grass-roots plant for the manufacturing of nylon 6,6. This plant is to produce 85 MM pounds of nylon 6,6 each year for however many years the project team sees fit. The main goal of the design is to maximize revenue and minimize cost while keeping safety standards and practices in mind.

The nylon 6,6 product is produced from the polymerization of adipic acid and hexamethylene diamine. These two reactants will be acquired from an outside source in their purest form to feed into the process. Since the price of plastics is increasing, both the feed and product materials should increase in demand and cost in the upcoming years, making this process a profitable and attractive venture.

Process Flow Diagram and Material Balances

A process flow diagram was constructed to provide a simple yet informative overview of the full process. This diagram, along with a list of the instrumentation is provided on the following page.

Instrument List																									
E-100	**E-200**	**E-300**	**C-100**	**C-200**	**P-100A/B**	**P-200A/B**	**P-300A/B**	**P-400A/B**	**P-500A/B**	**V-100**	**V-200**	**H-100**	**H-200**	**T-100**	**T-200**	**T-300**	**R-100**	**R-200**	**R-300**	**R-400**	**D-100**	**D-200**	**EG-100**	**EG-200**
Water Heater	HMDA Heater	Nylon Salt Heater	Evaporator Condenser	Finishing Reactor Condenser	Initial HMDA Pump	Initial AA Pump	Nylon Salt Pump	HMDA 2 Pump	Nylon Salt Pump	Evaporator	Finishing Reactor	AA Hopper	HMDA Hopper	AA Mixer	HMDA Mixer	Nylon Salt Mixer	Tubular Reactor	Tubular Reactor	Tubular Reactor	Tubular Reactor	Desiccant Dryer	Desiccant Dryer	Pelletizing Extruder	Pelletizing Extruder



100% and 67% Nylon 6,6 Production

Date: 03-08-2017

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After the inlet and outlet streams were calculated to achieve the desired amount of product, the total flowrate on each end was calculated and compared to each other. This is shown in Table 1 below.

Table 1: Material Balance

In		Out	
AA (H-100)	7394.02	Nylon	10213.891
HMDA (H-200)	5879.70	Water (V-100)	2708.49
Water	4304.30	Water (V-200)	4655.641
Sum	17578.02	Sum	17578.02

Process Description

To begin the process, H-100 and H-200 are halfway filled with solid adipic acid (AA) and hexamethylenediamine (HMDA), respectively. This amount will last 24 hours, so the process requires that the hoppers be filled at the beginning of each day.

The process water from an offsite entity was assumed to enter E-100 at 86^{o}F, which is a reasonable ambient temperature for process use. After low pressure steam exchanges heat with the process water, the stream exits at 59^{o}C (138.2^{o}F) as stream 2. This stream splits into streams 3 and 4 that feed into the two mixing vessels, T-100 and T-200, along with the feed of the solids from H-100 and H-200. These vessels have an hour-long residence time to ensure well-mixing and dissolution in the tank.

T-100 pumps AA solution to the mixing vessel T-300 in stream 7, while T-200 also pumps HMDA solution to T-300 in stream 11, where they will once again have a residence time of one hour. In a usual nylon 6,6 process, this salt solution is equimolar in AA and HMDA, but this is not the case for this project. According to US Patent 4,442,260, if the AA to HMDA ratio is 3:1 by weight, the salt solution can concentrate to ~93% solute by weight (Larsen, 1984). This saves costing on the process vessels, evaporator (V-100), and reactor by reducing the amount of flow into and out of each piece of equipment.

After T-300 is well mixed, the solution is pumped to an agitated film evaporator V-100 via P-300 in stream 13. The purpose of V-100 is to concentrate the solution, as mentioned earlier. A jacket with low-pressure steam is applied to keep the outlet temperature of the solution at a specified temperature of 284oF. This temperature is where the vaporization takes place while keeping the pressure at one atmosphere. The evaporated steam from this process has some HMDA present in the vapor, so stream 17 is ran through a condenser and sent to an off-site wastewater treatment facility.

Before being sent to the reactor, the concentrated solution undergoes two steps. First, it needs to reach a temperature of 374oF, and the only way to do this without vaporizing is to increase the pressure to 166.3 psia. This is achieved using centrifugal pump P-500, followed by the high-pressure steam heat exchanger E-300. Exiting from the heat exchanger at these specifications, the second step before reacting is adding the remaining HMDA to achieve an equimolar solution. P-400 and E-200 get the HMDA solution from T-200 to the specs required for the reaction process, and to the connector via stream 15. Once together, stream 20 enters the reactor at the desired temperature, pressure, and composition required for optimal production.

The original idea for the reactor design was a coiled-tube, expanding diameter, based on the design steps in Giudici (1999). After simulation and costing analysis, the best option was to have four spiral-tube reactors (R-100, R-200, R-300, and R-400) connected in series to achieve the desired amount of selectivity. The final reactor exits into the finishing reactor, V-200, which is essentially an agitated film evaporator used to separate the exiting steam from the nylon liquid. This exiting steam also has side products and unreacted reactants present, so it is condensed in C-200 and sent to wastewater treatment in stream 31.

The nylon 6,6 liquid is sent to two, parallel, desiccant rotary dryers (D-100 and D-200) to be dried for four hours at 180°F. The maximum size for the dryers held a little over half (5500 lb/hr) of the product stream, which is why the decision was made to have two parallel dryers. The dried nylon 6,6 is sent from D-100 and D-200 to the extruder/granulator EG-100 and EG-200 via stream 24 and 25, respectively. The extruders transfer the nylon to the granulators where the pellets are produced and packaged for consumption.

Energy Balance and Utility Requirements

In designing this process, specific temperatures were required as to abstain from degradation of the polymer into smaller constituents. These temperatures were maintained by using heat exchangers, reactors, and electric heaters throughout the process. Below is Table 2, detailing the Energy Balances done for the heating demands.

Table 2: Energy Balance for Process Equipment

Energy Balance (BTU/hr)				
	$mC_p\Delta T$	$m\Delta H$	Temperature (To, From) (°F)	Steam Temp (°F)
E-100	284,083.83	284,083.83	(138, 72)	320
E-200	688,399.32	688,399.32	(374, 138.2)	489.2
E-300	583,221.44	583,221.44	(374, 284)	489.2
C-100	2,418,682.94	2,418,682.94	284	(113, 86)
C-200	2,418,682.94	2,418,682.94	482	(113, 86)
V-100	297,392.37	297,392.37	(248, 138.2)	286
R-100	619,229.21	619,229.21	(375.1, 446)	489.2
R-200	157,209.11	157,209.11	(446, 464)	489.2
R-300	78,604.55	78,604.55	(464, 473)	489.2
R-400	78,604.55	78,604.55	(473, 482)	489.2

This table shows that energy is conserved within the process and gives the temperature ranges for the cold water and steam. To show how the demand is satisfied, another table was created. Table 3 shows how each energy demand was satisfied with steam or a cooling water stream.

Table 3: Energy Requirements and Provision

	Demand	Satisfied
E-100	285,000 BTU/hr to heat stream 1 from 72 to 138°F	285,000 BTU/hr from low pressure steam as it maintains 320°F
E-200	689,000 BTU/hr to heat stream 14 from 138.2 to 274°F	689,000 BTU/hr from high pressure steam as it maintains 489.2°F
E-300	584,000 BTU/hr to heat stream 18 from 284 to 374°F	584,000 BTU/hr from high pressure steam as it maintains 489.2°F
C-100	2,419,000 BTU/hr condense stream 17, saturated steam, for water treatment	2,419,000 BTU/hr from cooling water as it is cooled from 113 to 86°F
C-200	2,419,000 BTU/hr to condense stream 30, saturated steam, for water treatment	2,419,000 BTU/hr from cooling water as it is cooled from 113 to 86°F
V-100	298,000 BTU/hr to heat stream 13 from 138.2 to 248°F	298,000 BTU/hr from low pressure steam as it maintains 286°F
R-100	620,000 BTU/hr to heat stream 20 process fluid from 375.1 to 446°F	620,000 BTU/hr from high pressure steam as it maintains 489.2°F
R-200	158,000 BTU/hr to heat stream 20 process fluid from 446 to 464°F	158,000 BTU/hr from high pressure steam as it maintains 489.2°F
R-300	79,000 BTU/hr to heat stream 20 process fluid from 464 to 473°F	79,000 BTU/hr from high pressure steam as it maintains 489.2°F
R-400	79,000 BTU/hr to heat stream 20 process fluid from 473 to 482°F	79,000 BTU/hr from high pressure steam as it maintains 489.2°F

For the utilities, another table was created to show the cost in each piece of equipment. This is related to the energy requirements as the utility cost increases as the energy requirements increase. The utility costs are shown in Table 4.

Table 4: Utility Requirements for Process & Auxiliary Equipment

Utility Requirements with SF .95	
Equipment	Utility Cost
E-100	$33,286.28
E-200	$106,727.37
E-300	$90,420.91
C-100	$5,029,662.49
C-200	$5,029,662.49
V-100	$53,374.21
R-100	$88,731.91
R-200	$22,527.14
R-300	$11,263.57
R-400	$11,263.57
P-100	$76.45
P-200	$26.89
P-300	$103.10
P-400	$2,365.44
P-500	$880.49
D-100	$78,795.00
D-200	$78,795.00
EG-100	$103,753.81
EG-200	$103,753.81

Equipment List and Unit Descriptions

A complete list of the equipment used for this process is given below in Table 5. It shows the component name, corresponding to the PFD, and shows the type along with the material used.

Table 5: Equipment List and Sizes

List of Equipment				
Component	Type	Material	Size	Units
E-100	Double Pipe	CS-shell, SS-tube	0.673	m^2
E-200	Double Pipe	CS-shell, SS-tube	1.643	m^2
E-300	Double Pipe	CS-shell, SS-tube	1.889	m^2
C-100	Double Pipe	SS	6.632	m^2
C-200	Double Pipe	SS	3.195	m^2
P-100A/B	Reciprocating	SS	0.2	hp
P-200A/B	Reciprocating	SS	0.2	hp
P-300A/B	Reciprocating	SS	0.5	hp
P-400A/B	Centrifugal	SS	10	hp
P-500A/B	Centrifugal	SS	5	hp
V-100	Agitated Film	SS	1.858	m^2
H-100	Vertical Drum	SS clad	118.4	m^3
H-200	Vertical Drum	SS clad	152.4	m^3
T-100	Vertical Mixer	SS clad	2.615	m^3
T-200	Vertical Mixer	SS clad	1.356	m^3
T-300	Vertical Mixer	SS clad	3.183	m^3
SV-100	Fixed Roof	SS	3482	m^3
SV-200	Fixed Roof	SS	4482	m^3
R-100	Spiral Tube	CS-shell, Cu-tube	31.42	m^2
R-200	Spiral Tube	CS-shell, Cu-tube	62.83	m^2
R-300	Spiral Tube	CS-shell, Cu-tube	94.25	m^2
R-400	Spiral Tube	CS-shell, Cu-tube	117.8	m^2
V-200	Agitated Film	SS	1.680	m^2
D-100	Dessicant, Rotary	SS	5500	lb/hr
D-200	Dessicant, Rotary	SS	5500	lb/hr
EG-100	Pelletizing	SS	5500	lb/hr
EG-200	Pelletizing	SS	5500	lb/hr

Storage Tanks

The storage tanks are large vessels that are built to hold thirty days of raw material. These tanks also have a length to diameter ratio of three when being sized. This heuristic was used and solved for when sizing them. The vertical tanks are relatively large and need to be vertical tanks that are supported on a concrete foundation. API Fixed Roofs were chosen because the storage tank cannot be open to the air. The equation to determine the storage capacity required for thirty days is shown below as Equation (1).

$$V = \frac{q}{\rho} * \frac{24hr}{day} * 30days \qquad (1)$$

Where:
q = Flowrate (kg/hr)
ρ = Density (kg/m^3)

The material of construction for the storage tanks was stainless steel to withstand the corrosive nature of HMDA and Adipic Acid.

Vessels

There were five vessels designed for this process: two gravity feed hoppers to feed the solid particulates into the mixing vessel below each one, and the final mixing vessel to mix the salt solution. The designing process for each of them was very similar, with a couple of distinct differences between each type.

Each of the hoppers were designed to hold one day of volume to be slowly fed into the mixing vessels. The original idea was to have a 30-day storage vessel feed into a mixing vessel, but as the design process continued, it became evident that the storage vessel was going to be much too large to feed into the mixing vessel, much less be able to store a 30 day volume above ground-level. The new one-day hoppers were sized using a heuristic of double the volume of material needed, so there was plenty of space in the upper part of the vessel when loading. The volume calculation used Equation (2) as shown below.

$$V = 2 * \frac{24\dot{m}}{\rho} \qquad (2)$$

Where:
V = Volume (m^3)
$\dot{m}$ = Mass flowrate of water (lb/hr)
ρ = Density of solution (lb/m^3)

The mass flowrate was multiplied by a constant of 24 to account for the 24 hours in a day, resulting in the volume being twice the amount of volume needed for one day of solid.

Another heuristic was used to calculate the length and diameter of each of the vessels, based on the volume. This heuristic stated that the length to diameter ratio (or L/D) for each vessel should be equal to 3. This problem was solved using the Microsoft Excel Solver function, setting the volume to the previously calculated value, then solving for the length and diameter with the restrictions of Equations (3) and (4):

$$Length = 3 * Diameter \qquad (3) \qquad ; \qquad V = \frac{\pi D^2}{4} * L \qquad (4)$$

An example of the calculations used is shown below in Table 6. The rest of the calculations can be found in Appendix Table 15.

Table 6: Dimension Optimization for H-200

Solver for L/D=3 for H-200	
L (m)	12.0417
D (m)	4.0139
V (m^3)	152.37

For the three mixing vessels, the same design strategy was used to calculate the volume, length, and diameter, with the only difference being that these vessels had a one-hour residence time. This decision was to give the solution enough time to mix to where the outlet of the vessel had a uniformly mixed solution. This also allowed the cost of the equipment to stay at a reasonable level, due to the mixing vessels being much more expensive than the process vessels. An example of the calculations for these vessels is shown below in Table 7.

Table 7: Dimension Optimization for T-200

Solver for L/D=3 for T-200	
L (m)	2.495
D (m)	0.832
V (m^3)	1.356

Pumps

When designing the pumps needed for this process, two components were considered. The first and most important aspect is the pressure differential across the pump. For this process, each pressure on the inlet and outlet of each pump was known, so the pressure difference was the inlet pressure subtracted from the outlet pressure. Once that was determined, the head was calculated via the pressure difference divided by the specific gravity.

The second aspect that needed to be considered was the flowrate of material through the pump, also known as the capacity. The volumetric flowrate for each individual pump was calculated from mass flow rates and density values.

With the pressure differential and capacity values, as well as the assumed pump and motor efficiencies from Turton, the brake horsepower (BHP) and purchase horsepower (PHP) were calculated using Equations (5) and (6) shown below (Turton, 2012).

$$BHP = \frac{Q(gpm)*H(ft)*S.G.}{3960*\varepsilon_{pump}} \quad (5) \quad ; \quad PHP = \frac{BHP}{\varepsilon_{motor}} \quad (6)$$

Where:
Q = Capacity (gpm)
H = Head (ft.)
S.G. = Specific Gravity
ε_{pump} = Pump efficiency
ε_{motor} = Motor efficiency

For example, the quantities used in the design of the concentrated salt pump are shown below in Table 8.

Table 8: Example of Pump Calculations

P-500	
Head (delta P is known)	
P out (barg)	6.93
ΔP (psi)	102
Density (lb/ft3)	60.34
SG	0.967
Head (ft)	243.7
Brake Horsepower	
Capacity (bpd)	668
Capacity (gpm)	19.486
Head (ft)	243.7
Efficiency of Pump	0.65
Efficiency of Motor	0.88
BHP	1.78
PHP	2.03
Buying PHP	5

The first three pumps (P-100, P-200, and P-300) have a very low pressure differential, hence the low cost of each. These pumps were designed to pump from a vessel at atmospheric pressure to another vessel at atmospheric pressure. Although they were not necessary if the static head is larger than the friction losses over a short length, the pumps were implemented as a safety measure to be sure that there is no backflow in the line. The other two pumps have a large enough pressure differential and capacity to use centrifugal pumps, which are more commonly used and cost efficient.

Heat Exchangers

The heat exchangers in this process are used to heat up the process streams. This is required to maintain a specific temperature for nylon 6,6 to react and polymerize while also requiring the high temperature to mix its constituents. High pressure and low pressure steam at temperatures of 254°C and 160°C were used respectively to accomplish this. To achieve this increase in temperature for the process, the amount of duty required needed to be calculated. It can be shown below in Equation (7).

$$Q = U_o A \Delta T_{lm} \tag{7}$$

To get the duty required, Q, for the process, use Equation (8) as follows. This is the process required to calculate the area for the heat exchanger to be able to cost it.

$$Q = \dot{m}_c c_p \Delta T \tag{8}$$

Where:
$\dot{m}_c$= Mass flow rate of the cold process stream (lbm/hr)
c_p = Specific heat of water (BTU/lbm °F)
ΔT = Change in temperature for the process fluid (°F)

To obtain the ΔT_{lm}, Equation (9) must be used. It requires knowledge of the steam temperatures along with the inlet temperature of the cold process stream.

$$\Delta T_{lm} = \frac{(T_{in}-t_{out})-(T_{out}-t_{in})}{LN\frac{(T_{in}-t_{out})}{(T_{out}-t_{in})}} \tag{9}$$

Where:
T_{in} = The temperature in of the hot steam (°F)
T_{out} = The temperature out of the hot steam (°F)
t_{in} = The temperature in of the cold process fluid (°F)
t_{out} = The temperature out of the cold process fluid (°F)

Once the log mean temperature difference has been calculated, U_o the overall heat transfer coefficient was calculated using sensible heat transfer values, diameters, and resistance values that are all constants for the material and fluid being used. This equation is as follows.

$$U_o = \left(\left(\frac{1}{h_i}\right) * \left(\frac{D_o}{D_i}\right) + R"_{fi} * \left(\frac{D_o}{D_i}\right) + R_W + R"_{fo} + \left(\frac{1}{h_o}\right)\right)^{-1} \tag{10}$$

Now that all the variables have been obtained, all that is left is solving for the area of the heat exchanger. The area was calculated using Equation (12). Solving for the area of the heat exchanger allows for the costing of it. The utilities were solved for and costed based on the mass flow rate of the steam. This equation is shown below in Equation (11).

$$\dot{m}_h = \frac{Q}{\Delta H_{vap}} \tag{11}$$

Within all of the heat exchangers, the shell contains the steam while the tubes contain the process fluid. This is due to corrosion and pressure differences. The shells are constructed using carbon steel while the tubes are made of stainless steel. These heat exchangers are also double pipe heat exchangers, due to the areas of each one being below 10 m^2.

Evaporators

The first evaporator in this process (V-100) is used to remove most of the water from the salt solution. Before entering the evaporator, the salt solution contains about 65% solute by mass (35% water by mass), and exits the evaporator at about 93% solute by mass (7% water by mass). To achieve this separation, the solution is brought to a temperature of 120ºC (248ºF) at atmospheric pressure. The amount of utility steam needed was calculated using Equation (12) as shown below.

$$Q = \dot{m}H_{vap} \tag{12}$$

Where:
Q = Heat required (BTU/hr)
$\dot{m}$ = Mass flowrate of process steam (lbm/hr)
H_{vap} = Heat of vaporization (BTU/lbm)

This equation specified the amount of water that needed to be vaporized from the product stream and the heat of vaporization of that stream, and used these values to obtain the heat needed by the condensing steam on shell side.

To calculate the required area for the evaporator, the log-mean temperature difference was calculated using Equation (9). This value was then used in combination with the heat required and overall heat transfer coefficient, which was calculated using Equation (10), to calculate the area, as shown below in Equation (13).

$$A = \frac{Q}{\Delta T_{lm} * U_O} \tag{13}$$

Where:
A = Area (ft^2)
Q = Heat required (BTU/hr)
ΔT_{lm} = Log-Mean temperature difference (ºF)
U_O = Overall heat transfer coefficient (BTU/hr-ft^2-ºF)

After research and analysis on evaporator efficiencies and costing correlations at specific area values, the agitated film evaporator was chosen for this process.

The second evaporator (V-200) is used to separate the nylon product from the exiting steam in the reactor. It was suggested in the Giudici report that an agitated film separator is used, so the design of this process equipment was similar to that of V-100 (Giudici et al., 1999).

Unfortunately, for this design there was no steam jacket needed to evaporate the exiting steam, so the area was estimated using reasonable air cooling temperatures and condensing steam. This is not recommended, for the area was very unstable as the temperatures changed, so it is recommended in the future that another design process is used to size this agitated film separator.

Condensers

The purpose of the condensers in this process is to cool down the wastewater steam coming from separation equipment. The steam exiting from these evaporators has traces of HMDA, ammonia, and more, so once the steam has been condensed, the water is sent to an offsite wastewater treatment plant to remove impurities. The material of construction for the two condensers were chosen as a carbon steel shell and stainless steel tube. This decision was based on the tube side needing more reinforcement due to the corrosiveness of the HMDA passing through it, and the shell side temperatures and pressures being within the reasonable limits of carbon steel safety, with carbon steel being the most cost efficient choice.

The design of the condensers was similar to that of the heat exchangers, but the stream used to solve for the heat duty was being condensed, so Equation (12) was used.

The mass flowrate used was the amount of steam exiting from the evaporator. It was assumed that the heat of vaporization of this stream is very similar to that of pure water at the same temperature and pressure, since the stream consists of mostly water. These values were taken from Engineering Toolbox ("The Engineering ToolBox,").

Once the heat duty was obtained the amount of cooling water needed was calculated using a rearranged version of Equation (8), which can be found below as Equation (14).

$$\dot{m}_c = \frac{Q}{c_p \Delta T} \tag{14}$$

In the Turton costing correlations for offsite cooling water, found on pg.212, insists that when using cooling water, the maximum outlet temperature of the cooling water stream is 45^{o}C (Turton, 2012). This restriction causes the amount of cooling water used to be a very large number, but since this was the best costing correlation for utilities available, the restrictions and prices listed were followed and the calculated flowrates were used.

Reactors

The heated salt solution is pumped into the first coiled tube reactor with an internal tube diameter of 0.4 m. Each subsequent reactor is connected to the end of the previous and begins a new internal tube diameter. After leaving the first reactor, the tube diameter increases to 0.08 m. The next reactor has a tube diameter of 0.12 m, and the final reactor has 0.15 m diameter tubes. In order to prevent the corrosion of the reactor tubes, copper was the selected material due to its resistance to reaction with the raw materials. The outer shell of the reactors could be carbon steel since it is only exposed to steam. High pressure steam is used to provide a constant external temperature to the reactor tubes. The higher temperature helps to speed the reactions (Giudici et al., 1999). The internal temperature of the reactants was assumed to have a gradual increase as it passes through the four reactors. Through the polymerization reaction, water is produced and vaporized. Some of the unreacted hexamethylenediamine is also vaporized in the reactor, necessitating larger diameters to push the equilibrium reaction towards polymerization (Giudici et al., 1999). Each revolution of a coil was assumed to utilize 10 m of reactor distance, and the spacing between the coils is 1.25 times the diameter of the reactor tube. This was done to ensure the height of a reactor never exceeded 20 feet.

A more complete investigation into the thermodynamic properties of the Schiff base and stable end degradation products would improve the accuracy of the model. Inclusion of the effects of two-phase flow would also likely help further analysis. In addition, a working model of the reactor parameters would allow for a more complete economic analysis based on the necessary utility and feed component flow rates.

For simplicity in the reactor model, the gaseous pressure drop was assumed to be negligible compared to the pressure drop of the liquid. Later, it was decided to reduce the model further by assuming the material flows were only liquid. This was due to a lack of information regarding the vaporization constants. These assumptions were likely the cause of the failure of the reactor model. In addition, there was little data on the thermodynamic constants of the Schiff base and stable end created from the degradation of nylon 6,6. As a result, these two compounds were assumed to share the same heat capacity as nylon 6,6 and the same heat of formation as adipic acid ("Heats of formation and chemical compositions,") (Umesh Gaur, 1983) (NIST). A cross-link was assumed to share all thermodynamic data with nylon 6,6.

Dryer

The dryer was designed through rigorous research into nylon 6,6 use and drying times for different types. A vacuum batch dryer was originally considered but the flowrate requirement for the process was too high for current constraints of vacuum batch drying. A desiccant dryer with rotating honeycombs was chosen instead as only two would be required for this process instead of eleven that would be required for vacuum batch drying. The drying time, determined through research, was deemed to be four hours with a drying temperature of 180°F. This high amount of drying time is required because nylon 6,6 is a hygroscopic resin that readily attracts moisture. The moisture equilibrium desired for this process is .12%, which was deemed optimal for being sent into extrusion. No calculations were done as research was done for the entirety of the drying step (Sherman, 2005).

Extruders/Granulators

Similar to the drying apparatus, most of the design behind the extrusion came through research of other processes that used nylon 6,6. The optimal length of the extruder barrel was found to be 24D (diameters) in length with a screw diameter of 10 inches. This should have a bimetallic structure in order to reduce wear while the screw is a double parallel screw also known as a nylon screw. With these sizes, two extruders are required to be able to handle the amount of product for this process. Through further research, the temperatures for each zone was also determined. These temperatures for each zone, adapter, and die are shown below in Table 9 (Whelan).

Table 9: Dryer Temperature Ranges

Zone:	1	2	3	Adapter	Die
Range of Temp (°C)	265-290	275-285	280-290	280-290	270-290

The power was calculated for the extruder using Equation 15 as shown below.

$$P = \frac{\dot{m}c_p\Delta T + \dot{m}\Delta H_{fusion}}{3600} \tag{15}$$

Where:
P = Power (kWh)
ΔT = (The melting temperature – temperature coming in) (°C)
ΔH_{fusion} = Heat of fusion (kj/kg)

This equation determines the power required to heat nylon 6,6 to its molten state from the temperature that it is entering at within the feed. Another component of the extruder was finding the residence time within the barrel. Through research, the "residence time in the barrel should not exceed 2 to 3 minutes" where longer times can create degradation of the product along with the melt sticking to the barrel and screw (Whelan).Sizing and costing calculations were unable to be done due to lack of information through text. As a result, research replaced the calculations in order to determine the concerns dealing with the pelletizing extruder.

Equipment Specification Sheets

Below is Table 10, detailing the important specifications for each piece of process equipment.

Table 10: Equipment Specification Sheet

Equipment									
Vessels	T-100	T-200	T-300						
Temperature (°F)	138.2	138.2	138.2						
Pressure (psia)	64.7	64.7	64.7						
Orientation	Mixer	Mixer	Mixer						
Material	SS clad	SS clad	SS clad						
Volume (ft^3)	105.94	105.94	70.63						
Diameter (ft)	3.54	3.54	3.12						
Reactors	R-100	R-200	R-300	R-400					
Temperature (°F)	265	270	275	280					
Pressure (psia)	290	290	290	290					
Orientation	Tube Reactor	Tube Reactor	Tube Reactor	Tube Reactor					
Material	CS-shell Cu-Tube	CS-shell Cu-Tube	CS-shell Cu-Tube	CS-shell Cu-Tube					
Tube Diameter (ft)	0.13	0.26	0.39	0.49					
Heat Exchangers	E-100	E-200	E-300	C-100	C-200	V-100	V-200		
Type	Double Pipe	Double Pipe	Double Pipe	Condenser	Condenser	Agitated Film Evaporator	Finishing Reactor		
Area (ft^2)	7.24	17.68	20.34	71.39	34.39	20	18.08		
Duty (Btu/hr)	284000	688000	583000	2419000	2419000	297000	1116000		
Shell Temp In/Out (°F)	320/320	489/489	489/489	86/113	86/113	286/286	482/400		
Shell Pressure (psia)	87	609	609	64.7	64.7	87	609		
Shell Phase	Vapor	Vapor	Vapor	Liquid	Liquid	Vapor	Vapor		
Shell Material	SS	SS	SS	CS	CS	SS	SS		
Tube Temp In/Out	72/138	138/374	284/374	284/284	482/482	138/248	87/120		
Tube Pressure (psia)	90	166	166	166.3	166.3	65	64.7		
Tube Phase	Liquid	Liquid	Liquid	Cond.	Cond.	Liquid	Cond.		
Tube Material	SS	SS	SS	SS	SS	SS	SS		
Pumps	P-100A/B	P-200A/B	P-300A/B	P-400A/B	P-500A/B				
Type	Recipricating	Recipricating	Recipricating	Centrifugal	Centrifugal				
Capacity (gpm)	17.3	6.1	23.3	30.7	19.5				
Head (ft)	21.9	25.6	22.7	466.9	243.7				
Pdischarge (psia)	24.4	24.4	24.4	186.2	114.1				
Shaft Power (hp)	0.2	0.2	0.5	10	5				
Material	SS	SS	SS	SS	SS				
Dryers	D-100	D-200							
Type	Dessicant, Rotary	Dessicant, Rotary							
Material	SS	SS							
Temperature (°F)	180	180							
Moisture Equil. (%)	0.12	0.12							
Capacity (lb/hr)	5500	5500							
Extruder Pelletizers	EG-100	EG-200							
Type	Pelletizing	Pelletizing							
Screw Diameter (ft)	2.5	2.5							
Temperature Range (°F)	265-290	265-290							
Capacity (lb/hr)	5500	5500							
Hoppers	H-100	H-200							
Type	Vertical Drum	Vertical Drum							
Volume (ft3)	4181	5382							

This process was designed for continuous nylon production and as such all of the equipment had to perform under continuous conditions. Due to the nature of the HMDA and adipic acid, the process equipment that came into contact with them had to be stainless steel in order to prevent corrosion, as indicated by the SS notation in the materials section of the equipment specification sheet. This held true until the raw materials were reacted to form the nylon salt and were processed through the tubular reactor, represented by R-100, R-200, R-300, and R-400. The condensers C-100 and C-200 operated with cooling water in the shell side and the heaters operated with steam in the shell side. Due to restraints on commercially available dryers two dryers were required, splitting the reactor flow rate in half. The same reasoning applied to the Extruder Pelletizers.

Equipment Cost Summary

Shown below is Table 11, which lists the purchase price of each piece of designed and auxiliary equipment used in the process.

Table 11: Equipment Costs

Cost of Equipment		
Component	Purchase Price (USD)	Source
E-100	$2,691.84	Turton et al.
E-200	$3,501.33	Turton et al.
E-300	$3,670.80	Turton et al.
C-100	$8,634.04	Turton et al.
C-200	$7,395.89	Turton et al.
P-100A/B	$21,915.69	Turton et al.
P-200A/B	$20,897.21	Turton et al.
P-300A/B	$22,694.29	Turton et al.
P-400A/B	$21,781.18	Turton et al.
P-500A/B	$15,755.09	Turton et al.
V-100	$149,087.82	Turton et al.
H-100	$213,377.22	Turton et al.
H-200	$281,906.88	Turton et al.
T-100	$127,218.30	Turton et al.
T-200	$89,583.35	Turton et al.
T-300	$141,562.59	Turton et al.
SV-100	$762,208.30	Turton et al.
SV-200	$896,472.84	Turton et al.
R-100	$79,532.40	Turton et al.
R-200	$145,113.30	Turton et al.
R-300	$216,219.05	Turton et al.
R-400	$273,296.73	Turton et al.
V-200	$146,962.89	Turton et al.
D-100	$90,000.00	Plastics Technology
D-200	$90,000.00	Plastics Technology
EG-100	$100,000.00	Alibaba
EG-200	$100,000.00	Alibaba

The purchase cost for most pieces of equipment was calculated using a correlation in Turton et al. (2012), the rest of which were found from online sources. An example of the costing technique for the Turton et al. prices can be found in Appendix Table 3.

Fixed Capital Investment Summary

Detailed above in the previous section, Table 11 is the purchase cost for each piece of equipment. The grass roots cost was calculated by first calculating the total module cost. The equation for the total module cost is shown below in Equation (16).

$$C_{TM} = 1.18 \sum_{i=1}^{n} C_{BM} \tag{16}$$

This equation is for the total module cost using the summation of the installed costs. The total module cost "refers to the cost of making small to moderate expansions… to an existing facility" while the grass roots cost is for a "completely new facility" (Turton, 2012, p 198). This equation was then put into the grass roots costing equation detailed below.

$$C_{GR} = C_{TM} + .5 \sum_{i=1}^{n} C_{BM} \tag{17}$$

All of the equipment costed was initially costed for the year 2001, but using the costing correlation CEPCI (Chemical Engineering Plant Cost Index), the costing was brought to the current year 2017. This was done assuming that the CEPCI for the year 2017 was still the same for the 2016 year. The ratio used is shown in Equation (18)

$$CEPCI = \frac{540.9}{397} \tag{18}$$

Safety, Health, and Environmental Considerations

Safety, health, and environmental concerns were heavily considered while designing this process. To ensure that hazards were accounted for, a HAZOP analysis was done on each piece of equipment. This is shown in Tables 43 through 62 within the Appendix and details the deviation, the cause of the deviation, the consequence if that deviation were to occur and the proper action to take in order to correct the deviation. This hazard and operability study was conducted with the process design team contributing to each piece of process equipment as to possible hazards and corrections in order to determine and correct the most glaring concerns.

Concerning the safety of the designed process equipment, a 50 psi pressure component has been added when designing the equipment. This is a heuristic safety factor in order to protect from unforeseen pressure increases. Another important safety component to be added to the process is to insulate the steam lines. The insulation is required to protect workers from burns and maintain a safe working environment. While researching the pelletizing extruder, it was deemed necessary to place guards around the barrel, screw, die and granulator. The guard around the barrel protects the operator from burns as the barrel is operating around 550 °F. At these temperatures, the material is “like hot melt adhesives” and would cause severe burns (Whelan). The guard placed “between the base of the hopper and the screw” is to prevent fingers or any body part from getting caught. The die guard is to also protect from any body part getting caught while also preventing the operator from getting burned. The granulator should have a guard to prevent an operator from getting anything caught within as it can cause serious harm. This granulator is at the end of the extruder by the die and should be worked around cautiously.

The extruder is a large piece of equipment and requires many safeguards in order to be operated around safely. One such safeguard is a pressure measurement device located at the die and within the barrel. These are used to prevent high pressure situations and can give proper warning and action time to react to potentially catastrophic situations (Whelan).

Extrusion is also a messy process and there will be downtime in order to clean out the screw/barrel or clear the hopper. In any case, it is important to follow proper safety procedures while working around the equipment. The first step should always be to shut down the device, wait for it to stop operating and then unplug the power from the extruder. One such case is to never put hands within the device in order to clean anything out. Sharp equipment fills the extruding device and will cause harm to anyone not following proper procedure.
The heat exchangers should be operated with caution as they are using steam that can cause burns if not handled properly. Insulation should be placed on all the steam lines for the heat exchangers, but if it is necessary to work on the steam lines the operator must follow standard operating procedure and shutdown the heat exchanger for the line to cool down or wear proper glove protection.

An important aspect of protecting the facility is an automatic sprinkler system installed in the plant. This not only protects the plant but also prevents the spread of fire and allows workers to escape safely. For the size of the plant with the material not being highly flammable, it is recommended to have approximately a sprinkler head for every 100 square feet of plant with each head discharging at 20 gallons per minute. This ensures that each head is properly covering the plant and ensures the safety of the workers. This sprinkler system would be an automatic sprinkler system where each head acts as a fire detection system. It is important to have an automatic sprinkler system in case workers are unable to reach an activation point for the system (Harry E. Hickey, 2008).

As a secondary action for fighting fires, firefighters would be trained as to what materials are being used at this plant as well as how to fight the fire if one were to break out.

Other Important Considerations

Environmental Safety

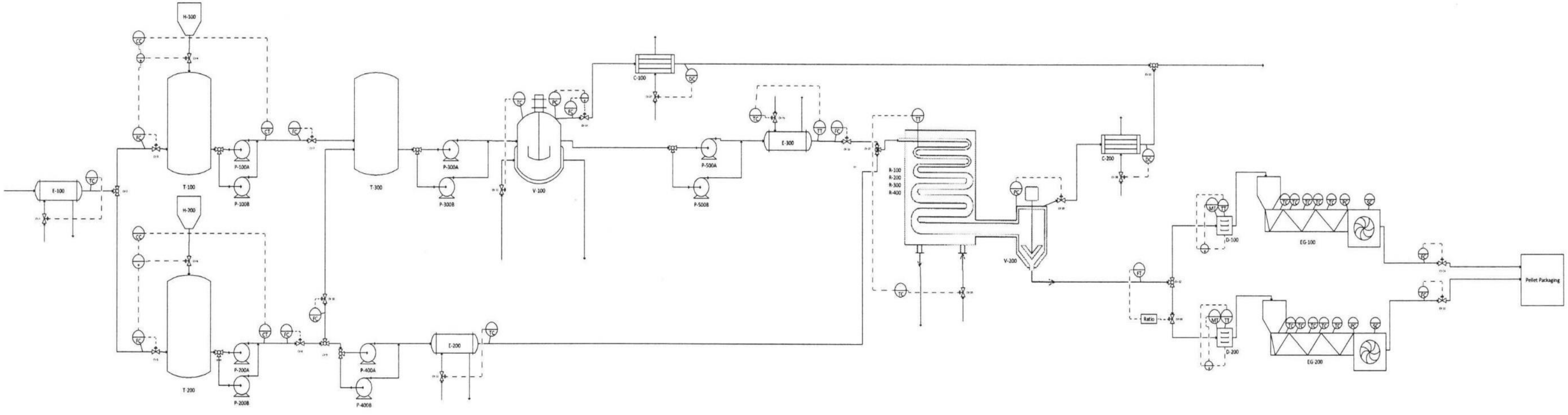
Environmental concerns were discussed as the adipic acid and hexamethylenediamine are harmful to the environment. Unreacted adipic acid and hexamethylenediamine are evaporated away from the main product along with other byproducts such as ammonia, carbon dioxide and water. This steam is then condensed within the condenser to be sent to an offsite treatment facility. This facility will ensure that this process abides by current health and safety standards while maintaining a healthy and safe environment.

Startup

A few operations need to be considered while undergoing startup for this process. The pumps need to be kept off until the flow of the process fluid has reached it. This is to ensure that the pump does not cavitate. A second operation that was taken into consideration was the residence times in vessels. The controls for the outlet of the vessels need to be kept off until the residence time has been reached for the vessel. Once the residence time has been reached, the control for the outlet flow will be opened to the correct percentage. Startup for the reactors should follow normal process procedure for startup of reactors. Operators should watch the reactors carefully and be ready for any deviations while startup is occurring. The extruder requires many checks to ensure safe operation while under startup procedure. Before operation begins, the heating system should be turned on and heated up to the correct barrel temperatures. Once this temperature has been reached, it is recommended that the temperatures “equilibrate for about 20 minutes before the material is introduced” and while this is happening, check the hopper and granulator portions for blockages. Another concern during startup for the extruder is that decomposition can occur within the die and cause the material to be “spit” up, so it is recommended that the operator, during start up, keep a safe distance while working around the die (Whelan).

Piping & Instrumentation Diagram

A piping and instrumentation diagram was created to provide a detailed view of the process and the control equipment involved in maintaining said process. The control strategy for each piece of process equipment is explained in detail in the *Controllability and Instrumentation* section.



FC-----------Flow Rate Control
CT-----------Concentration Transmitter
CC-----------Concentration Control
TC-----------Temperature Control
TT-----------Temperature Transmitter
PC-----------Pressure Control
DC-----------Density Control
MT----------Moisture Control
SC-----------Speed Control
+-------------Multiple Input Control

100% and 67% Nylon 6,6 Production

Date: 03-08-2017

Dolsky, Fenton, Sessler, Thomits

Controllability and Instrumentation

Process controllability and instrumentation was considered for this process. It was deemed necessary to install instruments as described below.

Heat Exchangers

The heat exchangers on the process pipelines were double pipe heat exchangers. The only way to control the process stream resulting temperature exiting these exchangers is to control either the process stream flow rate or the flow rate of the heating or cooling medium, in this case steam and cooling water. A temperature indicator was placed on the exiting process stream and, depending on the difference from the temperature set point, sends a signal to the flow valve on the steam line to increase or decrease the valve clearance in order to keep the resulting process stream at the desired temperature.

Raw Material Solution Tanks

According to the process outlined in the patent that allowed for improved nylon production, as well as material balances, the concentrations of the raw material solutions prior to the reactor had to be kept at specific conditions. In order to control both the resulting concentrations and the production rate, a cascade control strategy was proposed. The feed rate of the raw materials, hexamethylenediamine and adipic acid, was controlled by simultaneously considering the exiting process stream concentration and the incoming water flow rate with a concentration sensor and flow sensor respectively. This allowed the production flow rates to remain at required throughputs while maintaining the required concentrations for better production according to the patent. The level of both tanks were controlled through a flow rate control valve, set by material balance values, located after the centrifugal pumps.

HMDA Primary Mixing Stream

In order to set the material flow rates needed for the prepolymerization reaction, a flow control valve and flow sensor were used on the initial process stream line going to the primary prepolymerization mixing vessel. By setting this stream to the flow specified in the material balance it set the flow rate of the remaining HMDA stream headed to the secondary mixing vessel.

Primary Mixing

The incoming flow rates for this mixing vessel were set by the previous units. The only control on this vessel is the exiting flow rate which is controlled by a flow rate control valve and sensor located after both the pump and the heat exchanger on the line.

Evaporator

The evaporator is required to remove the majority of the water from the nylon salt solution. Therefore the flow off the top of the evaporator must be controlled, but also a pressure control system must be implemented. To remain within both of these constraints a cascade control strategy was used to keep the vapor flow from the top of the evaporator high enough to remove the water from the reactor while providing a pressure relief to the evaporator. The pressure would override the flow control allowing for safe vapor relief to depressurize the vessel. The temperature of the evaporator must also be closely controlled to prevent polymerization from occurring. This is accomplished by a jacket with low pressure steam circulating through it. The temperature is kept steady by a temperature sensor within the evaporator liquid hold up. The sensor then controls the flow of steam through the jacket. Level within the evaporator is controlled by a flow sensor and flow control valve located after the subsequent pump and heat exchanger.

Tubular and Finishing Reactor

The controlled variable in the tubular reactor was the temperature. The temperature was needed to be kept fairly constant in order to precipitate the polymerization reaction. For this particular reactor steam was used as the heat medium. A temperature sensor controlled the inlet flow rate of steam into the reactor. The pressure through the reactor was controlled by the increasing diameter of the process pipe, and the pressure through the following finishing reactor was controlled by a pressure sensor and a bleed line that allowed for depressurization.

Nylon Melt Split to Dryers

To achieve equal split of the material flow between the two drying and further granulation streams, a ratio control strategy was used. By taking a flow rate reading prior to the splitting valve, the ratio of ½ of the reading was used to set the valve on one of the streams thus setting the flow rate for the remaining stream.

Dryers

In order to dry the product completely prior to extrusion and granulation, two variables had to be considered. Moisture content and temperature were vital variables that had to be controlled. The moisture content indicated at what point the stream was fully dry and the temperature had to be controlled to prevent product degradation. Cascade control was once again implemented here. This allowed for temperature to be kept below the critical value for degradation and set a time period for which the process stream was held for drying.

Extruder and Granulator

The extruder consists of multiple temperature zones that must be controlled. The extruder utilized electrical heaters and as such could not be controlled by steam flow rates. Instead using electrical temperature current controls located within the extruder was the control strategy. Five temperature zones on the extruder meant five temperature controllers. A pressure sensor was also required at the end of the extruder. This allowed for adjustment of the temperatures of the extrusion process. The granulator, connected at the end of the extrusion process, possessed only one variable to control in this process. The impeller speed needed to be controlled in order to have consistent pellet size. This was again an electrical control system located on the granulator.

Hoppers

The raw material hoppers are filled with raw materials in order to provide a controllable flow rate for the continuous process. The flow rate from the hoppers to the raw material mixers was controlled with a flow rate sensor and control valve. The material flow rate was set according to the mass balances over the process. The flow rates were measured upstream of the control valves. This allowed for the required production flow rates to be achieved.

Manufacturing Costs

On pg.207 of Turton et al. the total cost of manufacturing can be calculated using Equation (19) as shown below (Turton, 2012).

$$COM = 0.280FCI + 2.73C_{OL} + 1.23(C_{UT} + C_{WT} + C_{RM}) \qquad (19)$$

Where:
COM = Cost of Manufacturing
FCI = Fixed Capital Investment
C_{OL} = Cost of Operating Labor
C_{UT} = Cost of Utilities
C_{WT} = Cost of Water Treatment
C_{RM} = Cost of Raw Materials

The fixed capital investment of this project is the sum of the equipment installed costs, in addition to the grassroots factors that were mentioned earlier. The values for these numbers can be found in Table 35 of the Appendix.

For the cost of operating labor, equations from pgs.208-209 in Turton et al.'s *Estimation of Manufacturing Costs* chapter were used. Equations (20) and (21) can be found below (Turton, 2012).

$$N_{OL} = \left(6.29 + 31.7P^2 + 0.23N_{np}\right)^{0.5} \qquad (20) \quad ; \qquad OL = 4.5N_{OL} \qquad (21)$$

Where:
N_{OL} = Number of operators per shift
P = Number of processing steps involving handling particulate solids
N_{np} = Number of processing steps involving non-particulate solids
OL = Total Operating Labor (rounded up to nearest whole number)

This process has only two steps that include handling particulate solids, both of which are the transportation of the solid adipic acid and hexamethylenediamine from the 30-day storage tanks to the gravity feed hoppers above the solution mixers. The number of process steps without particulate solids is any piece of equipment that includes heating, cooling, mixing, or reacting. For this process, that number totaled up to 17. When these values were input into the equation, the number of operators per shift comes out to 11.7.

The total amount of operating labor for this process is the number of operators per shift multiplied by the amount people that need to be hired per operator at the plant. This number is assumed to be 4.5 employees per operator from the Turton estimation (Turton, 2012). Once the total amount of operating labor is obtained, it can be multiplied by the average salary per operator, which was assumed to be similar to the 2010 average of $60,000, producing the total cost of the operating labor. These values can be found in Table 12 shown below.

Table 12: Operating Labor and Salaries

Operating Labor	People
Number of Operators/Shift	11.70469991
Operating Labor	53
Cost/yr Operating Labor	$3,157,740.00

To obtain the cost of utilities per year, the utility cost of each individual piece of equipment was added together in Table 4, as shown previously in the utilities section.

For the wastewater treatment, a price of $56/1000m^3 was used to calculate the total amount of cost per year (Turton, 2012, p 213). This is the price used for tertiary wastewater treatment which includes filtration, activated sludge, and chemical processing. This price was multiplied by the amount of wastewater accumulated in the process, as shown below in Table 13.

Table 13: Waste Water Costs

Waste Water Treatment	Evaporator	Reactors
lb / hr	2708.49	2506.53
kg / hr	1228.55	1136.94
m3 / hr	1.3267	1.2278
m3 / yr	11622.137	10755.509
$ / m3	56	56
$ / yr	$650,839.67	$602,308.53
Cost/yr Waste Water	$1,253,148.20	

The final and most impactful component of the total cost of manufacturing was the raw material cost. The prices for these materials have been quoted from INVISTA, a large company that produces nylon and nylon technologies. The total amount of raw material needed has been back-calculated from the specified production of nylon and the assumed selectivity of the reactors. These numbers have been calculated and tabulated in Table 14 as shown below.

Table 14: Raw Material Cost

Raw Materials	AA	HMDA	H2O
kg / hr	3353.869621	2666.985005	1952.396273
kg / yr	29379897.88	23362788.64	17102991.35
$ / kg	1.5	2.5	0.000067
$ / yr	44069846.82	58406971.61	1145.90042
Cost/yr Raw Material	$102,477,964.33		

Once all of the components have been obtained, the total cost of manufacturing can be calculated using Equation (19). The equation is used to calculate the values shown below in Table 15.

Table 15: Summary of All Costs

Cost/yr Utilities	$10,845,469.93
Cost/yr Raw Material	$102,477,964.33
Cost/yr Waste Water	$1,253,148.20
Fixed Capital Investment	$18,737,644.17
Cost/yr Operating Labor	$3,157,740.00
Cost of Manufacturing (COM)	$154,796,366.99

The working capital for this project has been estimated at approximately zero. The design for this process is based on the assumption that there is no leftover raw material after each yearly period. All raw material purchased is used and all product made is sold.

Economic Analysis

The preliminary design of this process was based on the minimization of the cost and maximization of the revenue. The results of this design method is shown on a large scale over a ten-year production period, which was determined to be the optimal amount of time that nylon production would be profitable. An example of the ten-year economic analysis is shown below in Table 16.

Table 16: Sample Economic Analysis

End of Year	2017	2018	2019	2020
	0	1	2	3
Production (kg Nylon/year)	0.00	38,555,000.00	38,555,000.00	38,555,000.00
x Sales Price ($/kg Nylon)	4.74	4.74	4.74	4.74
Sales Revenue = Net Revenue	0.00	182,905,696.93	182,905,696.93	182,905,696.93
-Cost of Manufacturing	0.00	(154,796,366.99)	(154,796,366.99)	(154,796,366.99)
MACRS Depreciation Scale at 10 years:	0.00	0.10	0.18	0.14
-Depreciation of CM	0.00	(1,873,764.42)	(3,372,775.95)	(2,698,220.76)
-Writeoff				
Taxable Income	0.00	26,235,565.52	24,736,553.99	25,411,109.18
Tax @ 40%	0.00	(10,494,226.21)	(9,894,621.60)	(10,164,443.67)
Net Income	0.00	15,741,339.31	14,841,932.39	15,246,665.51
+Depreciation of CM	0.00	1,873,764.42	3,372,775.95	2,698,220.76
+Writeoff				
Fixed Capital:				
-Grass Roots Cost (Total Installed)	(18,737,644.17)			
Cash Flow	(18,737,644.17)	17,615,103.73	18,214,708.34	17,944,886.27
Discount Factor (P/F)	1.00	0.87	0.76	0.66
Discounted Cash Flow	(18,737,644.17)	15,317,481.50	13,772,936.37	11,799,054.01
NPV @ i*=	**$70,122,531.65**	NPV > 0, so the project is economically attractive		
DCFROR =	69%	DFCROR > 15%, so project is economically attractive		

It was specified in the project statement that 85MM pounds of nylon 6,6 must be produced every year. When doing research, most equipment and prices used kilograms in the calculations, so the yearly production was converted to 38.6MM kg per year. After very thorough research, it was found that the price of nylon 6,6 pellets was $3.19 per kg in 2001 ("SRF Ltd. vs Commissioner of Customs, Chennai Respondent," 2003). After adjusting for inflation, the price of nylon 6,6 pellets are assumed to be ~$4.74 per kg in 2017.

The tax rate was assumed to be a flat 40% over all ten years of the project life, while also using the ten year MACRS depreciation scale to depreciate the total fixed capital investment. The minimum rate of return for this project was set at 15%, which dictated the discount factor and whether or not the DCFROR was economically attractive.

In addition to the net present value (NPV) being $70 million, the payback period for this project running at 100% capacity was 2.25 years, and the breakeven sales price for nylon 6,6 was $4.14 per kg. The leniency of the sales price in combination with the substantial NPV make this project economically attractive.

Although it is not expected, if nylon 6,6 demand is in decline, an economic analysis has been performed for a turndown capacity of 67%. An example of this analysis is shown below in Table 17.

Table 17: Sample of 67% Economic Analysis

End of Year	2017	2018	2019	2020
	0	1	2	3
Production (kg Nylon/year)	0.00	25,831,850.00	25,831,850.00	25,831,850.00
x Sales Price ($/kg Nylon)	4.74	4.74	4.74	4.74
Sales Revenue = Net Revenue	0.00	122,546,816.94	122,546,816.94	122,546,816.94
-Cost of Manufacturing	0.00	(107,395,594.62)	(107,395,594.62)	(107,395,594.62)
MACRS Depreciation Scale at 10 years:	0.00	0.10	0.18	0.14
-Depreciation of CM	0.00	(1,873,764.42)	(3,372,775.95)	(2,698,220.76)
-Writeoff				
Taxable Income	0.00	13,277,457.91	11,778,446.38	12,453,001.57
Tax @ 40%	0.00	(5,310,983.16)	(4,711,378.55)	(4,981,200.63)
Net Income	0.00	7,966,474.75	7,067,067.83	7,471,800.94
+Depreciation of CM	0.00	1,873,764.42	3,372,775.95	2,698,220.76
+Writeoff				
Fixed Capital:				
-Grass Roots Cost (Total Installed)	(18,737,644.17)			
Cash Flow	(18,737,644.17)	9,840,239.16	10,439,843.78	10,170,021.70
Discount Factor (P/F)	1.00	0.87	0.76	0.66
Discounted Cash Flow	(18,737,644.17)	8,556,729.71	7,894,021.76	6,686,954.35
NPV @ i*=	**$31,102,285.28**	NPV > 0, so the project is economically attractive		
DCFROR =	33%	DFCROR > 15%, so project is economically attractive		

All of the calculations used in the 100% capacity were also used in this 67% analysis. One key assumption that was made was the price of nylon 6,6 staying constant in this time of decreased demand. Although this will not necessarily be true, it helps compare the NPV and DCFROR between the two capacities when utilities, raw materials, and production have decreased.

Note that even when the plant was run at 67% capacity, the DCFROR was 33% and the NPV is $31 million, both of which are economically attractive for this minimum rate of return.

Conclusion and Recommendations

After creating a preliminary grass roots design for a continuous nylon 6,6 polymerization process, it was determined that this would be a profitable process that we recommend moving forward with. For a 100 percent production process producing 85 MM lbs/yr. of nylon 6,6, the economic analysis shows a net present value over a 10-year project life to be $70,120,000 while the 67 percent production is $31,100,000. These values were obtained with a sales price of $4.74/kg of nylon using an inflated price from 2001. A breakeven analysis was also performed, determining the minimum sales price of nylon 6,6 pellets to be $4.14 for the 100 percent process and $4.34 for 67 percent. The payback period was also determined to be 2.25 years for the 100 percent production of nylon 6,6 with a DCFROR of 69 percent and for 67 percent production a 33 percent DCFROR. Both production rates are economically viable and allows for the production of nylon 6,6 to be stifled when demand is low.

It is recommended that management move forward with the production of nylon 6,6 as it is an economically viable option with a positive NPV and a DCFROR greater than 15 percent. For costing of the equipment, costing correlations were used as estimations for the preliminary design so it is recommended to contact the sales representatives to get more accurate costing for the equipment. Another recommendation is to find a more accurate model for costing and sizing a finishing reactor. The closest model for costing that was available was for an evaporator which has many inherent flaws.

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Appendix

3/7/17 10:36 PM C:...\Polymerization Simulation onephase.m 1 of 4

```
%%Design Project 2: Nylon 6,6 Process
%6 Mar 2017
%% Nomenclature
%
% dydt is the vector of functions of the derivative of y with respect to t.
% soln is the solution matrix for the ODE problem.
% z is a vector containing the values the independent variable.
% z0 is the initial value of z.
% zf is the final value of z.
% y is a vector containing the values of the dependent variable.
% y0 is the initial value of y.
%
%%Function to solve system of ODEs
function Polymerization_Simulation_onephase
%%Setup
clear; % The function will cleanse.
z0=0; zf=250; % Integral limits (m).
y0=[0.0056698 0.005670 0 0.0099269 0 0 0 0 0 0.237528 463.15 1002000 10];%First 9↙
kmol/s, kg/s, K, next Pa, last m
%%Call ODE to solve the system of equations and store in soln
soln=ode45(@f,[z0,zf],y0);
%% Use model solution
z=linspace(z0,zf,100); % Generate the values of z using linspace
FA=deval(soln,z,1); % Retrieve value of y(1) from soln
FC=deval(soln,z,2); % Retrieve value of y(2) from soln
FL=deval(soln,z,3); % Retrieve value of y(3) from soln
FW=deval(soln,z,4); % Retrieve value of y(4) from soln
FSE=deval(soln,z,5);% Retrieve value of y(5) from soln
FSB=deval(soln,z,6);% Retrieve value of y(6) from soln
FCO2=deval(soln,z,7);% Retrieve value of y(7) from soln
FX=deval(soln,z,8); % Retrieve value of y(8) from soln
FNH3=deval(soln,z,9);% Retrieve value of y(9) from soln
%% Plot the solutions
plot(z,FA,'k-','LineWidth',2); % Plot y1 vs. z data
hold on
plot(z,FC,'g-.','LineWidth',2); %Plot y2 vs. z data
hold on
plot(z,FL,'b--','LineWidth',2); %Plot y3 vs. z data
hold on
plot(z,FW,'r-o','LineWidth',2); %Plot y4 vs. z data
hold on
plot(z,FX,'c--*','LineWidth',2);%Plot y8 vs. z data
hold off
%% Plot formatting options
xlabel('z (m)'); ylabel('Flowrate (kmol/s)');
legend('FA','FC','FL','FW','FX');
grid on; % Add grid to plot
title('Flowrates vs. Reactor Length');% Add title to plot

    %% User specified function for dydt for the dependent variables
    function dydz=f(z,y)
```

Figure 1: Matlab simulation for one-phase reactor

```
    % y(1) = y1 and y(2) = y2, etc.
    FA=y(1);
    FC=y(2);
    FL=y(3);
    FW=y(4);
    FSE=y(5);
    FSB=y(6);
    FCO2=y(7);
    FX=y(8);
    FNH3=y(9);
    WG=y(10);
    T=y(11);
    PL=y(12);
    H=y(13);
    % Insert any algebraic equations here
    R=1.9872036*10^(-3); %kcal/(K*mol)
    dt=.04; %(m)
    V=pi*dt^2/4*z;
    WL=FA/116.205+FC/146.141+FL/224.304+FW/18.015+FSE/146.141+FSB/(146.141-44.0095
+FCO2/44.0095+FX/224.304+FNH3/17.0305;
    rhoL=45.88;     %kg/m^3 From ASPEN, assuming the density of the mixture does not
change.
    vL=WL/(rhoL*pi/4*dt^2); %m/s
    CA=FA/(WL/rhoL);
    CC=FC/(WL/rhoL);
    CL=FL/(WL/rhoL);
    CW=FW/(WL/rhoL);
    CSE=FSE/(WL/rhoL);
    CSB=FSB/(WL/rhoL);
    CCO2=FCO2/(WL/rhoL);
    CX=FX/(WL/rhoL);
    CNH3=FNH3/(WL/rhoL);
    Ct=(CA+CC+CL+CW+CSE+CSB+CX);
    xw=CW/Ct;
    xc=CC/Ct;
    xA=CA/Ct;
    xL=CL/Ct;
    xSE=CSE/Ct;
    xSB=CSB/Ct;
    xCO2=CCO2/Ct;
    xX=CX/Ct;
    xNH3=CNH3/Ct;
    kp0=exp(2.55-.45*tanh(25*(xw-.55))+8.58*(tanh(xw-.1)-1)-1)*(1-30.05*xc);%Reaction
rate for polymerization
    DelHap=7650*tanh(6.5*(xw-.52))+6500*exp(-xw/.065)-800;%cal/mol
    K0=exp((1-.47*exp((-xw^.5)/.2))*(8.45-4.2*xw));   %Equilibrium Constant
    Kap=K0*exp(-DelHap/(R*1000)*(1/T-1/473));
    kp=kp0*exp(-21.4/R*(1/T-1/473));
    kd1=.06*exp(-30/R*(1/T-1/566));
    kd2=.005*exp(-30/R*(1/T-1/578));
    kd2c=.32*exp(-30/R*(1/T-1/578));
```

Figure 2: Matlab simulation continued 2/4

```
    kd3=.35*exp(-10/R*(1/T-1/578));
    kd4=10*exp(-50/R*(1/T-1/578));
    Rp=Ct*kp*(xA*xc-(xL*xw)/Kap);
    Rd1=Ct*kd1*xc;
    Rd2=Ct*xL*(kd2+kd2c*xA);
    Rd3=Ct*kd3*xA*xSE^.1;
    Rd4=Ct*kd4*xA*xSB^.3;
    HfA=-205*10^6; %NIST (J/kmol) solid. Heats of formation for basic reactants to
substitute as end groups, this is for solid HMDA
    HfC=-1021.32*10^6; %NIST (J/kmol) solid.
    HfL=231*4.184*224.304*1000;%(J/kmol) solid. engineering.purdue.
edu/~propulsi/propulsion/comb/propellants.html
    HfW=-285.83*10^6; %J/kmol liquid.
    HfSE=-HfC; %J/kmol based on carboxylic end groups
    HfSB=-HfC; %J/kmol based on carboxylic end groups again. These don't exist outside of
this process apparently
    HfCO2=-393.52*10^6; %J/kmol gas.
    HfNH3=-45.9*10^6; %J/kmol gas.
    HfX=231*4.184*224.304/1005*10^6;%J/kmol Assuming the crosslink is going to have the
same Hf of normal linkage.
    Hp=((HfL+HfW)-(HfA+HfC)); %J/kmol
    Hd1=((HfSE+HfW)-HfC);
    Hd2=((HfA+HfSE)-HfL);
    Hd3=((HfCO2+HfSB)-HfSE);
    Hd4=((HfX+2*HfNH3)-(HfSB+2*HfA));
    IV=.036*((2*10^6)/(CA+CC))^.85;
    muL=.026*IV^2.3;
    MW=18.0153;    %kg/kmol Molecular weight of water
    Umono=.1645/dt; %J/(m^2*s*K) ASPEN assuming it doesn't change from the entering
mixture
    Text=254+273.15; %K HPS
    CpLw=(-203.606+1523.29*T/1000-3196.413*(T/1000)^2+2474.455*(T/1000)^3+3.855326/
(T/1000)^2)*1000/MW; %J/(kg*K) NIST
    CpLa=(-306279.6+5800.38*T-18.81314*T^2+.02070235*T^3)/116.21;
    CpLc=(-7481880+49989.26*T-106.3641*T^2+.075455*T^3)/146.14;
    CpLl=(351.2+.04682*T)*1000/224.304;%(J/kgK)This is based on a Polymath Regression of
data found from NIST. Stable end and Schiff base will use linkage heat capacity due to
their structures basing on a link.
    CpL=FW*MW/WL*CpLw+FA*116.21/WL*CpLa+FC*146.14/WL*CpLc+((FL+FSE)*224.304+(FSB)*
(146.141-44.0095))/WL*CpLl; %An approximation to the heat capacity of a mixture.
    g=9.81; %m/s^2
    G=(CA*116.205+CC*146.141+CL*224.304+CW*MW+CSE*224.304+CSB*224.304+CX*224.304)*V*vL;%
Most momentum should be liquid anyway.
    ReL=rhoL*vL*dt/muL;

    fanning1=0;
    if ReL<3000         %This is from Bergman et al.
        fanning1=64/ReL;
    elseif ReL>=3000&&ReL<=5*10^6  %Assuming reactor is made of smooth tubes.
        fanning1=(.79*log(ReL)-1.64)^(-2);
    end
```

Figure 3: Continuation of Matlab simulation 3/4

```
    %System of ODEs
    dHdz=-1.25*dt/10; %Self-derived
    dWGdz=0;
    dFAdz=pi/4*dt^2*(-Rp+Rd2-2*Rd4);
    dFCdz=pi/4*dt^2*(-Rp-Rd1);
    dFLdz=pi/4*dt^2*(Rp-Rd2);
    dFWdz=pi/4*dt^2*(Rp+Rd1);
    dFSEdz=pi/4*dt^2*(Rd1+Rd2-Rd3);
    dFSBdz=pi/4*dt^2*(Rd3-Rd4);
    dFCO2dz=pi/4*dt^2*(Rd3);
    dFXdz=pi/4*dt^2*(Rd4);
    dFNH3dz=pi/4*dt^2*(2*Rd4);
    dTdz=(pi/4*dt^2*(-Hp*Rp-Hd1*Rd1-Hd2*Rd2-Hd3*Rd3-Hd4*Rd4)-Umono*pi*dt*(T-Text))/
(WL*CpL);
    dPLdz=-2*fanning1/(rhoL*dt)*G^2-rhoL*g*dHdz;

        dydz(1)=dFAdz;
        dydz(2)=dFCdz;
        dydz(3)=dFLdz;
        dydz(4)=dFWdz;
        dydz(5)=dFSEdz;
        dydz(6)=dFSBdz;
        dydz(7)=dFCO2dz;
        dydz(8)=dFXdz;
        dydz(9)=dFNH3dz;
        dydz(10)=dWGdz;
        dydz(11)=dTdz;
        dydz(12)=dPLdz;
        dydz(13)=dHdz;
        dydz=dydz'; % Return dydt as column vector
    end

end
```

Figure 4: Final page of Matlab simulation

Table 1: Polymath regression for heat capacity of nylon 6,6 with T in Kelvin

POLYMATH Report
Linear Regression

Model: Cp = a0 + a1*T_K

Variable	Value	95% confidence
a0	351.1703	0.0679648
a1	0.4682129	0.000144

General
Regression including a free parameter
Number of observations = 28

Statistics

R^2	0.9999994
R^2adj	0.9999994
Rmsd	0.0054519
Variance	0.0008963

Source data points and calculated data points

	T_K	Cp	Cp calc	Delta Cp
1	330	505.7	505.6805	0.0194581
2	340	510.4	510.3627	0.037329
3	350	515	515.0448	-0.0448002
4	360	519.7	519.7269	-0.0269294
5	370	524.4	524.4091	-0.0090586
6	380	529.1	529.0912	0.0088123
7	390	533.8	533.7733	0.0266831
8	400	538.5	538.4554	0.0445539
9	410	543.1	543.1376	-0.0375753
10	420	547.8	547.8197	-0.0197044
11	430	552.5	552.5018	-0.0018336
12	440	557.2	557.184	0.0160372
13	450	561.9	561.8661	0.033908
14	460	566.5	566.5482	-0.0482211
15	470	571.2	571.2304	-0.0303503
16	480	575.9	575.9125	-0.0124795
17	490	580.6	580.5946	0.0053914
18	500	585.3	585.2767	0.0232622
19	510	590	589.9589	0.041133
20	520	594.6	594.641	-0.0409962
21	530	599.3	599.3231	-0.0231253
22	540	604	604.0053	-0.0052545
23	550	608.7	608.6874	0.0126163
24	560	613.4	613.3695	0.0304871
25	570	618.1	618.0516	0.048358
26	580	622.7	622.7338	-0.0337712
27	590	627.4	627.4159	-0.0159004
28	600	632.1	632.098	0.0019704

Table 2: Equipment descriptions of operating conditions

Equipment									
Vessels	T-100	T-200	T-300						
Temperature (°F)	138.2	138.2	138.2						
Pressure (psia)	64.7	64.7	64.7						
Orientation	Mixer	Mixer	Mixer						
Material	SS clad	SS clad	SS clad						
Volume (ft^3)	105.94	105.94	70.63						
Diameter (ft)	3.54	3.54	3.12						
Reactors	R-100	R-200	R-300	R-400					
Temperature (°F)	265	270	275	280					
Pressure (psia)	290	290	290	290					
Orientation	Tube Reactor	Tube Reactor	Tube Reactor	Tube Reactor					
Material	CS-shell Cu-Tube	CS-shell Cu-Tube	CS-shell Cu-Tube	CS-shell Cu-Tube					
Tube Diameter (ft)	0.13	0.26	0.39	0.49					
Heat Exchangers	E-100	E-200	E-300	C-100	C-200	V-100	V-200		
Type	Double Pipe	Double Pipe	Double Pipe	Condenser	Condenser	Agitated Film Evaporator	Finishing Reactor		
Area (ft^2)	7.24	17.68	20.34	71.39	34.39	20	18.08		
Duty (Btu/hr)	284000	688000	583000	2419000	2419000	297000	1116000		
Shell Temp In/Out (°F)	320/320	489/489	489/489	86/113	86/113	286/286	482/400		
Shell Pressure (psia)	87	609	609	64.7	64.7	87	609		
Shell Phase	Vapor	Vapor	Vapor	Liquid	Liquid	Vapor	Vapor		
Shell Material	SS	SS	SS	CS	CS	SS	SS		
Tube Temp In/Out	72/138	138/374	284/374	284/284	482/482	138/248	87/120		
Tube Pressure (psia)	90	166	166	166.3	166.3	65	64.7		
Tube Phase	Liquid	Liquid	Liquid	Cond.	Cond.	Liquid	Cond.		
Tube Material	SS	SS	SS	SS	SS	SS	SS		
Pumps	P-100A/B	P-200A/B	P-300A/B	P-400A/B	P-500A/B				
Type	Recipricating	Recipricating	Recipricating	Centrifugal	Centrifugal				
Capacity (gpm)	17.3	6.1	23.3	30.7	19.5				
Head (ft)	21.9	25.6	22.7	466.9	243.7				
Pdischarge (psia)	24.4	24.4	24.4	186.2	114.1				
Shaft Power (hp)	0.2	0.2	0.5	10	5				
Material	SS	SS	SS	SS	SS				
Dryers	D-100	D-200							
Type	Dessicant, Rotary	Dessicant, Rotary							
Material	SS	SS							
Temperature (°F)	180	180							
Moisture Equil. (%)	0.12	0.12							
Capacity (lb/hr)	5500	5500							
Extruder Pelletizers	EG-100	EG-200							
Type	Pelletizing	Pelletizing							
Screw Diameter (ft)	2.5	2.5							
Temperature Range (°F)	265-290	265-290							
Capacity (lb/hr)	5500	5500							
Hoppers	H-100	H-200							
Type	Vertical Drum	Vertical Drum							
Volume (ft3)	4181	5382							

Table 3: E-100 excel sheet including costing correlations and utility cost

	Table 7.7 pg 176 in design book for lang factor for plant cost possibly					
	Ch 7.3					
		E-100				
	Utilities Flow				Duty Calculation	
	Duty	btu/hr	284083.833		Q (BTU/hr)	284083.8
	ΔH	btu/lb	893		mh (lbm/hr)	318.123
					cph (BTU/lbm F)	1.4
	Utility Flow Rate				Tin (F)	320
	lb/hr	318.1229933			Tout (F)	320
	lb/yr [SF included]	2649232.851			tin (F)	72
	kg/yr [SF included]	1201670.828			tout (F)	138
	SF Included	$29.29/thousand pounds			mc (lbm/hr)	4304.301
	Cost/yr HEX	$33,286.28			cpc (BTU/lbm F)	1
	Log Mean Temperature Difference				Area Calculation	
	mh	318.1229933			Q (BTU/hr)	284083.8
	cph	1.4			Uo (BTU/hr *ft^2 F)	183.9563
	mc (lb/hr)	4304.30			Delta Tlm (F)	213.3009
	Density Water (lb/ft3)	62.4			A (ft^2)	7.24001
	cpc (BTU/lb F)	1			A (m^2)	0.672619
	R	0				
	P	0.266129032				
	P'	0.266129032				
# on one-pass shells	n	1				
	F	1				
	Delta Tlm	213.3008881				
	Heat Transfer Coefficient		260-700 typical value for hot fluid steam and cold fluid water			
sensible heat transfer for water, lower value and steam higher value	hi	1000				
	ho	1200				
	Do	0.0625				
	Di	0.048666667				
	R''fi	0.002				
assuming low-carb. Steel 14 BWG	RW	0.00025				
	R''fo	0.0005				
	Uo	183.9563209				
	Costing					
	K1	3.3444				
pg. 955 used double pipe; area < 10m2	K2	0.2745				
	K3	-0.0472				
	A (ft^2)	7.240009571				
	A (m^2)	0.67261955				
	log Cpo	3.295722614				
	Cpo	1975.707342				
	C1	0				
	C2	0				
	C3	0				
	P operating (psia)	40				
	P design (barg)	5.227443				
	log Fp	0				
	Fp	1				
	Purchase Cost					
	ID #	1				
	Fm	1				
	Cp (2001)	$1,975.71				
	Cp (2017)	$2,691.84				
	Installed Cost					
	Fm	1				
	B1	1.63				
	B2	1.66				
	Cbm (2001)	$6,500.08				
	Cbm (2017)	$8,856.15				
	Installation Cost					
	Installation Cost	$6,164.31				

Table 4: E-200 excel costing sheet and utility cost

Page 193 for Grassroots cost

E-200

Utilities Flow		
Duty	btu/hr	688399.3151
ΔH	btu/lb	730.2

Duty Calculation	
Q (BTU/hr)	688399.3
mh (lbm/hr)	942.7545
cph (BTU/lbm F)	1.07
Tin (F)	489.2
Tout (F)	489.2
tin (F)	138.2
tout (F)	374
mc (lbm/hr)	4268.78
cpc (BTU/lbm F)	0.6839

Utility Flow Rate	
lb/hr	942.7544715
lb/yr [SF included]	7850976.413
kg/yr [SF included]	3561140.093
SF Included	$29.97/thousand pounds
Cost/yr HEX	$106,727.37

Area Calculation	
Q (BTU/hr)	688399.3
Uo (BTU/hr *ft^2 F)	183.9563
Delta Tlm (F)	211.6475
A (ft^2)	17.68123
A (m^2)	1.642639

	Log Mean Temperature Difference	
	mh	942.7544715
	cph	1.4
	mc (lb/hr)	4268.78
	Density Water (lb/ft3)	62.4
	cpc (BTU/lb F)	0.6839
	R	0
	P	0.671794872
	P'	0.671794872
# on one-pass shells	n	1
	F	1
	Delta Tlm	211.6475299

260-700 typical value for hot fluid steam and cold fluid water

	Heat Transfer Coefficient	
sensible heat transfer for water, lower value and steam higher value	hi	1000
	ho	1200
	Do	0.0625
	Di	0.048666667
	R''fi	0.002
assuming low-carb. Steel 14 BWG	RW	0.00025
	R''fo	0.0005
	Uo	183.9563209

	Costing	
	K1	3.3444
pg. 955 used double pipe; area < 10m2	K2	0.2745
	K3	-0.0472
	A (ft^2)	17.68123149
	A (m^2)	1.642641746
	log Cpo	3.401373662
	Cpo	2519.844042
	C1	0.03881
	C2	-0.11272
	C3	0.08138
	P operating (psia)	116.3
	P design (barg)	10.484513
	log Fp	0.008532596
	Fp	1.019841302

Purchase Cost	
ID #	1
Fm	1
Cp (2001)	$2,569.84
Cp (2017)	$3,501.33

Installed Cost	
Fm	1
B1	1.63
B2	1.66
Cbm (2001)	$8,373.28
Cbm (2017)	$11,408.33

Installation Cost	
Installation Cost	$7,907.01

Table 5: E-400 excel costing sheet and utility cost

Table 7.7 pg 176 in design book for lang factor for plant cost possibly

Ch 7.3

E-400

Utilities Flow		
Duty	btu/hr	583221.4425
ΔH	btu/lb	730.2

Duty Calculation	
Q (BTU/hr)	583221.4
mh (lbm/hr)	798.7147
cph (BTU/lbm F)	1.4
Tin (F)	489.2
Tout (F)	489.2
tin (F)	284
tout (F)	374
mc (lbm/hr)	10600.75
cpc (BTU/lbm F)	0.6113

Utility Flow Rate	
lb/hr	798.7146569
lb/yr [SF included]	6651456.049
kg/yr [SF included]	3017047.252
SF Included	$29.97/thousand pounds
Cost/yr HEX	$90,420.91

	Log Mean Temperature Difference		
	mh	798.7146569	
	cph	1.4	
	mc (lb/hr)	10600.75	From Hysys
	Density Water (lb/ft3)	62.4	
	cpc (BTU/lb F)	0.6113	
	R	0	
	P	0.438596491	
	P'	0.438596491	
# on one-pass shells	n	1	
	F	1	
	Delta Tlm	155.8939974	

Area Calculation	
Q (BTU/hr)	583221.4
Uo (BTU/hr *ft^2 F)	183.9563
Delta Tlm (F)	155.894
A (ft^2)	20.33712
A (m^2)	1.889379

	Heat Transfer Coefficient		260-700 typical value for hot fluid steam and cold fluid water
sensible heat transfer for water, lower value and steam higher value	hi	1000	
	ho	1200	
	Do	0.0625	
	Di	0.048666667	
	R''fi	0.002	
assuming low-carb. Steel 14 BWG	RW	0.00025	
	R''fo	0.0005	
	Uo	183.9563209	

	Costing	
	K1	3.3444
pg. 955 used double pipe; area < 10m2	K2	0.2745
	K3	-0.0472
	A (ft^2)	20.3371164
	A (m^2)	1.889381767
	log Cpo	3.416645921
	Cpo	2610.032535

C1	0.6072
C2	-0.921
C3	0.3327
P operating (psia)	116.3
P design (barg)	10.484513
log Fp	0.01378834
Fp	1.032258197

Purchase Cost	
ID #	1
Fm	1
Cp (2001)	$2,694.23
Cp (2017)	$3,670.80

Installed Cost	
Fm	1
B1	1.63
B2	1.66
Cbm (2001)	$8,587.01
Cbm (2017)	$11,699.53

Installation Cost	
Installation Cost	$8,028.73

Table 6: C-100 Condenser for steam from evaporator costing sheet and utility cost

	Table 7.7 pg 176 in design book for lang factor for plant cost possibly					
	Ch 7.3					
		C-100				
	Utilities Flow				Duty Calculation	
	Duty	btu/hr	2418682.937		Q (BTU/hr)	2418683
	ΔH	btu/lb	893		mh (lbm/hr)	2708.49
					cph (BTU/lbm F)	1.02
	Utility Flow Rate				Tin (F)	284
	lb/hr	89580.85			Tout (F)	284
	lb/yr [SF included]	746002440.6			tin (F)	86
	kg/yr [SF included]	338380739			tout (F)	113
	SF Included	$14.80 / 1000 m^3			mc (lbm/hr)	89580.85
	Cost/yr HEX	$5,029,662.49			cpc (BTU/lbm F)	1
	Log Mean Temperature Difference				Area Calculation	
	mh	2708.491531			Q (BTU/hr)	2418683
	cph	1.02			Uo (BTU/hr *ft^2 F)	183.9563
	mc (lb/hr)	89580.85	From Hysys		Delta Tlm (F)	184.1703
	Density Water (lb/ft3)	62.4			A (ft^2)	71.39121
	cpc (BTU/lb F)	1			A (m^2)	6.632457
	R	0				
	P	0.136363636				
	P'	0.136363636				
# on one-pass shells	n	1				
	F	1				
	Delta Tlm	184.1702603				
	Heat Transfer Coefficient		260-700 typical value for hot fluid steam and cold fluid water			
sensible heat transfer for water, lower	hi	1000				
value and steam higher value	ho	1200				
	Do	0.0625				
	Di	0.048666667				
	R"fi	0.002				
assuming low-carb. Steel 14 BWG	RW	0.00025				
	R"fo	0.0005				
	Uo	183.9563209				
	Costing		Double Pipe HEX K values	Fixed Tube HEX K values		
	K1	4.3247	3.3444	4.3247		
pg. 955 used double pipe; area < 10m2	K2	-0.303	0.2745	-0.303		
	K3	0.1634	-0.0472	0.1634		
	A (ft^2)	71.39120688				
	A (m^2)	6.632466567				
	log Cpo	3.53808273				
	Cpo	3452.094933				
	C1	0.03881	0.6072	0.03881		
	C2	-0.11272	-0.921	-0.11272		
	C3	0.08138	0.3327	0.08138		
	P operating (psia)	116.3				
	P design (barg)	10.484513				
	log Fp	0.008532596				
	Fp	1.019841302				
	Purchase Cost					
	ID #	4				
	Fm	1.8				
	Cp (2001)	$6,337.06				
	Cp (2017)	$8,634.04				
	Installed Cost					
	Fm	1.8				
	B1	1.63				
	B2	1.66				
	Cbm (2001)	$24,193.66				
	Cbm (2017)	$32,963.10				
	Installation Cost					
	Installation Cost	$24,329.06				

Table 7: C-200 Condenser for steam from reactor costing sheet and utility cost

	Table 7.7 pg 176 in design book for lang factor for plant cost possibly					
	Ch 7.3					
		C-200				
	Utilities Flow				Duty Calculation	
	Duty	btu/hr	2418682.937		Q (BTU/hr)	2418683
	ΔH	btu/lb	893		mh (lbm/hr)	2708.49
					cph (BTU/lbm F)	1.02
	Utility Flow Rate				Tin (F)	482
	lb/hr	89580.85			Tout (F)	482
	lb/yr [SF included]	746002440.6			tin (F)	86
	kg/yr [SF included]	338380739			tout (F)	113
	SF Included	$14.80 / 1000 m^3			mc (lbm/hr)	89580.85
	Cost/yr HEX	$5,029,662.49			cpc (BTU/lbm F)	1
	Log Mean Temperature Difference				Area Calculation	
	mh	2708.491531			Q (BTU/hr)	2418683
	cph	1.02			Uo (BTU/hr *ft^2 F)	183.9563
	mc (lb/hr)	89580.85	From Hysys		Delta Tlm (F)	382.3411
	Density Water (lb/ft3)	62.4			A (ft^2)	34.3885
	cpc (BTU/lb F)	1			A (m^2)	3.194795
	R	0				
	P	0.068181818				
	P'	0.068181818				
# on one-pass shells	n	1				
	F	1				
	Delta Tlm	382.3411237				
	Heat Transfer Coefficient		260-700 typical value for hot fluid steam and cold fluid water			
sensible heat transfer for water, lower	hi	1000				
value and steam higher value	ho	1200				
	Do	0.0625				
	Di	0.048666667				
	R''fi	0.002				
assuming low-carb. Steel 14 BWG	RW	0.00025				
	R''fo	0.0005				
	Uo	183.9563209				
	Costing		Double Pipe HEX values	Fixed Tube HEX values		
	K1	4.3247	3.3444	4.3247		
pg. 955 used double pipe; area < 10m2	K2	-0.303	0.2745	-0.303		
	K3	0.1634	-0.0472	0.1634		
	A (ft^2)	34.38849849				
	A (m^2)	3.194799142				
	log Cpo	3.470859089				
	Cpo	2957.052867				
	C1	0.03881	0.6072	0.03881		
	C2	-0.11272	-0.921	-0.11272		
	C3	0.08138	0.3327	0.08138		
	P operating (psia)	116.3				
	P design (barg)	10.484513				
	log Fp	0.008532596				
	Fp	1.019841302				
	Purchase Cost					
	ID #	4				
	Fm	1.8				
	Cp (2001)	$5,428.30				
	Cp (2017)	$7,395.89				
	Installed Cost					
	Fm	1.8				
	B1	1.63				
	B2	1.66				
	Cbm (2001)	$20,724.21				
	Cbm (2017)	$28,236.08				
	Installation Cost					
	Installation Cost	$20,840.19				

Table 8: P-100 Costing sheet and utility cost

Pump 1: AAsoln	P-100
Head (delta P is known)	
P out (barg)	0.67
ΔP (psi)	10
Density (lb/ft3)	65.73
SG	1.053
Head (ft)	21.9
Brake Horsepower	
Capacity (bpd)	591.6
Capacity (gpm)	17.257
Head (ft)	21.9
Efficiency of Pump	0.65
Efficiency of Motor	0.88
BHP	0.15
PHP	0.18
Buying PHP	0.2
Feed Pump 1 (Reciprocating)	
K1	3.8696
K2	0.3161
K3	0.122
Power (hp)	0.18
Power (kW)	0.13123495
logCp0	3.68571152
Cp0	$4,850
C1	-0.3935
C2	0.3957
C3	-0.00226
P (barg)	0.67
P Design (barg)	4.11
logFp	-0.15
Fp	0.71
Purchase Cost:	
Identification Number	28
Fm	2.35
Cp (2001)	$8,043
Cp (2016)	$10,958
Cp (2016) 1+spare	$21,916
Installed Cost:	
Fm	2.35
B1	1.89
B2	1.35
Cbm (2001)	$20,023
Cbm (2016)	$27,281
Cbm (2016) 1+spare	$54,563
Installation Cost	$32,647
Electricity for Pump 1	$76.45

Table 9: P-200 Costing sheet and utility cost

Pump 2: HMDAsoln	P-200
Head (delta P is known)	
P out (barg)	0.67
ΔP (psi)	10
Density (lb/ft3)	56.28
SG	0.902
Head (ft)	25.6
Brake Horsepower	
Capacity (bpd)	208.1
Capacity (gpm)	6.070
Head (ft)	25.6
Efficiency of Pump	0.65
Efficiency of Motor	0.88
BHP	0.05
PHP	0.06
Buying PHP	0.2
Feed Pump 2 (Reciprocating)	
K1	3.8696
K2	0.3161
K3	0.122
Power (hp)	0.06
Power (kW)	0.04616294
logCp0	3.66504482
Cp0	$4,624
C1	-0.3935
C2	0.3957
C3	-0.00226
P (barg)	0.67
P Design (barg)	4.11
logFp	-0.15
Fp	0.71
Purchase Cost:	
Identification Number	28
Fm	2.35
Cp (2001)	$7,669
Cp (2016)	$10,449
Cp (2016) 1+spare	$20,897
Installed Cost:	
Fm	2.35
B1	1.89
B2	1.35
Cbm (2001)	$19,093
Cbm (2016)	$26,013
Cbm (2016) 1+spare	$52,027
Installation Cost	$31,130
Electricity for Pump 2	$26.89

Table 10: P-300 Costing sheet and utility cost

Pump 3: SALTsoln	P-300
Head (delta P is known)	
P out (barg)	0.67
ΔP (psi)	10
Density (lb/ft3)	63.42
SG	1.016
Head (ft)	22.7
Brake Horsepower	
Capacity (bpd)	797.8
Capacity (gpm)	23.272
Head (ft)	22.7
Efficiency of Pump	0.65
Efficiency of Motor	0.88
BHP	0.21
PHP	0.24
Buying PHP	0.5
Feed Pump 3 (Reciprocating)	
K1	3.8696
K2	0.3161
K3	0.122
Power (hp)	0.24
Power (kW)	0.176976405
logCp0	3.700873066
Cp0	$5,022
C1	-0.3935
C2	0.3957
C3	-0.00226
P (barg)	0.67
P Design (barg)	4.11
logFp	-0.15
Fp	0.71
Purchase Cost:	
Identification Number	28
Fm	2.35
Cp (2001)	$8,328
Cp (2016)	$11,347
Cp (2016) 1+spare	$22,694
Installed Cost:	
Fm	2.35
B1	1.89
B2	1.35
Cbm (2001)	$20,735
Cbm (2016)	$28,251
Cbm (2016) 1+spare	$56,501
Installation Cost	$33,807
Electricity for Pump 3	$103.10

Table 11: P-400 Costing sheet and utility cost

Pump 4: HMDA 2	P-400
Head (delta P is known)	
P out (barg)	11.82
ΔP (psi)	174
Density (lb/ft3)	53.72
SG	0.861
Head (ft)	466.9
Brake Horsepower	
Capacity (bpd)	1052
Capacity (gpm)	30.687
Head (ft)	466.9
Efficiency of Pump	0.65
Efficiency of Motor	0.88
BHP	4.79
PHP	5.45
Buying PHP	10
Feed Pump 4 (Centrifugal)	
K1	3.3892
K2	0.0536
K3	0.1538
Power (hp)	5.45
Power (kW)	4.060563678
logCp0	3.478784258
Cp0	$3,012
C1	-0.3935
C2	0.3957
C3	-0.00226
P (barg)	11.82
P Design (barg)	15.27
logFp	0.07
Fp	1.18
Purchase Cost:	
Identification Number	39
Fm	2.25
Cp (2001)	$7,993
Cp (2016)	$10,891
Cp (2016) 1+spare	$21,781
Installed Cost:	
Fm	2.25
B1	1.89
B2	1.35
Cbm (2001)	$16,483
Cbm (2016)	$22,457
Cbm (2016) 1+spare	$44,914
Installation Cost	$23,133
Electricity for Pump 4	$2,365.44

Table 12: P-500 Costing sheet and utility cost

P-500	
Head (delta P is known)	
P out (barg)	6.93
ΔP (psi)	102
Density (lb/ft3)	60.34
SG	0.967
Head (ft)	243.7
Brake Horsepower	
Capacity (bpd)	668
Capacity (gpm)	19.486
Head (ft)	243.7
Efficiency of Pump	0.65
Efficiency of Motor	0.88
BHP	1.78
PHP	2.03
Buying PHP	5
Feed Pump 4 (Centrifugal)	
K1	3.3892
K2	0.0536
K3	0.1538
Power (hp)	2.03
Power (kW)	1.511464571
logCp0	3.403765574
Cp0	$2,534
C1	-0.3935
C2	0.3957
C3	-0.00226
P (barg)	6.93
P Design (barg)	10.37
logFp	0.01
Fp	1.01
Purchase Cost:	
Identification Number	39
Fm	2.25
Cp (2001)	$5,782
Cp (2016)	$7,878
Cp (2016) 1+spare	$15,755
Installed Cost:	
Fm	2.25
B1	1.89
B2	1.35
Cbm (2001)	$12,594
Cbm (2016)	$17,159
Cbm (2016) 1+spare	$34,319
Installation Cost	$18,563
Electricity for Pump 4	$880.49

Table 13: E-300 Agitated film evaporator costing and utility sheet

Table 7.7 pg 176 in design book for lang factor for plant cost possibly

Ch 7.3

E-300

Utilities Flow		
Duty	btu/hr	297392.3701
ΔH	btu/lb	583

Duty Calculation	
Q (BTU/hr)	297392.37
mh (lbm/hr)	510.10698
cph (BTU/lbm F)	1.07
Tin (F)	286
Tout (F)	286
tin (F)	138.2
tout (F)	248
mc (lbm/hr)	2708.4915
cpc (BTU/lbm F)	1

Utility Flow Rate	
lb/hr	510.1069813
lb/yr [SF included]	4248017.908
kg/yr [SF included]	1926866.939
SF Included	$27.70/thousand pounds
Cost/yr Evap	$53,374.21

Log Mean Temperature Difference		
mh	510.1069813	
cph	1.2	220 - 1.11, 300-1.35
mc (lb/hr)	2708.49	
Density Water (lb/ft3)	62.4	
cpc (BTU/lb F)	1	
R	0	
P	0.742895805	
P'	0.742895805	
n	1	# on one-pass shells
F	1	
Delta Tlm	80.83789591	

Area Calculation	
Q (BTU/hr)	297392.37
Uo (BTU/hr*ft^2 F	183.95632
Delta Tlm (F)	80.837896
A (ft^2)	19.998624
A (m^2)	1.8579321

260-700 typical value for hot fluid steam and cold fluid water

	Heat Transfer Coefficient	
sensible heat transfer for water, lower value	hi	1000
and steam higher value	ho	1200
	Do	0.0625
	Di	0.048666667
	R"fi	0.002
assuming low-carb. Steel 14 BWG	RW	0.00025
	R"fo	0.0005
	Uo	183.9563209

	Costing	Forced Circulation (Pumped)	Falling film	Agitated film (scraped wall	Short Tube	Long Tube
	K1	5.0238	3.9119	5	5.2366	4.642
pg. 955 used Agitated Film	K2	0.3475	0.8627	0.149	-0.6572	0.3698
	K3	0.0703	-0.0088	-0.0134	0.35	0.0025
	A (ft^2)	19.99862358	19.99862358	19.99862358	19.99862358	19.998624
	A (m^2)	1.857934724	1.857934724	1.857934724	1.857934724	1.8579347
	log Cpo	5.122376212	4.14335565	5.03911568	5.085125272	4.7416684
	Cpo	132548.9257	13910.91349	109424.7796	121653.6858	55165.607

C1	0	
C2	0	For 10<P<150 barg. P<10 Cx=0
C3	0	
P operating	14.7	
P design	3.484273	
log Fp	0	
Fp	1	

Purchase Cost	
ID #	1
Fm	1
Cp (2001)	$109,424.78
Cp (2017)	$149,087.82

Installed Cost		CS	Cu	SS	Ni	Ti
Fbm	3.9	2.9	3.63	3.9	9.66	14.5
Cbm (2001)	$426,756.64					
Cbm (2017)	$581,442.49					

Installation Cost	
Installation Cost	$432,354.67

Table 14: Process vessel direction/type optimization

	L/D=3 optimum but 2.5-5 common									
		Process Vessels								
		Types	K1	K2	K3	Capacity, Units	Min	Max	B1	B2
		Horizontal	3.5565	0.3776	0.0905	Volume, m3	0.1	628	1.49	1.52
		Vertical	3.4974	0.4485	0.1074	Volume, m3	0.3	520	2.25	1.82
		Mixer	4.7116	0.4479	0.0004	volume, m3	0.04	6	fbm=4	
		Name	Volume (m^3)	Cp0(Horizontal) 2001	Cp0(Vertical) 2001	Cp0 Mixer (2001)	Pressure (barg)	Diameter (m)	Fp	
60 min of flow also assuming no HMDA dissolves		H-100	118.3517066		77415.8033		1	3.689676104	1.189989248	
1 barg for vaccuum design		H-200	152.3731849		97320.67624		1	4.013892304	1.250619419	
		T-100	2.614998678	5369.202559	5050.726933	79187.2363	1	1.035349026	0.693615828	
		T-200	1.355999534	4055.312082	3619.071036	58999.18945	1	0.831794673	0.655550071	
		T-300	3.183001712	5878.326009	5624.421783	86481.21311	1	1.105457147	0.706726424	
		Material	Fm	Cp (Horizontal)	Cp (Vertical)	Cp (Mixer)	CBM (Horizontal	CBM (Vertical)	CBM (Mixer)	
		CS	1	$3,724.16	$3,503.26	$54,925.52	$13,660.84	$17,740.08	$219,702.08	
		SS clad	1.7	$6,331.08	$5,955.55	$93,373.38	$17,623.35	$22,203.23	$373,493.54	
		SS	3.1	$11,544.91	$10,860.12	$170,269.11	$25,548.37	$31,129.55	$681,076.45	
		Ni alloy clad	3.6	$13,406.99	$12,611.75	$197,731.87	$28,378.74	$34,317.52	$790,927.50	
		Ni alloy	7.1	$26,441.56	$24,873.18	$389,971.20	$48,191.29	$56,633.31	$1,559,884.78	
		Ti clad	4.7	$17,503.57	$16,465.34	$258,149.95	$34,605.54	$41,331.06	$1,032,599.79	
		Ti	9.4	$35,007.14	$32,930.68	$516,299.89	$61,210.97	$71,297.98	$2,065,199.57	

Table 15: Optimization of process vessel dimensions

CEPCI	
2001	2016
397	540.9

Solver for L/D=3 for T-200	
L (m)	2.495
D (m)	0.832
V (m^3)	1.356

Solver for L/D=3 for T-100	
L (m)	3.106047077
D (m)	1.035349026
V (m^3)	2.614998678

Solver for L/D=3 for T-300	
L (m)	3.316371442
D (m)	1.105457147
V (m^3)	3.183001712

Solver for L/D=3 for H-200	
L (m)	12.0417
D (m)	4.0139
V (m^3)	152.37

Solver for L/D=3 for H-100	
L (m)	11.06902831
D (m)	3.689676104
V (m^3)	118.3520723

Table 16: Pricing based on selected process vessel type- Highlight indicates selected type

Costing										
Name	Type	Volume (m3)	Pressure (barg)	Material	Diameter (m)	Cp (2001)	Cp (2017)	CBM (2001)	CBM (2017)	Install Cost (2017)
H-100	Vertical	118.3517066	1	SS clad	3.690	$156,610.76	$213,377.22	$459,217.13	$625,668.88	$412,291.66
H-200	Vertical	152.3731849	1	SS clad	4.014	$206,908.92	$281,906.88	$595,545.75	$811,412.33	$529,505.45
T-100	Horizontal	2.615	1	SS clad	1.035	$6,331.08	$8,625.90	$17,623.35	$24,011.26	$15,385.37
	Vertical	2.615	1	SS clad	1.035	$5,955.55	$8,114.25	$22,203.23	$30,251.21	$22,136.96
	Mixer	2.615	1	SS clad	1.035	$93,373.38	$127,218.30	$316,748.95	$431,560.46	$304,342.17
T-200	Horizontal	1.356	1	SS clad	0.832	$4,519.38	$6,157.52	$12,911.88	$17,592.02	$11,434.51
	Vertical	1.356	1	SS clad	0.832	$4,033.22	$5,495.14	$15,483.37	$21,095.60	$15,600.47
	Mixer	1.356	1	SS clad	0.832	$65,750.77	$89,583.35	$235,996.76	$321,538.15	$231,954.80
T-300	Horizontal	3.183	1	SS clad	1.105	$7,062.43	$9,622.33	$19,493.59	$26,559.41	$16,937.07
	Vertical	3.183	1	SS clad	1.105	$6,757.38	$9,206.71	$24,953.37	$33,998.19	$24,791.47
	Mixer	3.183	1	SS clad	1.105	$103,901.55	$141,562.59	$345,924.85	$471,311.72	$329,749.13

Table 17: Constants for storage vessel costing

L/D=3 optimum but 2.5-5 common										
	Storage Tanks									
									Bs for process vessel?	
	Types	**K1**	**K2**	**K3**	**Capacity, Units**	**C1**	**C2**	**C3**	**B1**	**B2**
Vertical Tank on concrete foundation	API Fixed Roof	4.8509	-0.3973	0.1445	Volume, m3	0	0	0	2.25	1.82
	API Floating Roof	5.9567	-0.7585	0.1749	Volume, m3	0	0	0	2.25	1.82

Table 18: Determination of storage vessel dimensions

Reactants	Density (kg/m3)	Flowrate (kg/h)	30 day storage (m3)	30 day storage (gal)
HMDA	840	5229.45	4482.385714	1184120.799
AA	1360	6576.3	3481.570588	919733.4654

Table 19: Solver optimization of tank dimensions

1 tank			1 tank	
Solver for L/D=3 for SV-200			Solver for L/D=3 for SV-100	
L (m)	37.17240133		L (m)	35.3091407
D (m)	12.39080044		D (m)	11.76971357
V (m^3)	4482.3857		V (m^3)	3841.570587

Table 20: Storage vessel costing

	Costing										
	Name	Type	Volume (m3)	Pressure (barg)	Material	Diameter (m)	Cp (2001)	Cp (2017)	CBM (2001)	CBM (2017)	Install Cost (2017)
1 tank	SV-100	Fixed Roof	3481.5706	0	SS	11.76971357	$559,431.87	$762,208.30	$1,424,205.26	$1,940,434.82	$1,178,226.51
	SV-200	Fixed Roof	4482.3857	0	SS	12.39080044	$657,976.93	$896,472.84	$1,675,081.90	$2,282,246.35	$1,385,773.51

Table 21: First reactor segment R-100 costing and utility sheet

Utilities Flow		
Duty	btu/hr	619229.2059
ΔH	btu/lb	730.2

Utility Flow Rate	
lb/hr	848.0268501
lb/yr [SF included]	7062113.2
kg/yr [SF included]	3203318.05
SF Included	$29.29/thousand pounds
Cost/yr HEX	$88,731.91

Log Mean Temperature Difference		
mh	848.0268501	
cph	1.4	
mc (lb/hr)	12720.42	From Hysys
Density Water (lb/ft3)	62.4	
cpc (BTU/lb F)	0.6866	
R	0	
P	0.62138475	
P'	0.62138475	
n	1	
F	1	
Delta Tlm	72.99985833	

Heat Transfer Coefficient		
		260-700 typical value for hot fluid steam and cold fluid water
hi	1000	
ho	1200	
Do	0.0625	
Di	0.048666667	
R''fi	0.002	
RW	0.00025	
R''fo	0.0005	
Uo	183.9563209	

Duty Calculation	
Q (BTU/hr)	619229.2059
mh (lbm/hr)	848.0268501
cph (BTU/lbm F)	1.4
Tin (F)	489.2
Tout (F)	489.2
tin (F)	375.1
tout (F)	446
mc (lbm/hr)	12720.42
cpc (BTU/lbm F)	0.6866

Area Calculation		
Q (BTU/hr)	619229.2059	
Uo (BTU/hr *ft^2 F)	183.9563209	
Delta Tlm (F)	72.99985833	
A (ft^2)	338.1583645	
A (m^2)	31.41592654	<-SOLVER THIS

R-100	
K1	3.9912
K2	0.0668
K3	0.243
D (m)	0.04
L (m)	250
A (m^2)	31.41592654
log Cpo	4.635883843
Cpo	43239.81654
C1	0.03881
C2	-0.11272
C3	0.08138
P operating (psia)	290.2
P design (barg)	22.466223
log Fp	0
Fp	1

Purchase Cost	
ID #	2
Fm	1.35
Cp (2001)	$58,373.75
Cp (2017)	$79,532.40

Installed Cost	
Fm	1.35
B1	1.74
B2	1.55
Cbm (2001)	$197,384.36
Cbm (2017)	$268,929.97

Installation Cost	
Installation Cost	$189,397.57

Table 22: R-200 Second reactor segment cost and utility sheet

Utilities Flow		
Duty	btu/hr	157209.1073
ΔH	btu/lb	730.2

Utility Flow Rate	
lb/hr	215.2959563
lb/yr [SF included]	1792920.135
kg/yr [SF included]	813254.23
SF Included	$29.29/thousand pounds
Cost/yr HEX	$22,527.14

Log Mean Temperature Difference		
mh	215.2959563	
cph	1.4	
mc (lb/hr)	12720.42	From Hysys
Density Water (lb/ft3)	62.4	
cpc (BTU/lb F)	0.6866	
R	0	
P	0.416666667	
P'	0.416666667	
n	1	
F	1	
Delta Tlm	33.39539306	

Heat Transfer Coefficient		
		260-700 typical value for hot fluid steam and cold fluid water
hi	1000	
ho	1200	
Do	0.0625	
Di	0.048666667	
R"fi	0.002	
RW	0.00025	
R"fo	0.0005	
Uo	183.9563209	

Duty Calculation	
Q (BTU/hr)	157209.1073
mh (lbm/hr)	215.2959563
cph (BTU/lbm F)	1.4
Tin (F)	489.2
Tout (F)	489.2
tin (F)	446
tout (F)	464
mc (lbm/hr)	12720.42
cpc (BTU/lbm F)	0.6866

Area Calculation		
Q (BTU/hr)	157209.1073	
Uo (BTU/hr *ft^2 F)	183.9563209	
Delta Tlm (F)	33.39539306	
A (ft^2)	676.316729	
A (m^2)	62.83185307	<--SOLVER THIS

R-200	
K1	3.9912
K2	0.0668
K3	0.243
D (m)	0.08
L (m)	250
A (m^2)	62.83185307
log Cpo	4.897046969
Cpo	78894.54377
C1	0.03881
C2	-0.11272
C3	0.08138
P operating (psia)	290.2
P design (barg)	22.466223
log Fp	0
Fp	1

Purchase Cost	
ID #	2
Fm	1.35
Cp (2001)	$106,507.63
Cp (2017)	$145,113.30

Installed Cost	
Fm	1.35
B1	1.74
B2	1.55
Cbm (2001)	$360,143.73
Cbm (2017)	$490,684.49

Installation Cost	
Installation Cost	$345,571.20

Table 23: R-300 Third reactor segment cost and utility sheet

Utilities Flow		
Duty	btu/hr	78604.55365
ΔH	btu/lb	730.2

Utility Flow Rate	
lb/hr	107.6479781
lb/yr [SF included]	896460.0676
kg/yr [SF included]	406627.115
SF Included	$29.29/thousand pounds
Cost/yr HEX	$11,263.57

Log Mean Temperature Difference		
mh	107.6479781	
cph	1.4	220 = 1.11, 300=1.35
mc (lb/hr)	12720.42	From Hysys
Density Water (lb/ft3)	62.4	
cpc (BTU/lb F)	0.6866	
R	0	
P	0.357142857	
P'	0.357142857	
n	1	
F	1	
Delta Tlm	20.36969861	

Heat Transfer Coefficient		
hi	1000	260-700 typical value for hot fluid steam and cold fluid water
ho	1200	
Do	0.0625	
Di	0.048666667	
R"fi	0.002	
RW	0.00025	
R"fo	0.0005	
Uo	183.9563209	

Duty Calculation	
Q (BTU/hr)	78604.55365
mh (lbm/hr)	107.6479781
cph (BTU/lbm F)	1.4
Tin (F)	489.2
Tout (F)	489.2
tin (F)	464
tout (F)	473
mc (lbm/hr)	12720.42
cpc (BTU/lbm F)	0.6866

Area Calculation		
Q (BTU/hr)	78604.55365	
Uo (BTU/hr *ft^2 F)	183.9563209	
Delta Tlm (F)	20.36969861	
A (ft^2)	1014.475093	
A (m^2)	94.24777961	<--SOLVER THIS

R-300	
K1	3.9912
K2	0.0668
K3	0.243
D (m)	0.12
L (m)	250
A (m^2)	94.24777961
log Cpo	5.070233707
Cpo	117552.9973
C1	0.03881
C2	-0.11272
C3	0.08138
P operating (psia)	290.2
P design (barg)	22.466223
log Fp	0
Fp	1

Purchase Cost	
ID #	2
Fm	1.35
Cp (2001)	$158,696.55
Cp (2017)	$216,219.05

Installed Cost	
Fm	1.35
B1	1.74
B2	1.55
Cbm (2001)	$536,614.74
Cbm (2017)	$731,120.69

Installation Cost	
Installation Cost	$514,901.64

Table 24: R-400 Fourth reactor segment cost and utility sheet

Utilities Flow		
Duty	btu/hr	78604.55365
ΔH	btu/lb	730.2

Utility Flow Rate	
lb/hr	107.6479781
lb/yr [SF included]	896460.0676
kg/yr [SF included]	406627.115
SF Included	$29.29/thousand pounds
Cost/yr HEX	$11,263.57

Log Mean Temperature Difference		
mh	107.6479781	
cph	1.4	220 = 1.11, 300=1.35
mc (lb/hr)	12720.42	From Hysys
Density Water (lb/ft3)	62.4	
cpc (BTU/lb F)	0.6866	
R	0	
P	0.555555556	
P'	0.555555556	
n	1	
F	1	
Delta Tlm	11.09836558	

Heat Transfer Coefficient		
hi	1000	260-700 typical value for hot fluid steam and cold fluid water
ho	1200	
Do	0.0625	
Di	0.048666667	
R''fi	0.002	
RW	0.00025	
R''fo	0.0005	
Uo	183.9563209	

Duty Calculation	
Q (BTU/hr)	78604.55365
mh (lbm/hr)	107.6479781
cph (BTU/lbm F)	1.4
Tin (F)	489.2
Tout (F)	489.2
tin (F)	473
tout (F)	482
mc (lbm/hr)	12720.42
cpc (BTU/lbm F)	0.6866

Area Calculation		
Q (BTU/hr)	78604.55365	
Uo (BTU/hr *ft^2 F)	183.9563209	
Delta Tlm (F)	11.09836558	
A (ft^2)	1268.093867	
A (m^2)	117.8097245	<--SOLVER THIS

R-400	
K1	3.9912
K2	0.0668
K3	0.243
D (m)	0.15
L (m)	250
A (m^2)	117.8097245
log Cpo	5.17197419
Cpo	148584.7336
C1	0.03881
C2	-0.11272
C3	0.08138
P operating (psia)	290.2
P design (barg)	22.466223
log Fp	0
Fp	1

Purchase Cost	
ID #	2
Fm	1.35
Cp (2001)	$200,589.39
Cp (2017)	$273,296.73

Installed Cost	
Fm	1.35
B1	1.74
B2	1.55
Cbm (2001)	$678,270.74
Cbm (2017)	$924,122.52

Installation Cost	
Installation Cost	$650,825.79

Table 25: V-200 Final evaporator cost and sizing

Table 7.7 pg 176 in design book for lang factor for plant cost possibly

Ch 7.3

Utilities Flow		
Duty	btu/hr	1116089.513
ΔH	btu/lb	583

Duty Calculation	
Q (BTU/hr)	1116089.5
mh (lbm/hr)	12720.42
cph (BTU/lbm F)	1.07
Tin (F)	482
Tout (F)	400
tin (F)	87
tout (F)	120
mc (lbm/hr)	0.00
cpc (BTU/lbm F)	1

Utility Flow Rate	
lb/hr	0
lb/yr [SF included]	0
kg/yr [SF included]	0
SF Included	$27.70/thousand pounds
Cost/yr Evap	$0.00

	Log Mean Temperature Difference		
	mc	0	
	cph	1.2	220 - 1.11, 300-1.35
	mh (lb/hr)	12720.42	
	Density Water (lb/ft3)	62.4	
	cpc (BTU/lb F)	1	
	R	2.484848485	
	P	0.083544304	
	P'	0.083544304	
# on one-pass shells	n	1	
	F	0.996009685	
	Delta Tlm	335.5619626	

Area Calculation	
Q (BTU/hr)	1116089.5
Uo (BTU/hr *ft^2 F	183.95632
Delta Tlm (F)	335.56196
A (ft^2)	18.080548
A (m^2)	1.6797371

	Heat Transfer Coefficient		260-700 typical value for hot fluid steam and cold fluid water
sensible heat transfer for water, lower value and steam higher value	hi	1000	
	ho	1200	
	Do	0.0625	
	Di	0.048666667	
	R"fi	0.002	
assuming low-carb. Steel 14 BWG	RW	0.00025	
	R"fo	0.0005	
	Uo	183.9563209	

	Costing	Forced Circulation (Pumped)	Falling film	Agitated film (scraped wall	Short Tube	Long Tube
	K1	5.0238	3.9119	5	5.2366	4.642
pg. 955 used Agitated Film	K2	0.3475	0.8627	0.149	-0.6572	0.3698
	K3	0.0703	-0.0088	-0.0134	0.35	0.0025
	A (ft^2)	18.08054789	18.08054789	18.08054789	18.08054789	18.080548
	A (m^2)	1.679739489	1.679739489	1.679739489	1.679739489	1.6797395
	log Cpo	5.105638167	4.105769756	5.032881213	5.106327877	4.7254213
	Cpo	127537.5784	12757.62277	107865.1653	127740.2839	53139.97

C1	0	
C2	0	For 10<P<150 barg. P<10 Cx=0
C3	0	
P operating	14.7	
P design	3.484273	
log Fp	0	
Fp	1	

Purchase Cost	
ID #	1
Fm	1
Cp (2001)	$107,865.17
Cp (2017)	$146,962.89

Installed Cost		CS	Cu	SS	Ni	Ti
Fbm	3.9	2.9	3.63	3.9	9.66	14.5
Cbm (2001)	$420,674.14					
Cbm (2017)	$573,155.28					

Installation Cost	
Installation Cost	$426,192.39

Table 26: D-100 and D-200 Cost and Utility Sheet

D-100 and D-200	180 F	
4 hrs dry time	Cost	
2 desiccant dryer w/ rotating honeycomb	$180,000.00	
Moisture equil: .12%		
Utilities		
Power use	6.18	kw/100lb
Flowrate	51.0694545	100lb/hr
Total Cost/hr	18.9365537	$/hr
Total Cost/yr	$157,590.00	Cost/yr

Table 27: EG-100 and EG-200 Cost, utilities and properties

Extruder barrels atleast 24D in length					
Pressure transducer at end of barrel to monitor melt pressure					
Screw Diameter 2.5					
Type: std					
Temps (degree C)	Rear	Center	Front		
Zone:	1	2	3	Adapter	Die
Range of Temp	265-290	275-285	280-290	280-290	270-290
Residence time to not exceed 5 mins in barrel for 280C					

Power Calculation	
m (kg/h)	2316.494344
cp (kj/kgC)	2.15
Delta T (°C)	197.8
Hfusion (kj/kg)	188.28
Power (kWh)	394.801418
Power (hp)	536.9299285
Power Cost/yr	$207,507.63
Cost per extruder	$100,000.00
Number of Extruders	2
Total Cost	$200,000.00

Table 28: Energy Balance

Energy Balance (BTU/hr)				
	mCpΔT	mΔH	Temperature (To, From) (°F)	Steam Temp (°F)
E-100	284,083.83	284,083.83	(138, 72)	320
E-200	688,399.32	688,399.32	(374, 138.2)	489.2
E-300	583,221.44	583,221.44	(374, 284)	489.2
C-100	2,418,682.94	2,418,682.94	284	(113, 86)
C-200	2,418,682.94	2,418,682.94	482	(113, 86)
V-100	297,392.37	297,392.37	(248, 138.2)	286
R-100	619,229.21	619,229.21	(375.1, 446)	489.2
R-200	157,209.11	157,209.11	(446, 464)	489.2
R-300	78,604.55	78,604.55	(464, 473)	489.2
R-400	78,604.55	78,604.55	(473, 482)	489.2

Table 29: Energy balance demand/provision

	Demand	Satisfied
E-100	285,000 BTU/hr to heat stream 1 from 72 to 138°F	285,000 BTU/hr from low pressure steam as it maintains 320°F
E-200	689,000 BTU/hr to heat stream 14 from 138.2 to 274°F	689,000 BTU/hr from high pressure steam as it maintains 489.2°F
E-300	584,000 BTU/hr to heat stream 18 from 284 to 374°F	584,000 BTU/hr from high pressure steam as it maintains 489.2°F
C-100	2,419,000 BTU/hr condense stream 17, saturated steam, for water treatment	2,419,000 BTU/hr from cooling water as it is cooled from 113 to 86°F
C-200	2,419,000 BTU/hr to condense stream 30, saturated steam, for water treatment	2,419,000 BTU/hr from cooling water as it is cooled from 113 to 86°F
V-100	298,000 BTU/hr to heat stream 13 from 138.2 to 248°F	298,000 BTU/hr from low pressure steam as it maintains 286°F
R-100	620,000 BTU/hr to heat stream 20 process fluid from 375.1 to 446°F	620,000 BTU/hr from high pressure steam as it maintains 489.2°F
R-200	158,000 BTU/hr to heat stream 20 process fluid from 446 to 464°F	158,000 BTU/hr from high pressure steam as it maintains 489.2°F
R-300	79,000 BTU/hr to heat stream 20 process fluid from 464 to 473°F	79,000 BTU/hr from high pressure steam as it maintains 489.2°F
R-400	79,000 BTU/hr to heat stream 20 process fluid from 473 to 482°F	79,000 BTU/hr from high pressure steam as it maintains 489.2°F

Table 30: Utility requirements summary

Utility Requirements with SF .95	
Equipment	Utility Cost
E-100	$33,286.28
E-200	$106,727.37
E-300	$90,420.91
C-100	$5,029,662.49
C-200	$5,029,662.49
V-100	$53,374.21
R-100	$88,731.91
R-200	$22,527.14
R-300	$11,263.57
R-400	$11,263.57
P-100	$76.45
P-200	$26.89
P-300	$103.10
P-400	$2,365.44
P-500	$880.49
D-100	$78,795.00
D-200	$78,795.00
EG-100	$103,753.81
EG-200	$103,753.81

Table 31: Grassroots cost from original unit costs

Equipment	E-100	E-200	E-300	C-100	C-200
CBM	$8,856.15	$11,408.33	$11,699.53	$32,963.10	$28,236.08
	P-100 A/B	P-200 A/B	P-300 A/B	P-400 A/B	P-500 A/B
	$54,562.57	$52,026.92	$56,501.03	$18,563.48	$44,914.26
	H-100	H-200	T-100	T-200	T-300
	$625,668.88	$811,412.33	$431,560.46	$321,538.15	$471,311.72
	R-100	R-200	R-300	R-400	V-200
	$268,929.97	$490,684.49	$731,120.69	$924,122.52	$573,155.28
	V-100	EG-100 and EG-200	D-100 and D-200	SV-200	SV-100
	$581,442.49	$200,000.00	$180,000.00	$2,282,246.35	$1,940,434.82
CTM	$ 13,160,964.35				
CGR	$ 18,737,644.17				

Table 32: Raw material costs for 100% capacity

Raw Materials	AA	HMDA	H2O
kg / hr	3353.869621	2666.985005	1952.396273
kg / yr	29379897.88	23362788.64	17102991.35
$ / kg	1.5	2.5	0.000067
$ / yr	44069846.82	58406971.61	1145.90042

Table 33: Waste water treatment cost from evaporator and finisher -100% capacity

Waste Water Treatment	Evaporator	Reactors
lb / hr	2708.49	2506.53
kg / hr	1228.55	1136.94
m3 / hr	1.3267	1.2278
m3 / yr	11622.137	10755.509
$ / m3	56	56
$ / yr	$650,839.67	$602,308.53

Table 34: Operating labor numbers -100% capacity

Operating Labor	People
Number of Operators/Shift	11.70469991
Operating Labor	53

Table 35: Total costs for economic analysis -100% capacity

Cost/yr Utilities	$10,845,469.93
Cost/yr Raw Material	$102,477,964.33
Cost/yr Waste Water	$1,253,148.20
Fixed Capital Investment	$18,737,644.17
Cost/yr Operating Labor	$3,157,740.00
Cost of Manufacturing (COM)	$154,796,366.99

Table 36: Raw material costs for 67% capacity

Raw Materials	AA	HMDA	H2O
kg / hr	2247.092646	1786.879953	1308.105503
kg / yr	19684531.58	15653068.39	11459004.2
$ / kg	1.5	2.5	0.000067
$ / yr	29526797.37	39132670.98	767.7532816

Table 37: Waste water treatment costs for 67% capacity

Waste Water Treatment	Evaporator	Reactor(s)
lb / hr	1814.69	1679.373451
kg / hr	823.13	761.75
m3 / hr	0.888907733	0.822624581
m3 / yr	7786.83174	7206.191331
$ / m3	56	56
$ / yr	436062.5774	403546.7146

Table 38: Operating labor for 67% capacity

Operating Labor	People
Number of Operators/Shift	11.67518736
Operating Labor	53

Table 39: Total costs for economic analysis -67% capacity

Cost/yr Utilities	6539523.753
Cost/yr Raw Material	68660236.1
Cost/yr Waste Water	839609.292
Fixed Capital Investment	18737644.17
Cost/yr Operating Labor	3157740
Cost of Manufacturing (COM)	107395594.6

Table 40: Economic Analysis for 100% capacity

Project Title:	Nylon 66 Design Project										
Corporate Financial Situation:	Expense										
Minimum Rate of Return, i*:	0.15										
Other relevant project info.:	1 = $1										
End of Year	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
	0	1	2	3	4	5	6	7	8	9	10
Production (kg Nylon/year)	0.00	38,555,000.00	38,555,000.00	38,555,000.00	38,555,000.00	38,555,000.00	38,555,000.00	38,555,000.00	38,555,000.00	38,555,000.00	38,555,000.00
x Sales Price ($/kg Nylon)	4.744020	4.744020	4.744020	4.744020	4.744020	4.744020	4.744020	4.744020	4.744020	4.744020	4.744020
Sales Revenue = Net Revenue	0.00	182,905,696.93	182,905,696.93	182,905,696.93	182,905,696.93	182,905,696.93	182,905,696.93	182,905,696.93	182,905,696.93	182,905,696.93	182,905,696.93
-Cost of Manufacturing	0.00	(154,796,366.99)	(154,796,366.99)	(154,796,366.99)	(154,796,366.99)	(154,796,366.99)	(154,796,366.99)	(154,796,366.99)	(154,796,366.99)	(154,796,366.99)	(154,796,366.99)
MACRS Depreciation Scale at 10 years:	0.00	0.10	0.18	0.14	0.12	0.09	0.07	0.07	0.07	0.07	0.07
-Depreciation of CM	0.00	(1,873,764.42)	(3,372,775.95)	(2,698,220.76)	(2,158,576.61)	(1,727,610.79)	(1,380,964.38)	(1,227,315.69)	(1,227,315.69)	(1,229,189.46)	(1,227,315.69)
-Writeoff											(614,594.73)
Taxable Income	0.00	26,235,565.52	24,736,553.99	25,411,109.18	25,950,753.33	26,381,719.15	26,728,365.56	26,882,014.25	26,882,014.25	26,880,140.48	26,882,014.25
Tax @ 40%	0.00	(10,494,226.21)	(9,894,621.60)	(10,164,443.67)	(10,380,301.33)	(10,552,687.66)	(10,691,346.23)	(10,752,805.70)	(10,752,805.70)	(10,752,056.19)	(10,752,805.70)
Net Income	0.00	15,741,339.31	14,841,932.39	15,246,665.51	15,570,452.00	15,829,031.49	16,037,019.34	16,129,208.55	16,129,208.55	16,128,084.29	16,129,208.55
+Depreciation of CM	0.00	1,873,764.42	3,372,775.95	2,698,220.76	2,158,576.61	1,727,610.79	1,380,964.38	1,227,315.69	1,227,315.69	1,229,189.46	1,227,315.69
+Writeoff											614,594.73
Fixed Capital:											
-Grass Roots Cost (Total Installed)	(18,737,644.17)										
Cash Flow	(18,737,644.17)	17,615,103.73	18,214,708.34	17,944,886.27	17,729,028.61	17,556,642.28	17,417,983.71	17,356,524.24	17,356,524.24	17,357,273.75	17,971,118.97
Discount Factor (P/F)	1.00	0.87	0.76	0.66	0.57	0.50	0.43	0.38	0.33	0.28	0.25
Discounted Cash Flow	(18,737,644.17)	15,317,481.50	13,772,936.37	11,799,054.01	10,136,629.65	8,728,754.09	7,530,275.02	6,524,960.35	5,673,878.56	4,934,020.50	4,442,185.76
NPV @ i*=	**$70,122,531.65**	NPV > 0, so the project is economically attractive									
DCFROR =	69%	DFCROR > 15%, so project is economically attractive									
Payback Period (years)	2.248324872										

Table 41: Breakeven analysis of 100% capacity

Project Title:	Nylon 66 Design Project										
Corporate Financial Situation:	Expense										
Minimum Rate of Return, i*:	0.15										
Other relevant project info.:	1 = $1										
End of Year	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
	0	1	2	3	4	5	6	7	8	9	10
Production (kg Nylon/year)	0.00	38,555,000.00	38,555,000.00	38,555,000.00	38,555,000.00	38,555,000.00	38,555,000.00	38,555,000.00	38,555,000.00	38,555,000.00	38,555,000.00
x Sales Price ($/kg Nylon)	4.14	4.14	4.14	4.14	4.14	4.14	4.14	4.14	4.14	4.14	4.14
Sales Revenue = Net Revenue	0.00	159,618,908.54	159,618,908.54	159,618,908.54	159,618,908.54	159,618,908.54	159,618,908.54	159,618,908.54	159,618,908.54	159,618,908.54	159,618,908.54
-Cost of Manufacturing	0.00	(154,796,366.99)	(154,796,366.99)	(154,796,366.99)	(154,796,366.99)	(154,796,366.99)	(154,796,366.99)	(154,796,366.99)	(154,796,366.99)	(154,796,366.99)	(154,796,366.99)
MACRS Depreciation Scale at 10 years:	0.00	0.10	0.18	0.14	0.12	0.09	0.07	0.07	0.07	0.07	0.07
-Depreciation of CM	0.00	(1,873,764.42)	(3,372,775.95)	(2,698,220.76)	(2,158,576.61)	(1,727,610.79)	(1,380,964.38)	(1,227,315.69)	(1,227,315.69)	(1,229,189.46)	(1,227,315.69)
-Writeoff											(614,594.73)
Taxable Income	0.00	2,948,777.14	1,449,765.60	2,124,320.79	2,663,964.94	3,094,930.76	3,441,577.18	3,595,225.86	3,595,225.86	3,593,352.10	3,595,225.86
Tax @ 40%	0.00	(1,179,510.85)	(579,906.24)	(849,728.32)	(1,065,585.98)	(1,237,972.30)	(1,376,630.87)	(1,438,090.34)	(1,438,090.34)	(1,437,340.84)	(1,438,090.34)
Net Income	0.00	1,769,266.28	869,859.36	1,274,592.48	1,598,378.97	1,856,958.46	2,064,946.31	2,157,135.52	2,157,135.52	2,156,011.26	2,157,135.52
+Depreciation of CM	0.00	1,873,764.42	3,372,775.95	2,698,220.76	2,158,576.61	1,727,610.79	1,380,964.38	1,227,315.69	1,227,315.69	1,229,189.46	1,227,315.69
+Writeoff											614,594.73
Fixed Capital:											
-Grass Roots Cost (Total Installed)	(18,737,644.17)										
Cash Flow	(18,737,644.17)	3,643,030.70	4,242,635.31	3,972,813.24	3,756,955.57	3,584,569.25	3,445,910.68	3,384,451.21	3,384,451.21	3,385,200.71	3,999,045.94
Discount Factor (P/F)	1.00	0.87	0.76	0.66	0.57	0.50	0.43	0.38	0.33	0.28	0.25
Discounted Cash Flow	(18,737,644.17)	3,167,852.78	3,208,041.82	2,612,189.19	2,148,051.54	1,782,164.44	1,489,762.28	1,272,340.57	1,106,383.10	962,285.32	988,502.99
NPV @ i*=	**-$70.12**										
DCFROR =	0%										

Table 42: Economic analysis for 67% capacity

Project Title:	Nylon 66 Design Project										
Corporate Financial Situation:	Expense										
Minimum Rate of Return, i*:	0.15										
Other relevant project info.:	1 = $1										
End of Year	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
	0	1	2	3	4	5	6	7	8	9	10
Production (kg Nylon/year)	0.00	25,831,850.00	25,831,850.00	25,831,850.00	25,831,850.00	25,831,850.00	25,831,850.00	25,831,850.00	25,831,850.00	25,831,850.00	25,831,850.00
x Sales Price ($/kg Nylon)	4.74	4.74	4.74	4.74	4.74	4.74	4.74	4.74	4.74	4.74	4.74
Sales Revenue = Net Revenue	0.00	122,546,816.94	122,546,816.94	122,546,816.94	122,546,816.94	122,546,816.94	122,546,816.94	122,546,816.94	122,546,816.94	122,546,816.94	122,546,816.94
-Cost of Manufacturing	0.00	(107,395,594.62)	(107,395,594.62)	(107,395,594.62)	(107,395,594.62)	(107,395,594.62)	(107,395,594.62)	(107,395,594.62)	(107,395,594.62)	(107,395,594.62)	(107,395,594.62)
MACRS Depreciation Scale at 10 years:	0.00	0.10	0.18	0.14	0.12	0.09	0.07	0.07	0.07	0.07	0.07
-Depreciation of CM	0.00	(1,873,764.42)	(3,372,775.95)	(2,698,220.76)	(2,158,576.61)	(1,727,610.79)	(1,380,964.38)	(1,227,315.69)	(1,227,315.69)	(1,229,189.46)	(1,227,315.69)
-Writeoff											(614,594.73)
Taxable Income	0.00	13,277,457.91	11,778,446.38	12,453,001.57	12,992,645.72	13,423,611.53	13,770,257.95	13,923,906.63	13,923,906.63	13,922,032.87	13,923,906.63
Tax @ 40%	0.00	(5,310,983.16)	(4,711,378.55)	(4,981,200.63)	(5,197,058.29)	(5,369,444.61)	(5,508,103.18)	(5,569,562.65)	(5,569,562.65)	(5,568,813.15)	(5,569,562.65)
Net Income	0.00	7,966,474.75	7,067,067.83	7,471,800.94	7,795,587.43	8,054,166.92	8,262,154.77	8,354,343.98	8,354,343.98	8,353,219.72	8,354,343.98
+Depreciation of CM	0.00	1,873,764.42	3,372,775.95	2,698,220.76	2,158,576.61	1,727,610.79	1,380,964.38	1,227,315.69	1,227,315.69	1,229,189.46	1,227,315.69
+Writeoff											614,594.73
Fixed Capital:											
-Grass Roots Cost (Total Installed)	(18,737,644.17)										
Cash Flow	(18,737,644.17)	9,840,239.16	10,439,843.78	10,170,021.70	9,954,164.04	9,781,777.71	9,643,119.15	9,581,659.67	9,581,659.67	9,582,409.18	10,196,254.40
Discount Factor (P/F)	1.00	0.87	0.76	0.66	0.57	0.50	0.43	0.38	0.33	0.28	0.25
Discounted Cash Flow	(18,737,644.17)	8,556,729.71	7,894,021.76	6,686,954.35	5,691,325.60	4,863,272.31	4,168,986.52	3,602,100.77	3,132,261.54	2,723,918.75	2,520,358.15
NPV @ i*=	**$31,102,285.28**	NPV > 0, so the project is economically attractive									
DCFROR =	33%	DFCROR > 15%, so project is economically attractive									

Table 43: Equipment list summary

List of Equipment				
Component	Type	Material	Size	Units
E-100	Double Pipe	CS-shell, SS-tube	0.673	m^2
E-200	Double Pipe	CS-shell, SS-tube	1.643	m^2
E-300	Double Pipe	CS-shell, SS-tube	1.889	m^2
C-100	Double Pipe	CS-shell, SS-tube	6.632	m^2
C-200	Double Pipe	CS-shell, SS-tube	3.195	m^2
P-100A/B	Reciprocating	SS	0.2	hp
P-200A/B	Reciprocating	SS	0.2	hp
P-300A/B	Reciprocating	SS	0.5	hp
P-400A/B	Centrifugal	SS	10	hp
P-500A/B	Centrifugal	SS	5	hp
V-100	Agitated Film	SS	1.858	m^2
H-100	Vertical Drum	SS clad	118.4	m^3
H-200	Vertical Drum	SS clad	152.4	m^3
T-100	Vertical Mixer	SS clad	2.615	m^3
T-200	Vertical Mixer	SS clad	1.356	m^3
T-300	Vertical Mixer	SS clad	3.183	m^3
SV-100	Fixed Roof	SS	3482	m^3
SV-200	Fixed Roof	SS	4482	m^3
R-100	Spiral Tube	CS-shell, Cu-tube	31.42	m^2
R-200	Spiral Tube	CS-shell, Cu-tube	62.83	m^2
R-300	Spiral Tube	CS-shell, Cu-tube	94.25	m^2
R-400	Spiral Tube	CS-shell, Cu-tube	117.8	m^2
V-200	Agitated Film	SS	1.680	m^2
D-100	Dessicant, Rotary	SS	5500	lb/hr
D-200	Dessicant, Rotary	SS	5500	lb/hr
EG-100	Pelletizing	SS	5500	lb/hr
EG-200	Pelletizing	SS	5500	lb/hr

Table 44: Equipment cost summary

Cost of Equipment		
Component	Purchase Price (USD)	Source
E-100	$2,691.84	Turton et al.
E-200	$3,501.33	Turton et al.
E-300	$3,670.80	Turton et al.
C-100	$8,634.04	Turton et al.
C-200	$7,395.89	Turton et al.
P-100A/B	$21,915.69	Turton et al.
P-200A/B	$20,897.21	Turton et al.
P-300A/B	$22,694.29	Turton et al.
P-400A/B	$21,781.18	Turton et al.
P-500A/B	$15,755.09	Turton et al.
V-100	$149,087.82	Turton et al.
H-100	$213,377.22	Turton et al.
H-200	$281,906.88	Turton et al.
T-100	$127,218.30	Turton et al.
T-200	$89,583.35	Turton et al.
T-300	$141,562.59	Turton et al.
SV-100	$762,208.30	Turton et al.
SV-200	$896,472.84	Turton et al.
R-100	$79,532.40	Turton et al.
R-200	$145,113.30	Turton et al.
R-300	$216,219.05	Turton et al.
R-400	$273,296.73	Turton et al.
V-200	$146,962.89	Turton et al.
D-100	$90,000.00	Plastics Technology
D-200	$90,000.00	Plastics Technology
EG-100	$100,000.00	Alibaba
EG-200	$100,000.00	Alibaba

Table 45: Preliminary HAZOP for P-100

Process Unit: P-100				
Intention: To pump from T-100 to T-300				
HAZOP for the Pump that Feeds AAsoln to Salt tank				
Guide Word	Deviation	Cause	Consequence	Action
No	No flow	Blockage in line	Cavitation and Composition of T-300 becomes incorrect	Shutdown operation, check line
↓	No Power	Power Failure	Reverse flow	Turn on generators or stop process until power regained
↓	No Backup Pump	Forgot to Install	If pump goes down shuts down process until new one put in	Put the new pump in parrallel to the original
More of	More flow	Momentary increase in water supply	Possible Cavitation	Change valve controls to adjust
Less of	Less Flow	Momentary decrease in water supply	Less flow to next process	Change valve controls to adjust
Reverse	Reverse Flow	Pump stops working	AAsoln for mixing will begin to flow back towards purification	Switch over to backup pump
Other than	Impurities in Stream 6	Water purification deviation	Fouling	Correct water purification deviation

Table 46: Preliminary HAZOP for P-200

Process Unit: P-200				
Intention: To pump from T-200 to T-300				
HAZOP for the Pump that Feeds HMDAsoln to salt tank				
Guide Word	Deviation	Cause	Consequence	Action
No	No flow	Blockage in line	Cavitation and Composition of T-300 becomes incorrect	Shutdown operation, check line
↓	No Power	Power Failure	Reverse flow	Turn on generators or stop process until power regained
↓	No Backup Pump	Forgot to Install	If pump goes down shuts down process until new one put in	Put the new pump in parrallel to the original
More of	More flow	Momentary increase in water supply	Possible Cavitation	Change valve controls to adjust
Less of	Less Flow	Momentary decrease in water supply	Less flow to next process	Change valve controls to adjust
Reverse	Reverse Flow	Pump stops working	HMDAsoln for mixing will begin to flow back towards	Switch over to backup pump
Other than	Impurities in Stream 9	Water purification deviation	Fouling	Correct water purification deviation

Table 47: Preliminary HAZOP for P-300

Process Unit: P-300				
Intention: To pump from T-300 to V-100				
HAZOP for the Pump that Feed Salt solution to evaporator				
Guide Word	Deviation	Cause	Consequence	Action
No	No flow	Blockage in line	V-100 has no cool stream and starts heating up	Shutdown steam line to V-100 until fixed
↓	No Power	Power Failure	Reverse flow	Turn on generators or stop process until power regained
↓	No Backup Pump	Forgot to Install	If pump goes down shuts down process until new one put in	Put the new pump in parrallel to the original
More of	More flow	Momentary increase in water supply	Possible Cavitation	Change valve controls to adjust
Less of	Less Flow	Momentary decrease in water supply	Less flow to next process	Change valve controls to adjust
Reverse	Reverse Flow	Pump stops working	Steam flows into T-300, pump runs dry	Switch to spare pump
Other than	Impurities in Stream 12	Water purification deviation	Poor Concentration, evaporation affected	Correct water purification deviation

Table 48: Preliminary HAZOP for P-400

Process Unit: P-400				
Intention: To pump from T-200 to R-100				
HAZOP for the Pump that Feeds HMDAsoln to Reactor				
Guide Word	Deviation	Cause	Consequence	Action
No	No flow	Blockage in line	Not enough HMDA in salt to react properly	Shutdown until blockage is fixed
↓	No Power	Power Failure	Reverse flow	Turn on generators or stop process until power regained
↓	No Backup Pump	Forgot to Install	If pump goes down shuts down process until new one put in	Put the new pump in parrallel to the original
More of	More flow	Momentary increase in water supply	Possible Cavitation	Change valve controls to adjust
Less of	Less Flow	Momentary decrease in water supply	Less flow to next process	Change valve controls to adjust
Reverse	Reverse Flow	Pump stops working	Concentrated salt flows into T-300, concentrations ruined	Switch to spare pump
Other than	Impurities in Stream 10	Water purification deviation	Poor Concentration, reaction affected	Correct water purification deviation

Table 49: Preliminary HAZOP for P-500

Process Unit: P-500				
Intention: To pump from V-100 to R-100				
HAZOP for the Pump that Feeds Concentrated Salt to Reactor				
Guide Word	Deviation	Cause	Consequence	Action
No	No flow	Blockage in line	No AA in reactor at all, no reaction takes place	Shutdown until blockage is fixed
↓	No Power	Power Failure	Reverse flow	Turn on generators or stop process until power regained
↓	No Backup Pump	Forgot to Install	If pump goes down shuts down process until new one put in	Put the new pump in parrallel to the original
More of	More flow	Momentary increase in water supply	Possible Cavitation	Change valve controls to adjust
Less of	Less Flow	Momentary decrease in water supply	Less flow to next process	Change valve controls to adjust
Reverse	Reverse Flow	Pump stops working	Concentrated HMDA flows into V-100, Evaporator flows busted	Switch to spare pump
Other than	Impurities in Stream 16	Water purification deviation	Poor Concentration, reaction affected	Correct water purification deviation

Table 50: Preliminary HAZOP for T-100

Process Unit: T-100				
Intention: To mix AA and water to correct concentration				
HAZOP for the AA/water Mixer				
Guide Word	Deviation	Cause	Consequence	Action
No	No mixing	Mixer stopped mixing	Motor is broken	Replace motor
↓	No AA flow	Blockage in pipe	Process can not continue without reactants	Check AA control valve for failure and or blockage
More of	Concentration of AA	Process Control Upset	Concentration of AA too high for the process	Increase flow of water to the mixer and check AA control valve
↓	Concentration of Water	Process Control Upset	Concentration of water too high for the process	Increase flow of AA to the mixer and check controller
↓	More residence time	Process control valve deviation	Build up of reactants and backflow	Check process control valve
Less of	Less mixing	Mixer deviates from normal hp	Incomplete mixing of reactants	Check motor and replace if necessary
↓	Less Residence time	Process control valve deviation	Process flow control valve failure	Check valve and replace if necessary

Table 51: Preliminary HAZOP for T-200

Process Unit: T-200				
Intention: To mix HMDA and water to correct concentration				
HAZOP for the HMDA/water Mixer				
Guide Word	Deviation	Cause	Consequence	Action
No	No mixing	Mixer stopped mixing	Motor broke	Replace motor
↓	No HMDA flow	Blockage in pipe	Process can not continue without reactants	Check HMDA control valve for failure and or blockage
More of	Concentration of HMDA	Process Control Upset	Concentration of HMDA too high for the process	Increase flow of water to the mixer and check HMDA control valve
↓	Concentration of Water	Process Control Upset	Concentration of water too high for the process	Increase flow of HMDA to the mixer and check control valve
↓	More residence time	Process control valve deviation	Build up of reactants and backflow	Check process control valve
Less of	Less mixing	Mixer deviates from normal hp	Incomplete mixing of reactants	Check motor and replace if necessary
↓	Less Residence time	Process control valve deviation	Process flow control valve failure	Check valve and replace if necessary

Table 52: Preliminary HAZOP for T-300

Process Unit: T-300				
Intention: To mix Salt solution				
HAZOP for the reactants Mixer				
Guide Word	Deviation	Cause	Consequence	Action
No	No mixing	Mixer stopped mixing	Motor broke	Replace motor
More of	Concentration of HMDA	Process Control Upset	Concentration of HMDA too high for the process	Increase flow of water to the mixer and check HMDA control valve
↓	Concentration of AA	Process Control Upset	Concentration of AA too high for the process	Increase flow of water to the mixer and check AA control valve
↓	Concentration of Water	Process Control Upset	Concentration of water too high for the process	Increase flow of HMDA to the mixer and check water control valve
↓	More residence time	Process control valve deviation	Build up of reactants and backflow	Check process control valve
Less of	Less mixing	Mixer deviates from normal hp	Incomplete mixing of reactants	Check motor and replace if necessary
↓	Less Residence time	Process control valve deviation	Process flow control valve failure	Check valve and replace if necessary

Table 53: Preliminary HAZOP for V-100

Process Unit: V-100				
Intention: To remove water from the salt solution				
HAZOP for the removal of water from reactants				
Guide Word	Deviation	Cause	Consequence	Action
No	No Heat being applied	Steam Valve failed	No separation	Check Steam Valve
More of	More Product in the top stream	Too much heat	Lose product	Decrease steam flowrate
↓	More Water in the Product	Not enough heat	Reaction can not take place	Increase steam flowrate
Less of	Less steam	Steam Valve fail to open properly	Too much water in the salt	Check Steam Valve & replace

Table 54: Preliminary HAZOP for V-200

Process Unit: V-200				
Intention: To remove water from the product stream				
HAZOP for the removal of water from nylon				
Guide Word	Deviation	Cause	Consequence	Action
No	No Steam exiting top	Steam line blocked	Increased pressure in V-200	Check Steam Valve
More of	More Steam Exiting	Too much heat	Degradation of product	Decrease Heat in Reactor
↓	More Water in the Product	Not enough heat	Impure product	Increase steam flowrate in reactor
Less of	Less steam exiting top	Not enough heat	Impure product	Increase steam flowrate in reactor

Table 55: Preliminary HAZOP for R-100 – 400

Process Unit: R-100, 200, 300, 400				
Intention: To polymerize nylon 6,6				
HAZOP for the polymerization of nylon 6,6				
Guide Word	Deviation	Cause	Consequence	Action
No	No reaction taking place	No heat being applied	No polymerization occurs	Check steam valve to ensure steam being applied, replace if necessary
↓	No steam flow	Temperature controller malfunction	Polymerization will not occur	Check steam valve and temperature controls
↓	No process flow	Blockage in pipes	Stops process	Scheduled maintenance
More of	Corrosion	Constant use	Loss of product and safety hazard	Stop process and replace/repair as necessary
As Well as	Reactor product in shell	Corrosion	Loss of product and safety hazard	Shut down process and replace

Table 56: Preliminary HAZOP for EG-100,200

Process Unit: EG-100, EG-200				
Intention: To mold and shape the material into constant cross section area				
HAZOP for the molding and shaping of the product				
Guide Word	Deviation	Cause	Consequence	Action
No	No power	Motor failure	Screw does not turn	Replace Motor
↓	No turning of the screw	Screw is blocked with material	No product being produced	Take out and clean screw
↓	No temperature gradient in zones	Electrical heater failure	Polymer fails to finish reactions	Check temperature controls and replace heater if necessary
More of	More heat in zones	Thermocouple failure	Material adheres to screw	Check thermocouple not loos/replace thermocouple if needed
↓	More pressure within barrel	Pressure monitor failure	Break screw and other components	Reduce pressure inside barrel and check controls
↓	Higher temperature in barrel	Flat Temperature profile through zones	Material adheres to screw	Reduce output of heater to reduce temperature
Less of	Less product being produced	Flat Temperature profile through zones	Loss of profit	Raise the die exit temperature
↓	Less temperature in die	Thermocouple malfunction	Excessive pressure in barrel and surging output	Raise the temperature in the die to correct
As Well as	High die pressure fluctuations	Flat Temperature profile through zones	Affects the quality of the product	Raise the feed zone temperature
Other than	Other than correct RPM of screw	Drive system power surges	Surging output	Check drive system to handle the electrical inputs

Table 57: Preliminary HAZOP for D-100,200

Process Unit: D-100, D-200				
Intention: To remove all liquid from the product				
HAZOP for the removal of all liquid				
Guide Word	Deviation	Cause	Consequence	Action
No	No process heater	Loss of power	Nylon does not dry	Check heater/replace heater if needed
↓	No cooling coil	Loss of power	Efficiency of dryer drops	Check cooling coil connection/replace if necessary
↓	Pellet screen blocked	Constant use	Lose efficiency	Clean with compress air/ maintenance every 2 months
More of	More drying	Resin moisture levels not being monitored properly	Nylon becomes brittle	Install moisture measuring device
↓	Temperature too high	Set-point malfunction	Nylon becomes brittle	Over-temperature alarm and shutdown enacts, check set-point
Less of	Temperature too low	Set-point malfunction	Nylon is too saturated	Increase output of process heaters and check set-point
As Well as	Leaks in Hopper Gaskets and Seals	Continuous use	Lose heat and efficiency	Check for leaks and replace if necessary
Part of	Filter clogged	Constant use	Lose efficiency	Alarm light shows to clean/replace filters
↓	Plasticizer drain clogged	Constant use	Blockage and backup of material	Required maintenance every 2 weeks

Table 58: Preliminary HAZOP for E-100

Process Unit: E-100				
Intention: To heat water for mixing				
HAZOP for the heating of mixing water				
Guide Word	Deviation	Cause	Consequence	Action
No	No Steam flow	Failure of inlet steam flow valve to open	Process water temperature not raised accordingly	Install temperature indicators
More of	More pressure on tube side	Process fluid valve failure	Tube will burst	High pressure alarm system needs to be installed
↓	More steam flow	Failure of inlet steam flow valve to close properly	Output process fluid temperature too high	Install temperature indicators
Less of	Less steam flow	Pipe leakage	Process fluid temperature too high	Install a Flow Meter
↓	Less steam flow	Pipe blockage	Process fluid temperature will remain constant	Install temperature indicator
Reverse	Reverse process fluid flow	Failure of process fluid inlet valve	Product concentration off-set	Install check valve
Other than	Contamination of the process fluid	Contamination in steam	Outlet temperature too high	Proper Maintenance

Table 59: Preliminary HAZOP for E-200

Process Unit: E-200				
Intention: To heat HMDA for reacting				
HAZOP for the heating of HMDAsoln				
Guide Word	Deviation	Cause	Consequence	Action
No	No Steam flow	Failure of inlet steam flow valve to open	Process water temperature not raised accordingly	Install temperature indicators
More of	More pressure on tube side	Process fluid valve failure	Tube will burst	High pressure alarm system needs to be installed
↓	More steam flow	Failure of inlet steam flow valve to close properly	Output process fluid temperature too high	Install temperature indicators
Less of	Less steam flow	Pipe leakage	Process fluid temperature too high	Install a Flow Meter
↓	Less steam flow	Pipe blockage	Process fluid temperature will remain constant	Install temperature indicator
Reverse	Reverse process fluid flow	Failure of process fluid inlet valve	Product concentration off-set	Install check valve
Other than	Contamination of the process fluid	Contamination in steam	Outlet temperature too high	Proper Maintenance

Table 60: Preliminary HAZOP for E-300

Process Unit: E-300				
Intention: To heat Concentrated Salt for reacting				
HAZOP for the heating of Concentrated Salt				
Guide Word	Deviation	Cause	Consequence	Action
No	No Steam flow	Failure of inlet steam flow valve to open	Process water temperature not raised accordingly	Install temperature indicators
More of	More pressure on tube side	Process fluid valve failure	Tube will burst	High pressure alarm system needs to be installed
↓	More steam flow	Failure of inlet steam flow valve to close properly	Output process fluid temperature too high	Install temperature indicators
Less of	Less steam flow	Pipe leakage	Process fluid temperature too high	Install a Flow Meter
↓	Less steam flow	Pipe blockage	Process fluid temperature will remain constant	Install temperature indicator
Reverse	Reverse process fluid flow	Failure of process fluid inlet valve	Product concentration off-set	Install check valve
Other than	Contamination of the process fluid	Contamination in steam	Outlet temperature too high	Proper Maintenance

Table 61: Preliminary HAZOP for C-100,200

Process Unit: C-100,200				
Intention: To condense V-100,200 steam for ww				
HAZOP for the condesation of evaporator steam				
Guide Word	Deviation	Cause	Consequence	Action
No	No Cooling water flow	Failure of inlet water flow valve to open	Process steam temperature not condensed accordingly	Install temperature indicators
More of	More pressure on tube side	Process fluid valve failure	Tube will burst	High pressure alarm system needs to be installed
↓	More cooling water flow	Failure of inlet water flow valve to close properly	Cost of water utility increase	Install flowmeter
Less of	Less cooling water flow	Pipe leakage	Process fluid will not condense	Install a Flow Meter
↓	Less cooling water flow	Pipe blockage	Process fluid will not condense	Install a Flow Meter
Reverse	Reverse process fluid flow	Pressure drop in evaporator	Steam enters evap	Maintain Evap temperature/pressure
Other than	Contamination of the process fluid	Contamination in steam	Outlet not condensed enough	Proper Maintenance

Table 62: Preliminary HAZOP for Storage Vessel 1 and 2

Process Unit: Storage Vessel 1 and 2				
Intention: To store AA and HMDA for process use				
HAZOP for the storage of raw material				
Guide Word	Deviation	Cause	Consequence	Action
More of	More raw material than it can hold	Level controls malfunction	Backflow	Stop filling storage tank and let it be used in the process
Less of	Less raw material than needed	Storm/miscommunication	Loss of operating time	Request raw material for storage
As Well as	Corrosion	Material corroded through siding	Loss of raw material	Repair leak while wearing proper safety equipment