5-2017

Proposal to Build Nylon 6,6 Plant: A Grassroots Economic Analysis

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Spring 2017 AIChE Design Project

This project was conducted according to the rules of both the competition and the classroom.

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March 2, 2017

PROPOSAL TO BUILD NYLON 6,6 PLANT

A grassroots economic analysis

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4.) Abstract

This report analyzes the profitability of building a grass roots Nylon 6,6 plant in Calvert City, Kentucky. A rigorous process simulation was produced, equipment prices were estimated, utility usage was assessed, and a plan for the plant organization was developed. The calculations yielded values for fixed capital investment ($10.5 million), working capital ($101 million) and revenue ($114 million). The discounted cash flow rate of return was calculated to be 8.94%.

The conclusion drawn from these calculated values is that the current plan for the plant would not be profitable on a 10 year project life basis. However, recommendations are presented that suggest the plant's profitability could increase after a more thorough analysis and changes in market conditions.

5.) Introduction

This project was conducted for the American Institute for Chemical Engineers Design Competition. The goal was to prepare a complete economic analysis for building a grass roots plant to produce 85 million pounds of Nylon 6,6 per year. This analysis required a full simulation of the plant, along with organizational tasks that come with designing a plant. These tasks include plans for safety, health and environmental concerns, process control schemes, startup procedures, and reduced rate procedures.

The timeline for this project was exactly one month from the assignment date. There was to be no communication with other students, faculty, or business professionals for help on this project. Only sources that were open for public access were to be used.

Aside from the numerical values that were produced from the economic analysis, great skills in chemical engineering were developed during the course of this project. It presented opportunities to pool all knowledge gained through university and industrial education and find a solution to a difficult problem.

6.) Process Flow Diagram and Material Balances

It is important when designing a plant to begin with an organized naming system. Below in Figure 6.1 is the nomenclature used for types of equipment and streams. This allows for easy identification of equipment type and location in the process.

The Material Balance Block can be seen below in Table 6.2, and the Process Flow Diagram (PFD) can be found on the following page in Figure 6.1.

Table 6.1: Plant Naming System

Equipment	Prefix	Stream	Prefix
Cooler	C	Bottoms	B
Extruder	E	Condensate	C
Heater	H	Feed	F
Pump	P	Product	P
Reactor	R	Vent	V
Tower	T		
Vessel	V		

In addition to this table, it should be noted that higher equipment numbers denote that the equipment is further down the process.

Table 6.2: Material Balance Block

Stream	B-T-101	C-H-101A	C-H-102A	C-H-102B	C-T-101	F-H-101A	F-H-101C	F-H-102A	F-H-102B
Temperature (F)	357.024	147.7862	214.3513	281.205	356.989	77	135.0083	77	158.9839
Pressure (psia)	146.9595	146.1575	146.4671	146.7071	146.9595	14.69595	14.22438	14.69595	14.45109
Vapor Fraction	0	0	0	0	0	0	0	0	0
Mass Flow (lb/hr)	2374.296	3482.475	3482.475	3482.475	3482.475	6904.854	6904.854	6214.014	6214.014
Component mass Flow (lb/hr)									
ADA	0.1475691	6.44E-38	6.44E-38	6.44E-38	6.44E-38	0	0	6214.014	6214.014
HMDA	6.854129	2.20E-09	2.20E-09	2.20E-09	2.20E-09	4937.024	4937.024	0	0
H2O	2367.294	3482.475	3482.475	3482.475	3482.475	1967.83	1967.83	0	0
NYLON	0	0	0	0	0	0	0	0	0
Enthalpy Flow (Btu/hr)	-1.54E+07	-2.35E+07	-2.33E+07	-2.30E+07	-2.27E+07	-1.62E+07	-1.59E+07	-1.77E+07	-1.75E+07

Stream	F-H-102C	F-R-1011	F-R-1012	F-V-1011	P-R-101	P-R-102	V-R-101	V-R-102	
Temperature (F)	251.4771	350.33	350.33	77	431.33	539.33	431.33	539.33	
Pressure (psia)	14.24067	146.9595	146.9595	14.69595	146.9595	14.69595	146.9595	14.69595	
Vapor Fraction	0	0	0	0	0	0	1	1	
Mass Flow (lb/hr)	6214.014	6904.854	6214.014	4937.024	10050.77	9636.274	5856.771	414.4943	
Component mass Flow (lb/hr)									
ADA	6214.014	0	6214.014	0	6.983917	0.133263	0.147569	0.0229786	
HMDA	0	4937.024	0	4937.024	5.288901	0.0704341	6.854129	0.2723931	
H2O	0	1967.83	0	0	395.5388	10.75828	5849.769	414.1989	
NYLON	0	0	0	0	9642.956	9625.312	1.67E-79	1.27E-76	
Enthalpy Flow (BTU/hr)	-1.49E+07	-1.68E+07	-2.74E+06	-1.34E+07	-7.89E+06	-4.54E+06	-3.29E+07	-2.30E+06	

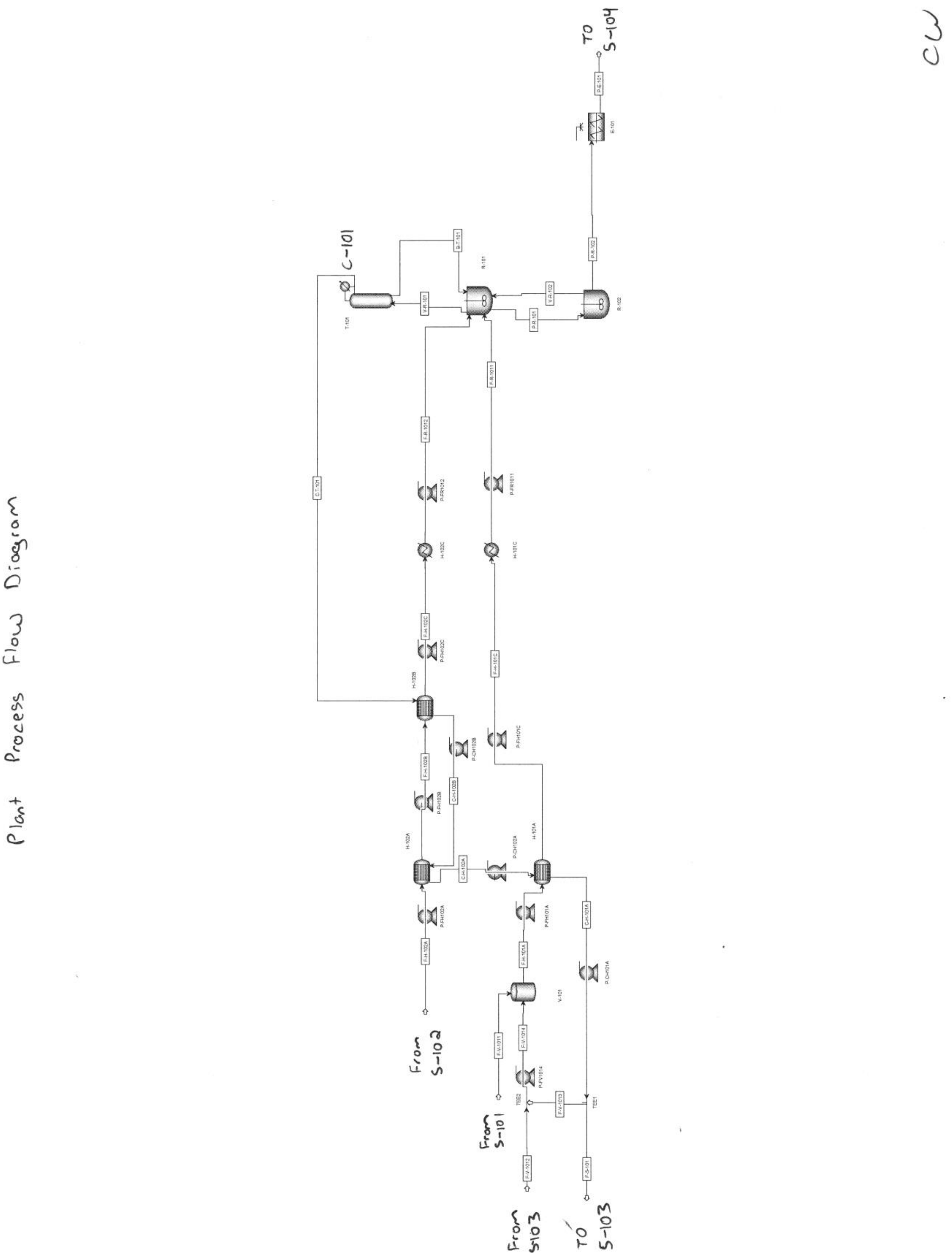

Figure 6.1: Plant Process Flow Diagram

7.) Process Description

a.) Overall Description

The process begins with the introduction of the three reactants: adipic acid (ADA), hexamethylenediamine (HMDA), and water (H2O). The preheated reactants are directed to a reactor at a temperature of 431.33^{o}F and a pressure of 10 atm for initial step-growth polymerization. This initial reactor aids in the conversion of HMDA and ADA into low-molecular-weight oligomers. The high pressure is to mitigate the issue of the relatively low volatility of ADA (Seavey & Liu, 2008).

The combined oligomer stream from the first reactor is routed to a second reactor with a temperature of 539.33^{o}F and atmospheric pressure. The second reactor under said conditions helps devolatilize the polymer and increase the molecular weight (Seavey & Liu, 2008). H2O is the by-product of the reaction between ADA and HMDA, and is created in excess.

A vent stream from the second reactor is recycled to the first reactor in order to keep H2O out of the product stream and recycle excess reactants. The first reactor also has a vent stream, which is connected to an enriching column. A nearly pure (>99.9% H2O) stream exits the top of the column, while more than 99.9% of the ADA and HMDA from the reactor vent exit the bottom of the column and reenter the reactor.

The nylon product from the second reactor is extruded and sold.

b.) Process Flow Diagram

The process begins with the introduction of the three reactants: adipic acid (ADA), hexamethylenediamine (HMDA), and water (H2O). The reactants are preheated before entering the reactors. To avoid premature reactions, ADA and HMDA are preheated separately.

V-101, a process vessel, is fed with stream F-V-1014. Due to the nature of HMDA being solid at ambient temperature, it is added to H2O in V-101 before being preheated. The exiting stream is F-H-101A. Refer to subsection 9v for more information about V-101.

H-101A, a floating head shell and tube heat exchanger, is fed with stream F-H-101A which contains HMDA and H2O. This is cross-exchanged with condensate stream C-H-102A in order to save costs on heating with a fired heater. This is the third exchanger that the condensate from T-101 enters. The stream temperature increases from 77^{o}F to 135^{o}F. The floating head design was chosen for its availability to remove the tubes for cleaning. Refer to subsection 9c for more information for more information about H-101A.

H-101C, a nonreactive-fired heater, is fed with stream F-H-101C which is the stream exiting H-101A. A fired heater is used rather than a heat exchanger due to lack of additional streams from the process to perform heat integration. This heater is powered by electricity and has a required duty of 1019320 Btu/hr. The stream temperature increases from 135^{o}F to 350^{o}F. Refer to subsection 9d for more information about H-101C.

H-102A, a floating head shell and tube heat exchanger, is fed with stream F-H-102A which contains pure ADA. This is cross-exchanged with condensate stream C-H-102B in order to save costs on heating with a fired heater. This is the second exchanger that the condensate from T-101 enters. The stream temperature increases from 77^{o}F to 159^{o}F. The floating head design was chosen for its availability to remove the tubes for cleaning. Refer to subsection 9e for more information about H-102A.

H-102B, a floating head shell and tube heat exchanger, is fed with stream F-H-102B which is the stream exiting H-102A. This stream is cross-exchanged with condensate stream C-H-102A in order to save costs on heating with a fired heater. This is the first exchanger that the condensate from T-101 enters. The stream temperature increases from 158^{o}F to 251^{o}F. The floating head design was chosen for its availability to remove the tubes for cleaning. Refer to subsection 9f for more information about H-102B.

H-102C, a nonreactive-fired heater, is fed with stream F-H-102C which is the stream exiting H-102B. A fired heater is used rather than a heat exchanger due to lack of additional streams from the process to perform heat integration. This heater is powered by electricity and has a required duty of 347271 Btu/hr. The stream temperature increases from 251^{o}F to 350^{o}F. Refer to subsection 9g for more information about H-102C.

R-101, a continuously stirred tank reactor (CSTR), is fed by streams F-R-1011 and F-R-1012 which are the streams exiting H-101C and H-102C, respectively. This reactor is operated at a temperature of 431.33^{o}F and a pressure of 10 atm for initial step-growth polymerization. R-101 aids in the conversion of HMDA and ADA into low-molecular-weight oligomers. The high pressure is to mitigate the issue of the relatively low volatility of ADA (Seavey & Liu, 2008). A CSTR was chosen as opposed to a batch reactor due to a drastically higher conversion rate, as well as a better functionality for continuous polymer processing. This reactor is powered by electricity and has a required duty of 8726270 Btu/hr. Due to the production of water as a byproduct in the polymerization reaction, a vent is included above the reactor. This vent stream feeds T-101 on the bottom stage. The vent stream from R-102 (V-R-102) is fed to R-101 to recycle excess ADA, and HMDA. R-101 is set on a skid above R-102, and the product stream P-R-101 is gravity-fed to R-102 as the feed for the second reactor. This skid set-up is chosen rather than a ground-level scheme in order to avoid any reactions within any pumps. Refer to subsection 9s for more information about R-101.

R-102, a CSTR, is gravity-fed by stream P-R-101, which is the stream exiting R-101. This reactor is operated at a temperature of 539.33^{o}F and a pressure of 1 atm for initial step-growth polymerization. R-102 helps to devolatilize the polymer and increase the molecular weight (Seavey & Liu, 2008). A CSTR was chosen as opposed to a batch reactor due to a drastically higher conversion rate, as well as a better functionality for continuous polymer processing. This reactor is powered by electricity and has a required duty of 1046950 Btu/hr. Due to the production of water as a byproduct in the polymerization reaction, a vent is included above the reactor. This vent stream feeds T-101 on the bottom stage. Refer to subsection 9t for more information about R-102.

T-101, an enriching column, is fed by stream V-R-101 on the bottom stage of the column. The column has 13 sieve trays and 1 total condenser at the top. The purpose of this column is to create an enriched H2O by-product stream and rid it of corrosive HMDA. The column is set at a pressure of 10 atm, the same pressure as R-101. The reflux ratio is set to 0.75, which optimizes both H2O purity and flowrate. The number of stages was the minimum amount of stages at these conditions, which allowed only “trace” amounts of both ADA and HMDA to exit the top of the column. The bottoms of the column recycle to R-101 in stream B-T-101, and the distillate is heat integrated into the preheat network in stream C-T-101. Refer to subsection 9u for more information about T-101.

E-101, an extruder, is fed by stream P-R-102, which is the stream exiting R-102. This facilitates the product finishing of the molten Nylon 6,6. Due to lack of proper solids processing software, an extruder was chosen for simplicity reasons. Refer to subsection 9b for more information about E-101.

8.) Energy Balance and Utility Requirements

From energy balance for the plant in Figure 8.1 below, it can be shown that the simulation has been run correctly and follows the First Law of Thermodynamics:

Energy in = Energy out

$$\sum Q_{in} + \text{F-H-102A} + \text{F-V-1011} + \text{F-V-1014} = \text{P-R-102} + \text{C-H-101A} + \sum Q_{out}$$

$$-5.27 - 17.75 - 2.74 - 13.42 = -4.54 - 23.51 - (1.02 + 0.35 + 8.73 + 1.05)$$

$$-39.18 = -39.20$$

The enthalpy flow values on the following figure are all in units of Btu/hr X 10^6. Full information for enthalpy flow values is located in Table 6.2.

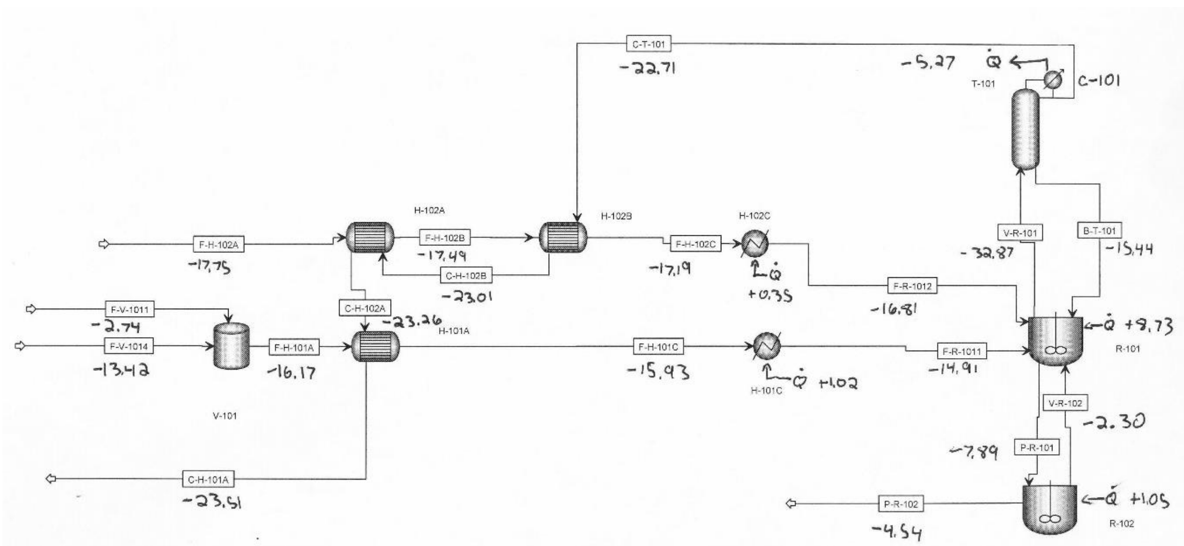

Figure 8.1: Energy Balance

As seen in Figure 8.1, the condensate from T-101 is used for in a preheat network which consists of exchangers H-102B, H-102A, and H-101A in that order. This optimally integrates the heat of the condensate stream by introducing it at its hottest point in the hottest of the three exchangers (H-102B). As the condensate stream loses heat, it is passed through the other exchangers in the preheat network. H-102A and H-101A have colder process feed streams that require less heat, so the condensate stream can efficiently preheat these feed streams. This preheat network is used as opposed to one large heat exchanger for multiple reasons. It is cheaper to have smaller exchangers than one large exchanger. Additionally, using multiple exchangers gives a bypass option if one exchanger needs to be repaired or cleaned.

Additional energy is supplied by electricity to multiple places in the plant, as illustrated in Figure 8.1. To complete the preheating of the R-101 feed streams, Q terms are shown with values of 1.02 for H-101C and 0.35 for H-102C. To heat the CSTRs, Q terms are shown with values of 8.73 for R-101 and 1.05 for R-102.

Energy must be removed from the system at the condenser for reflux to the column. In Figure 8.1, a Q term with a value of -5.27 is shown for C-101.

9.) Equipment List and Unit Descriptions

Below, every process unit included in the PFD is described. For price estimates for the equipment, refer to section 11.

a) C-101

This is an air-cooled condenser. The condenser requires a duty of -5269160 Btu/hr, and 2.4E6 lb/hr of air. The condenser will have several fins connected to the side with the overhead water stream in order to maximize surface area of the heat exchange and optimize the use of airflow. The duty calculation was performed in Aspen Plus V8.8 using the RadFrac column model, and no further calculations were performed to size the condenser. Due to the approximate duty-to-surface area ratio of 10 observed in H-102A and H-102B, a required surface area for C-101 is estimated to be 1615 ft^2 for bare module costing purposes. The material carbon steel is used because of the lack of necessity for stronger chemical resistance. Refer to Figure A2-1 for the specification sheet for this process unit.

b) E-101

This is an extruder that will process the product in stream P-R-102. The material of construction is carbon steel due to the lack of necessity for stronger chemical resistance. No calculations for this equipment item were performed because resources were not available. It is assumed that molten Nylon 6,6 is extruded to solid at a 1:1 mass ratio and that it can be sold in this extruded condition. Refer to Figure A2-2 for the specification sheet for this process unit.

c) H-101A

This is a floating head shell-and-tube heat exchanger. The hot condensate in stream C-H-102A is on the shell side and the cold HMDA-H2O solution in stream F-H-101A is on the tube side. The material 25Cr, 12 Ni steel is used because of its excellent chemical resistance at high temperatures (Turton, Bailie, Whiting, Shaeiwitz, & Bhattacharyya, 2012). The rigorous sizing calculations were performed in Aspen Plus V8.8 using the POLYNRTL property method. The full design specifications can be seen in Appendix 1 Figures A1-1 and A1-2. Refer to Figure A2-3 for the specification sheet for this process unit.

d) H-101C

This is a nonreactive-fired heater powered by electricity. The material 25Cr, 12 Ni steel is used because of its excellent chemical resistance at high temperatures (Turton, Bailie, Whiting, Shaeiwitz, & Bhattacharyya, 2012). The energy calculations were performed in Aspen Plus V8.8 using the POLYNRTL property method. For simplicity purposes, H-101C was simulated using electricity for power. Refer to Figure A2-1 for the specification sheet for this process unit.

e) H-102A

This is a floating head shell-and-tube heat exchanger. The hot condensate in stream C-H-102B is on the shell side and the cold ADA in stream F-H-102A is on the tube side. The material carbon steel is used because of the lack of necessity for stronger chemical resistance. The rigorous sizing calculations were performed in Aspen Plus V8.8 using the POLYNRTL property method. The full design specifications can be seen in Appendix 1 Figures A1-3 and A1-4. Refer to Figure A2-5 for the specification sheet for this process unit.

f) H-102B

This is a floating head shell-and-tube heat exchanger. The hot condensate in stream C-T-101 is on the shell side and the cold ADA in stream F-H-102B is on the tube side. The material carbon steel is used because of the lack of necessity for stronger chemical resistance. The rigorous sizing calculations were performed in Aspen Plus V8.8 using the POLYNRTL property method. The full design specifications can be seen in Appendix 1 Figures A1-5 and A1-6. Refer to Figure A2-6 for the specification sheet for this process unit.

g) H-102C

This is a nonreactive-fired heater. The material carbon steel is used because of the lack of necessity for stronger chemical resistance. The energy calculations were performed in Aspen Plus V8.8 using the POLYNRTL property method. For simplicity purposes, H-102C was simulated using electricity for power. Refer to Figure A2-7 for the specification sheet for this process unit.

h) P-CH-101A

This is a positive-displacement pump with a required shaft work of 224 Btu/hr. The material chosen is carbon steel due to the lack of necessity for stronger chemical resistance. It is estimated that the pump will have a head differential of 40 feet due to pumping from the bottom outlet of H-101A to the top of S-104. Refer to Figure A2-8 for the specification sheet for this process unit.

i) P-CH-102A

This is a positive-displacement pump with a required shaft work of 56 Btu/hr. The material chosen is carbon steel due to the lack of necessity for stronger chemical resistance. It is estimated that the pump will have a head differential of 10 feet due to pumping from the bottom outlet of H-102A to the top inlet of H-101A. Refer to Figure A2-9 for the specification sheet for this process unit.

j) P-CH-102B

This is a positive-displacement pump with a required shaft work of 56 Btu/hr. The material chosen is carbon steel due to the lack of necessity for stronger chemical resistance. It is estimated that the pump will have a head differential of 10 feet due to pumping from the bottom outlet of H-102B to the top inlet of H-102A. Refer to Figure A2-10 for the specification sheet for this process unit.

k) P-FH-101A

This is a positive-displacement pump with a required shaft work of 55 Btu/hr. The material chosen is Ni alloy because of its excellent chemical resistance at high temperatures (Turton, Bailie, Whiting, Shaeiwitz, & Bhattacharyya, 2012). It is estimated that the pump will have a head differential of 5 feet due to pumping from the bottom of V-101 to the cold inlet of H-101A. Refer to Figure A2-11 for the specification sheet for this process unit.

l) P-FH-101C

This is a positive-displacement pump with a required shaft work of 55 Btu/hr. The material chosen is Ni alloy because of its excellent chemical resistance at high temperatures (Turton, Bailie, Whiting, Shaeiwitz, & Bhattacharyya, 2012). It is estimated that the pump will have a head differential of 5 feet due to pumping from the cold outlet of H-101A to the cold inlet of H-101C. Refer to Figure A2-12 for the specification sheet for this process unit.

m) P-FH-102A

This is a positive-displacement pump with a required shaft work of 50 Btu/hr. The material chosen is carbon steel due to the lack of necessity for stronger chemical resistance. It is estimated that the pump will have a head differential of 5 feet due to pumping from ground-level to the cold inlet of H-102A. Refer to Figure A2-13 for the specification sheet for this process unit.

n) P-FH-102B

This is a positive-displacement pump with a required shaft work of 50 Btu/hr. The material chosen is carbon steel due to the lack of necessity for stronger chemical resistance. It is estimated that the pump will have a head differential of 5 feet due to pumping from the cold outlet of H-102A to the cold inlet of H-102B. Refer to Figure A2-14 for the specification sheet for this process unit.

o) P-FH-102C

This is a positive-displacement pump with a required shaft work of 50 Btu/hr. The material chosen is carbon steel due to the lack of necessity for stronger chemical resistance. It is estimated that the pump will have a head differential of 5 feet due to pumping from the cold outlet of H-102B to the cold inlet of H-102C. Refer to Figure A2-15 for the specification sheet for this process unit.

p) P-FR-1011

This is a positive-displacement pump with a required shaft work of 333 Btu/hr. The material chosen is Ni alloy because of its excellent chemical resistance at high temperatures (Turton, Bailie, Whiting, Shaeiwitz, & Bhattacharyya, 2012). It is estimated that the pump will have a head differential of 30 feet due to pumping from the cold outlet of H-101C to the top of R-101, which is located on a skid. Refer to Figure A2-16 for the specification sheet for this process unit.

q) P-FR-1012

This is a positive-displacement pump with a required shaft work of 300 Btu/hr. The material chosen is carbon steel due to the lack of necessity for stronger chemical resistance. It is estimated that the pump will have a head differential of 30 feet due to pumping from the cold outlet of H-102C to the top of R-101, which is located on a skid. Refer to Figure A2-17 for the specification sheet for this process unit.

r) P-FV-1012

This is a positive-displacement pump with a required shaft work of 16 Btu/hr. The material chosen is Ni alloy because of its excellent chemical resistance at high temperatures (Turton, Bailie, Whiting, Shaeiwitz, & Bhattacharyya, 2012). It is estimated that the pump will have a head differential of 5 feet due to pumping from ground-level to the top of V-101. Refer to Figure A2-18 for the specification sheet for this process unit.

s) R-101

This is a 64 ft^3 CSTR. The material Nickel alloy is used because of its excellent chemical resistance at high temperatures (Turton, Bailie, Whiting, Shaeiwitz, & Bhattacharyya, 2012). The reaction of ADA and HMDA to form Nylon 6,6 was modeled using a step-growth polymerization reaction model in Aspen Plus V8.8. The reaction kinetics used to characterize the step-growth polymerization can be found in Appendix 1 Figures A1-7 and A1-8 (Chaves, López, Zapata, Robayo, & Niño, 2016). The energy calculations were performed in Aspen Plus V8.8 using the POLYNRTL property method. Refer to Figure A2-19 for the specification sheet for this process unit.

t) R-102

This is a 64 ft^3 CSTR. The material Nickel alloy is used because of its excellent chemical resistance at high temperatures (Turton, Bailie, Whiting, Shaeiwitz, & Bhattacharyya, 2012). The reaction kinetics used to characterize the step-growth polymerization can be found in Appendix 1 Figures A1-6 and A1-7 (Chaves, López, Zapata, Robayo, & Niño, 2016). The energy calculations were performed in Aspen Plus V8.8 using the POLYNRTL property method. Refer to Figure A2-20 for the specification sheet for this process unit.

u) T-101

This is a 13-stage enriching column. The material Nickel alloy is used because of its excellent chemical resistance at high temperatures (Turton, Bailie, Whiting, Shaeiwitz, & Bhattacharyya, 2012). The rigorous tower design was performed in Aspen Plus V8.8 using the POLYNRTL property method and the RadFrac column model. The column profile for composition, temperature, and pressure can be seen in Appendix 1 Figure A1-8. Refer to Figure A2-21 for the specification sheet for this process unit.

v) V-101

This is a 64 ft^3 open-top vertical vessel. The material Nickel alloy is used because of its excellent chemical resistance at high temperatures (Turton, Bailie, Whiting, Shaeiwitz, & Bhattacharyya, 2012). This was modeled as a mixer in Aspen Plus V8.8 under the assumption of perfect mixing within the vessel. Refer to Figure A2-22 for the specification sheet for this process unit.

10.) Equipment Specification Sheets

Specification sheets for the equipment listed in Section 9 can be found in Appendix 2.

11.) Equipment Cost Summary

The summary for the cost of the equipment is shown below in Table 11.1. This calculation is based on a bare module costing model from the textbook *Analysis, Synthesis and Design of Chemical Processes* (Turton, Bailie, Whiting, Shaeiwitz, & Bhattacharyya, 2012). This book is based on a 2001 Chemical Engineering Plant Cost Index (CEPCI) value of 397. To account for inflation, a 2016 CEPCI value of 536.5 was used in a conversion (Economic Indicators, 2016). As shown in Table 11.1, the bare module cost for all of the equipment sums to be $7,192,129,446.

Table 11.1: Equipment Cost Summary

Equipment	Modeled as:	Bare Module Cost	Equipment	Modeled as:	Bare Module Cost
C-101	air cooler cs	$ 176,163.85	PFH102C	positive displacement pump cs	$ 20,681.27
E-101	extruder (value from other book)	$ 467,424.98	PFR1011	positive displacement pump ni	$ 34,565.53
H-101a	floating head cs shell/ni tube	$ 172,608.40	PFR1012	positive displacement pump cs	$ 15,995.57
H-101c	nonreactive fired heater ni alloy	$ 1,912,162.06	PFV1012	positive displacement pump cs	$ 35,389.42
H-102a	floating head cs shell/ss tube	$ 102,345.25	R-101	mixer/settler ni alloy	$ 362,077.74
H-102b	floating head cs shell/ss tube	$ 93,343.02	R-102	mixer/settler ni alloy	$ 362,077.74
H-102c	nonreactive fired heater ni alloy	$ 1,892,614.33	S-101	storage tank (api, ss, horizontal)	$ 262,683.77
PCH101A	positive displacement pump cs	$ 16,881.53	S-102	storage tank (api, cs, horizontal)	$ 262,683.77
PCH102A	positive displacement pump cs	$ 25,310.27	S-103	storage tank (api, cs, horizontal)	$ 262,683.77
PCH102B	positive displacement pump cs	$ 25,315.08	S-104	storage tank (api, cs, horizontal)	$ 367,806.37
PFH101A	positive displacement pump ni	$ 37,221.57	T-101	Ni tower	$ 63,454.00
PFH101C	positive displacement pump ni	$ 37,015.11	trays	Ni sieve	$ 106,403.16
PFH102A	positive displacement pump cs	$ 20,742.47	V-101	vertical ss	$ 35,769.75
PFH102B	positive displacement pump cs	$ 20,709.70			
	Total	**$ 7,192,129.46**			

Storage vessels S-101, S-102, S-103, and S-104 are included in this equipment costing. These vessels hold HMDA, ADA, H2O, and Nylon 6,6, respectively.

Table 11.1 only shows a summary of the equipment costs. For a more detailed table of the bare module costs, see Appendix 3.

Analysis, Synthesis and Design of Chemical Processes does not include information for extruders, and alternative bare module cost data is difficult to obtain. *Preliminary Chemical Engineering Plant Design* (Baasel) gives a 1964 bare module cost for an extruder of $90,000. Although this value may not be the same capacity as which is required, the value was used nonetheless as an order-of-magnitude value, and the CEPCI was converted accordingly.

All equipment which deals with HMDA at high temperatures was modeled using a nickel alloy material of construction. Carbon steel is assumed to be sufficient for equipment which deals with HMDA at ambient temperature or for storage (Ascend Performance Materials, 2013).

12.) Fixed Capital Investment Summary

The fixed capital investment (FCI) is based on a grassroots costing module defined in *Analysis, Synthesis and Design of Chemical Processes.* Contingency and fee costs are accounted for as the total module cost, C_{TM}. Auxiliary facilities costs are accounted for within the grass roots costs, C_{GR}. The equations used in this analysis are:

$$C_{TM} = 1.18*\sum C_{Bm,i} \qquad (12.1)$$

$$C_{GR} = C_{TM} + 0.5*\sum C^{o}_{BM,i} \qquad (12.2)$$

Where C_{BM} is the bare module cost defined in section 11, and C^{o}_{BM} is the bare module cost at base case. Base case conditions replace some constants within the bare module cost equation with values of 1. However, some of the equipment within this plant are not affected by this base condition. For a quicker estimate, the following equation will be used instead of 12.2:

$$C_{GR} = C_{TM} + 0.4*\sum C_{BM,i} \qquad (12.3)$$

The sum of grass root costs for all equipment will be modeled as the FCI. The grass root costs, total module costs, and the FCI are illustrated in Table 12.1.

Table 12.1: FCI Summary

Equipment	Cgr	Ctm	Equipment	Cgr	Ctm
C-101	$ 260,016.52	$ 207,873.34	PFH102C	$ 30,525.40	$ 24,403.90
E-101	$ 587,561.47	$ 551,561.47	PFR1011	$ 51,018.47	$ 40,787.33
H-101a	$ 254,768.72	$ 203,677.92	PFR1012	$ 23,609.34	$ 18,874.77
H-101c	$ 2,822,336.94	$ 2,256,351.23	PFV1012	$ 52,234.52	$ 41,759.52
H-102a	$ 151,060.82	$ 120,767.39	R-101	$ 534,424.05	$ 427,251.74
H-102b	$ 137,773.60	$ 110,144.76	R-102	$ 534,424.05	$ 427,251.74
H-102c	$ 2,793,484.64	$ 2,233,284.91	S-101	$ 387,719.28	$ 309,966.85
PCH101A	$ 24,917.02	$ 19,920.21	S-102	$ 387,719.28	$ 309,966.85
PCH102A	$ 37,357.77	$ 29,866.12	S-103	$ 387,719.28	$ 309,966.85
PCH102B	$ 37,364.86	$ 29,871.79	S-104	$ 542,879.45	$ 434,011.51
PFH101A	$ 54,938.75	$ 43,921.45	T-101	$ 93,657.62	$ 74,875.71
PFH101C	$ 54,634.03	$ 43,677.83	trays	$ 157,050.27	$ 125,555.73
PFH102A	$ 30,615.73	$ 24,476.11	V-101	$ 52,795.88	$ 42,208.31
PFH102B	$ 30,567.37	$ 24,437.45			
Total	**$ 10,513,175.15**				

13.) Safety, Health, and Environmental Considerations

a.) Safety Considerations

This system uses raw materials and generates products that are hazardous and flammable, and several aspects of safety should be taken into consideration for the operation of this plant.

i.) Personnel Protective Equipment

Due to the hazards listed in the following subsections, all persons within boundary of unit shall wear the following personnel protective equipment (PPE):

- Flame-retardant long-sleeve shirt and long pants on the outer layer of all clothing
- Hard hat
- Safety glasses
- Steel-toe boots
- Hearing protection

In addition, all persons within boundary of unit shall have the following PPE on their person and be prepared to use in designated sections:

- Cut-resistant gloves for operation on machinery or climbing ladders
- Chemical splash-resistant safety goggles for "Chemical Hazard Zones"
- Extra hearing protection for "Double Hearing Zones"

The following PPE shall be available within the plant to all persons entering the unit:

- Self-contained breathing apparatus for "Chemical Hazard Zones"

If anything is worn on the face for cold weather, it must be flame-retardant.

ii.) Safety Zones

The following safety zones will be marked in the plant with lines painted on the ground in the indicated color:

- Process unit: white lines
- Chemical Hazard Zone: yellow lines
- Double Hearing Zone: 2 parallel green lines
- Path to Eyewash and Shower Stations: blue lines

These zones may have associated PPE requirements listed in subsection 13ai.

iii.) Intrinsically Safe Devices

All electronic equipment used within the unit must be certified as "intrinsically safe devices." This is defined by OSHA as:

> *"Equipment and associated wiring in which any spark or thermal effect, produced either normally or in specified fault conditions, is incapable, under certain*

prescribed test conditions, of causing ignition of a mixture of flammable or combustible material in air in its most easily ignitable concentration." (United Sates Department of Labor, n.d.)

As a standard, no cell phones, pagers, beepers, or tablets, which have not been approved by the plant, shall be brought into the unit.

iv.) Eyewash and Shower Stations

Emergency eyewash and shower stations are to be placed throughout the unit. There shall be one eyewash and one shower station for each piece of equipment within a "Chemical Hazard Zone." There will be blue lines painted on the ground to quickly and safely direct anyone within the unit to either station.

v.) Hazards of ADA with HMDA

A report generated by Cameo Chemicals can be found in the Appendix 5. According to this report, the hazards associated with mixing ADA and HMDA solution are:

- *Corrosive: Reaction products may be corrosive*
- *Generates gas: Reaction liberates gaseous products and may cause pressurization*
- *Generates heat: Exothermic reaction at ambient temperatures (releases heat)*
- *Toxic: Reaction products may be toxic*
- *May produce the following gases:*
    - *Acid Fumes*
    - *Base Fumes*

vi.) Hazards of ADA

The Cameo Chemical report in Appendix 5 does not list any hazards worse than those of HMDA. Refer to the following subsection for hazard mitigation.

vii.) Hazards of HMDA

The Cameo Chemical report in Appendix 5 states that there is a fire hazard associated with HMDA:

"*Combustible material: may burn but does not ignite readily. When heated, vapors may form explosive mixtures with air: indoors, outdoors and sewers explosion hazards. Those substances designated with a (P) may polymerize explosively when heated or involved in a fire. Contact with metals may evolve flammable hydrogen gas. Containers may explode when heated. Runoff may pollute waterways. Substance may be transported in a molten form*."

To mitigate hazards associated with HMDA, all equipment which operates with HMDA will be deemed a "Chemical Hazard Zone," where lines shall be painted according to the spill isolation guidelines given in the Cameo Chemical report:

"As an immediate precautionary measure, isolate spill or leak area in all directions for at least 50 meters (150 feet) for liquids and at least 25 meters (75 feet) for solids."

Within the "Chemical Hazard Zones," fire hoses shall be available for the risk of a fire. The fire hose stations shall have red indicator signs above each station that is easily visible in the event of a fire. This is based on the Firefighting section of the Cameo Chemical report.

Any railcar on which HMDA is brought to the plant, as well as any HMDA storage tanks, shall be spaced from the regular process unit and the general public according to the fire isolation guidelines given in the Cameo Chemical report:

"If tank, rail car or tank truck is involved in a fire, ISOLATE for 800 meters (1/2 mile) in all directions. Also, consider initial evacuation for 800 meters (1/2 mile) in all directions."

For first aid considerations, consult the Cameo Chemical report:

"Ensure that medical personnel are aware of the material(s) involved and take precautions to protect themselves. Move victim to fresh air. Call 911 or emergency medical service. Give artificial respiration if victim is not breathing. Do not use mouth-to-mouth method if victim ingested or inhaled the substance;. Give artificial respiration with the aid of a pocket mask equipped with a one-way valve or other proper respiratory medical device. Administer oxygen if breathing is difficult. Remove and isolate contaminated clothing and shoes. In case of contact with substance, immediately flush skin or eyes with running water for at least 20 minutes. For minor skin contact, avoid spreading material on unaffected skin. Keep victim calm and warm. Effects of exposure (inhalation, ingestion or skin contact) to substance may be delayed."

viii.) <u>Relief Devices</u>

Relief devices shall be installed in the plant according to the following guidelines from Table 9-1 *Chemical Process Safety* (Crowl & Louvar, 2011).

- All vessels need reliefs, including reactors, storage tanks, towers, and drums.
- Blocked-in sections of cool liquid-filled lines that are exposed to heat (such as the sun) or refrigeration need reliefs.
- Positive displacement pumps, compressors, and turbines need reliefs on the discharge side.
- Storage vessels need pressure and vacuum reliefs to protect against pumping in or out of a blocked-in vessel or against the generation of a vacuum by condensation.
- Vessel steam jackets are often rated for low-pressure steam. Reliefs are installed in jackets to prevent excessive steam pressures due to operator error or regulator failure.

See Appendix 4 for information for every relieve device which is to be installed in the plant, along with the relief destination for each device.

The relief destination for some relief valves involve vessels that have not yet been mentioned in this report. These include V-101A, V-201, and V-202. These are small knockout vessels that will be put in place for reactant or product recovery. Operators will have the capability of pumping the contents back into the original process vessels. The flare and waste water treatment plant (WWTP) also have not yet been mentioned in this report. They will be installed for relief purposes. A later, more in-depth economic analysis will include these five relief locations.

ix.) Inherently Safer Design Technique Considerations

The principles of inherently safe process design will be used to reduce risks in the plant. The following is a list from Chapter 13 of *Chemical Process Safety* (Crowl & Louvar, 2011), with ways in which the principles are implemented in the sub-bullets.

- Moderate: Use milder conditions.
    - The temperature and pressure subjected to HMDA and ADA are as low as possible for the best reaction conversion.
- Substitute: Replace hazardous with nonhazardous chemicals.
    - An opportunity for this is not available due to the necessity of HMDA for the production of Nylon 6,6.
- Minimize: Use smaller vessels (reactors or storage) and quantities.
    - HMDA solution is sent through less preheaters than ADA
    - Exact stoichiometric proportions of ADA and HMDA are introduced to the system so that no excess HMDA is present.
    - T-101, R-101, and R-102 will be stacked on a 41 ft skid. This minimizes the amount of ground space exposed to a spill of HMDA.
- Simplify: Design systems to be easy to understand, including the mechanical designs and computer screens.
    - The DCS system will be carefully set up so that it is easy to understand.

b.) Health Considerations

i.) Hazards of ADA

The report generated by Cameo Chemicals mentions the health hazards of ADA:

> *"Inhalation of vapor irritates mucous membranes of the nose and lungs, causing coughing and sneezing. Contact with liquid irritates eyes and has a pronounced drying effect on the skin; may produce dermatitis."*

ii.) Hazards of HMDA

The report generated by Cameo Chemicals mentions the health hazards due to the toxic nature of HMDA:

"TOXIC. Inhalation, ingestion or skin contact with material may cause severe injury or death. Contact with molten substance may cause severe burns to skin and eyes. Avoid any skin contact. Effects of contact or inhalation may be delayed. Fire may produce irritating, corrosive and/or toxic gases. Runoff from fire control or dilution water may be corrosive and/or toxic and cause pollution."

iii.) Mitigation

The hazards stated in subsections i and ii are to be taken seriously and the culture of the plant will be to report any minor contact with either of the chemicals.

c.) Environmental Considerations

An environmental engineer will be employed at the plant to carefully monitor the following considerations.

**Subsections i – iv are originated from a 2015 report by Westlake Chemical, which has a PVC plant in Calvert City, KY (Westlake Chemical, n.d.).

i.) The Federal Clean Air Act

Monitoring of emissions will be necessary if coal burning or another CO_2 producing system is implemented for power production. The electricity usage currently will be through the city.

ii.) Release Reporting

The release of HMDA or ADA will be subject to federal and state environmental reporting regulations. Any spills will be monitored and recorded as necessary.

iii.) Clean Water Act

This act will be followed accordingly. This plant should not result in any discharges to water outside the plant, but if any accidental spills of water occur, they will be recorded.

iv.) The Resource Conservation and Recovery Act

If hazardous wastes are spilled, released, or disposed, this act may require expensive investigations, studies, and response actions. This will be followed accordingly.

v.) Kentucky Wetland Reserve Program

Calvert City, Kentucky is in Marshall County, which has areas included in Kentucky's Wetlands Reserve Program (Natural Resources Conservation Service, n.d.). This means that the plant will have to be sure not to contaminate the water in the area. The water stream produced during the reaction is integrated in the feed preheat network, and then recycled to the water reserve. Therefore, contaminating a Kentucky reserved wetland should not be an issue.

vi.) CO_2 Emissions

Currently, it is planned for the plant to use electricity for H-101C, H-102C, R-101, and R-102. This is estimated in the Aspen simulation to emit 2496.8628 lb/hr of CO_2.

14.) Other Important Considerations

a.) Process Control

Multiple variables throughout the plant will be controlled. These variables are explained below. The control scheme can be seen in Appendix 4 Figure A4-2.

i.) Condensate recycle to H2O feed

The condensate in stream C-H-101A that is used in the feed preheat network will be added to the H2O feed in stream F-V-1012 upstream of to P-FV1014. This addition will occur through a “T” connection. A flow transmitter will be located on C-H-101A downstream of P-CH101A which will transmit the flow value to a control valve. This control valve will be located on F-V-1012 upstream of P-FV1014.

The amount of H2O in C-H-101A is greater than in F-V-1012 in normal operating conditions. Therefore, the control valve will be programmed to fail close in the case of lost power to the plant as to not dilute the system.

A second control valve will be placed on line F-S-101. This is to allow part of the flow of water in line C-H-101A to be fed to S-104 and to not dilute the system. The flow transmitter on C-H-101A will signal this second control valve in addition to the first one on line F-V-1012. These two control valves will work within the same system to control the flow of H2O and keep the total flow of H2O to V-101 constant at 1967 lb/hr.

This second control valve will be programmed to fail open in the case of lost power to the plant so as to not dilute the system.

ii.) Level control of V-101

The level of V-101 must be kept under control in order to ensure the vessel does not overflow. A level transmitter will be placed on V-101, and a control valve will be installed on line F-H-101A upstream of P–FH101A. The transmitter will signal to the control valve in order to keep V-101 at a maximum of 80% full. The control valve will remain at 70% open in normal conditions, and will open more if V-101 becomes more than 80% full. The control valve will be programmed to fail close in the case of lost power to the plant for the same reason mentioned in subsection 14ai.

The control valve will also be connected to the control room. This will give control through the DCS for startup/shutdown purposes.

iii.) Temperature control of H-101C

The temperature of H2O in C-T-101 will fluctuate, causing the effectiveness of the preheat network to also fluctuate. This will change the required duty of H-101C. A temperature transmitter will be placed on line F-H-101C. This transmitter will signal a temperature controller on H-101C in order to adjust for this change in required duty.

iv.) Temperature control of H-102C

The temperature of H_2O in C-T-101 will fluctuate, causing the effectiveness of the preheat network to also fluctuate. This will change the required duty of H-102C. A temperature transmitter will be placed on line F-H-102C. This transmitter will signal a temperature controller on H-102C in order to adjust for this change in required duty.

b.) Reduced Rates

Several conditions within the plant will need to be adjusted in the case of reducing rates due to market demands or plant maintenance. The following points are the most important conditions and are based on running the plant at 67% capacity:

i.) Feed flow

The plant is normally run to produce 85 MM pounds per year (ppy) of Nylon 6,6. At reduced rates, only 56.95 MM pounds ppy will need to be made. The feed flow will need to be adjusted by the control room operators accordingly.

Decreasing feed flow will create a ripple effect throughout the plant. In the preheat network, there will initially be less feed than condensate flowing through the exchangers. This will heat the feed more than normal. H-101C and H-102C will adjust accordingly with the temperature control discussed in subsections 14aiii and 14aiv, respectively. However, careful attention will have to be paid to the temperature of R-101, and the set temperature may need to be decreased so as to not overheat the reaction.

ii.) R-101 pressure

The pressure of R-101 is set to 10 atm at normal operating conditions. This should be decreased at reduced rates so as to not overpressure the reactants and prematurely create more excess polymer before the stream enters R-102.

iii.) Flow control valve on stream F-H-101A

This control valve will need to be set to full open by the control room operator when the rates are initially being reduced. This will help compensate for the ripple effect mentioned in subsection 14bi. As the process unit adjusts to lower rates, the operator can bring the control valve back to normal percent open.

c.) Startup

Starting the plant will cause procedures to be followed that are in addition or exception to normal procedures. Below are some of the most important:

i.) Flow control valve on stream F-H-101A

This is the same issue listed in subsection 14aiii. The operator will need to run the control valve at full open so as to not constrict feed flow while the plant is starting operation.

ii.) Reflux to T-101

T-101 will need to be started before it is fed with flow from V-R-101. Water should be fed into the tower to begin reflux for optimal tower operation. This water will come from the water storage tank S-103 and will need to be pretreated to tower conditions shown in Figure A1-8.

iii.) Blind on H2O recycle tee

The tee connection located upstream of P-FV1014 is in place to help facilitate recycle of condensate from T-101 (see subsection 14ai). If there is little to no flow of condensate during startup, the H2O feed stream F-V-1012 will enter stream F-V-1013. This justifies installing a blind flange at this tee connection to avoid misdirection of the H2O feed stream.

15.) Manufacturing Costs

Calculation of manufacturing costs for this plant is based on the model set up in *Analysis, Synthesis and Design of Chemical Processes.* The literature defines manufacturing costs as the sum of direct, fixed, and general manufacturing costs. These are summarized in Table 15.1.

Table 15.1: Manufacturing Cost Summary

Direct Manufacturing Costs		**Operating Labor**			
Raw materials	$ 86,138,722.32		Nnp		P
Waste treatment	$ -		**21**		3
Utilities	$ 2,297,501.58	pumps	11	extruders	1
Operating labor	$ 4,607,616.00	heat xrs	3	transport	1
Direct supervisory and clerical labor	$ 829,370.88	heaters	2	quality contr	1
Maintenance and repairs	$ 630,790.51	tower	1	N_ol	17.21685221
Operating supplies	$ 94,618.58	condense	1	Actual Nol	77.476
Lab charges	$ 691,142.40	reactors	2	Mean hr wag	$ 28.40
Total Direct Manufacturing Costs	$ 95,289,762.26	vessels	1	Salary	$ 59,072.00
Fixed Manufacturing Costs		Material Pricing			
Depreciation	$ 1,051,317.52		$/lb	lb/year	$/year
Local taxes and insurance	$ 336,421.60	ADA	$ 0.68	54472100	$ 37,062,237.48
Plant overhead costs	$ 3,640,666.43	HMDA	$ 1.13	43278000	$ 49,076,484.84
Total Fixed Manufacturing Costs	$ 5,028,405.55				
		Nylon66 Manufacture Price			
General Manufacturing Expenses			$/lb	lb/year	$/year
Administration costs	$ 910,166.61	Nylon66	$ 1.20	84471500	$ 101,228,334.42
Total General Manufacturing Costs	$ 910,166.61	Nylon66 Selling Price			
			$/lb	lb/year	$/year
Total Costs	$ 101,228,334.42	Nylon66	$ 1.35	84471500	$ 114,036,525.00

As illustrated in the table, the largest expense among these costs is the raw materials. This price was quoted by Investa, and is assumed to be a very reliable source. The price of Nylon 6,6 was taken from a 2015 average (Smock, 2015), but should still be reliable.

The Calvert City, KY price of electricity (Calvert City, KY Electricity Statistics, n.d.) was used to estimate the price of both electricity and air in the plant. Since the cost of cooling air originates from the cost of electricity to run the fan, this should be a safe assumption.

The book also takes into account patents and royalties, distribution and selling costs, and research and development. In sufficient data is available for this analysis, however they are neglected because the total cost is not sensitive to this data.

As shown in the bottom right hand corner of Table 15.1, there is a net profit of $0.15/lb for the production of Nylon 6,6 in this plant.

16.) Economic Analysis

This plant has been economically analyzed by calculating and evaluating the discounted cash flow rate of return (DCFRR). This is defined to be the interest rate at which all the cash flows must be discounted in order for the net present value of the project to be equal to zero (Turton, Bailie, Whiting, Shaeiwitz, & Bhattacharyya, 2012). The calculations can be seen in Table A3-3, and a cumulative cash flow diagram is given in Figure A3-1.

The taxation rate is calculated by incorporating the six most common tax rates within the United States: income, sales, property, franchise, severance, and vehicle (Baasel):

- The federal tax rate schedule for corporations is shown to be close to 35% (Turton, Bailie, Whiting, Shaeiwitz, & Bhattacharyya, 2012).
- The Kentucky state income tax for 2017 is listed as 6% (Scarboro, 2017).
- The Kentucky state sales tax rate is currently listed as 6% (Kentucky Sales Tax, n.d.).
- The Marshall County average effective property tax is 0.79% (Kentucky Property Tax Calculator, n.d.).
- The Kentucky bank franchise tax is assessed at the rate of 1.1% (Bank Franchise Tax, n.d.).
- Severance tax is neglected because no material is being extracted from its natural state for this plant.
- Vehicle fuel tax is neglected under the assumption that all transportation will occur on railcar and not highways.

Thus, the final sum for the tax rate is 48.89%

The fixed capital investment value is used from section 12. It is assumed that two-thirds of this FCI will be paid in the first year.

The area of land to be purchased for this chemical plant consists of 139.6 acres and costs 4.2 million dollars. This property is an industrial site with 2846 foot frontage on the Tennessee River, 929 foot railroad frontage, and approximately 6 miles downstream from Calvert City Industrial Complex toward Paducah (LandWatch, 2017). This site perfectly fits the safety recommendations made in subsection 13avii.

The working capital value is used as the total manufacturing costs value from section 15. The value for revenue is also given in Table 15.1 in the bottom right hand corner cell.

The cost of manufacturing without depreciation, COM_D, is defined in *Analysis, Synthesis and Design of Chemical Processes* as another important factor in calculating the DCFRR. This value is calculated by subtracting the amount of depreciation from the working capital, both of which are found in Table 15.1.

The analysis is based on a 10 year project life, where the life is began after 2 years of plant startup and construction.

As seen in Table A3-3, the final DCFRR calculated value is 8.94%. This is the highest after-tax interest rate at which this plant can break even. This is a rather low rate, and it is likely that DCFRR<IRR (internal rate of return). Therefore, this is not a profitable investment.

17.) Conclusions and Recommendations

To paraphrase the conclusion made in section 16, the current plan for this plant is not likely to be greater than a chosen IRR by the plant, and therefore will not be profitable. However, there are some opportunities for improvement in profitability for this project, and these opportunities can be explored given more time for a deeper analysis:

a.) Utility improvements

Much of the plant's utility needs are currently planned to be run with electricity. This is a much more expensive option than using steam for heating the necessary equipment. A steam production system should be implemented for the plant in order to save cost and also for environmental purposes.

A more in-depth analysis of the power used by C-101 with air cooling could improve costs on utilities as well. This analysis could also include evaluating whether cooling water is more profitable than air.

b.) Product finishing equipment

It is difficult to evaluate how to finish the Nylon 6,6 product. A new analysis can be performed on the best option for finishing the product and selling it. The monetary value for different Nylon 6,6 grades should also be assessed in order to evaluate which finishing technique should be pursued in the plant.

Although Nylon 6,6 prices have decreased recently due to decreases in oil prices, worldwide demand and production is expected to increase (Smock, 2015). It is recommended to wait a few years before building this plant. This will allow Nylon 6,6 prices to increase and will allow the company to assess the value of the feedstock prices, as the feed is the highest cost of the plant. During that time, the analyses mentioned above in subsections 17a and 17b can be performed for optimal plant conditions.

18. Acknowledgements

This section is to acknowledge the great education I have received from the Chemical Engineering Department that has prepared me for the difficult task of performing this analysis and writing this report.

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Appendix 1: Aspen Data

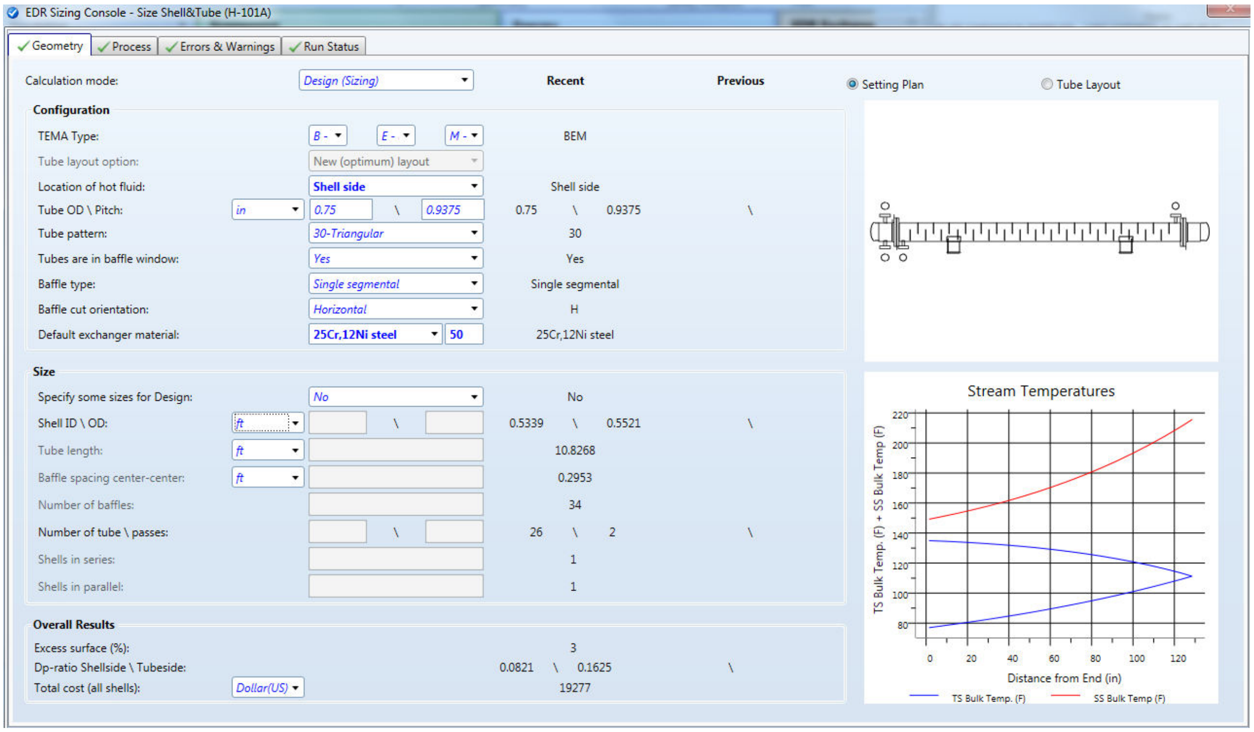
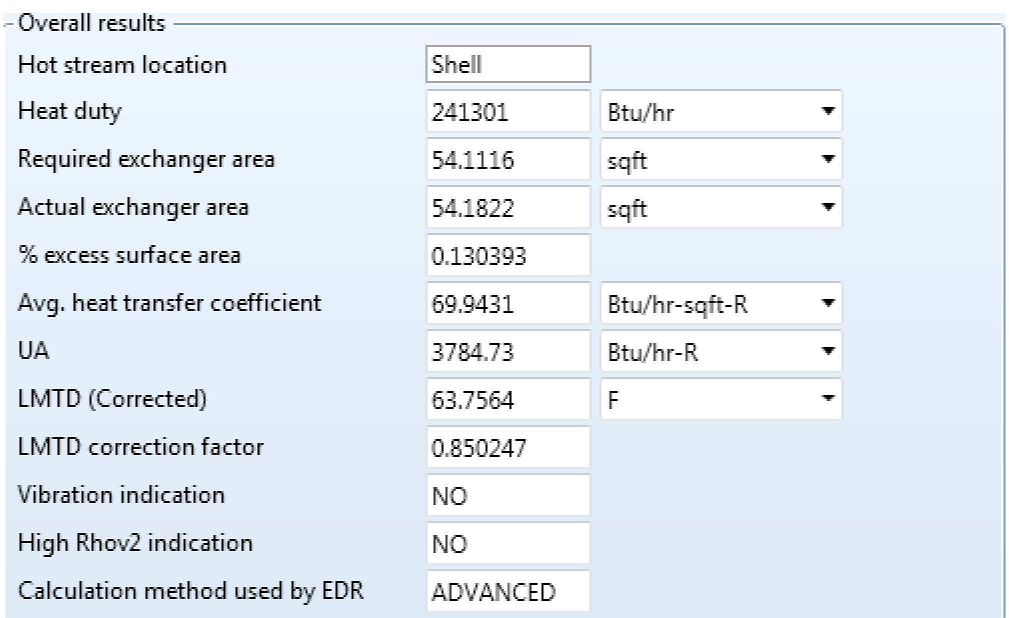


Figure A1-1: Aspen Sizing H-101A



Overall results		
Hot stream location	Shell	
Heat duty	241301	Btu/hr
Required exchanger area	54.1116	sqft
Actual exchanger area	54.1822	sqft
% excess surface area	0.130393	
Avg. heat transfer coefficient	69.9431	Btu/hr-sqft-R
UA	3784.73	Btu/hr-R
LMTD (Corrected)	63.7564	F
LMTD correction factor	0.850247	
Vibration indication	NO	
High Rhov2 indication	NO	
Calculation method used by EDR	ADVANCED	

Figure A1-2: Aspen EDR Results H-101A

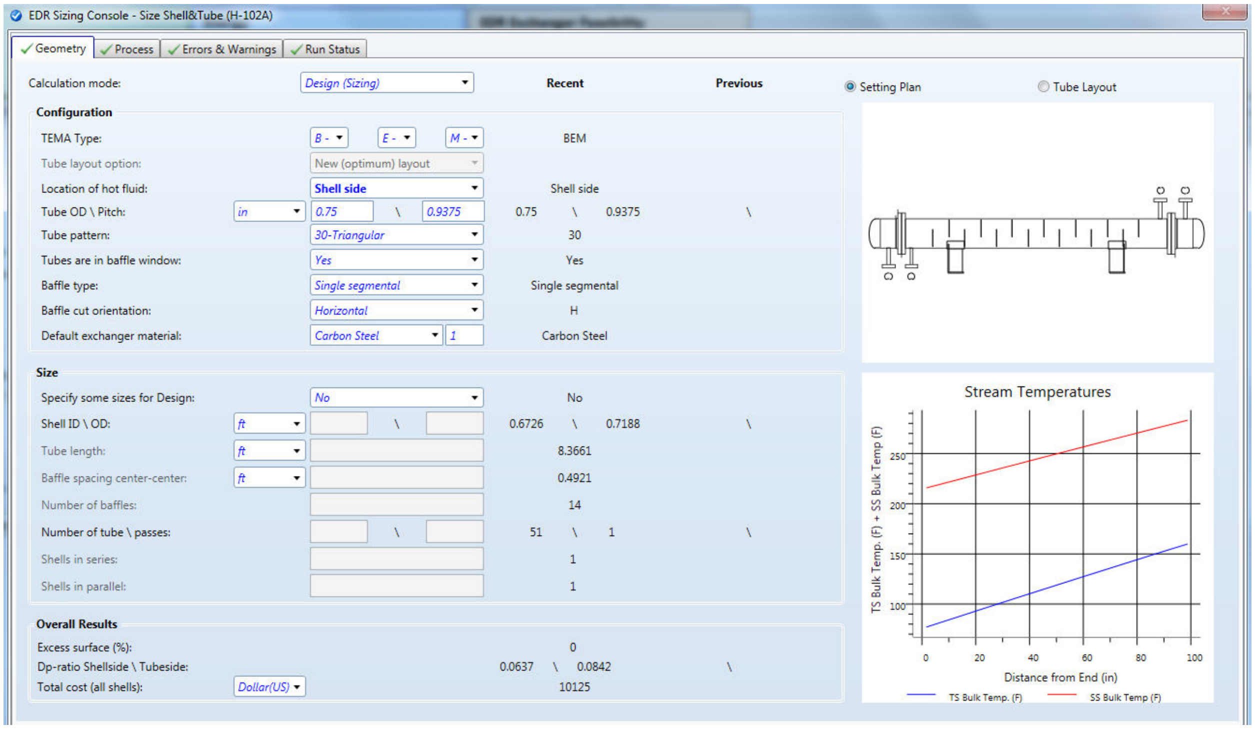


Figure A1-3: Aspen Sizing H-102A

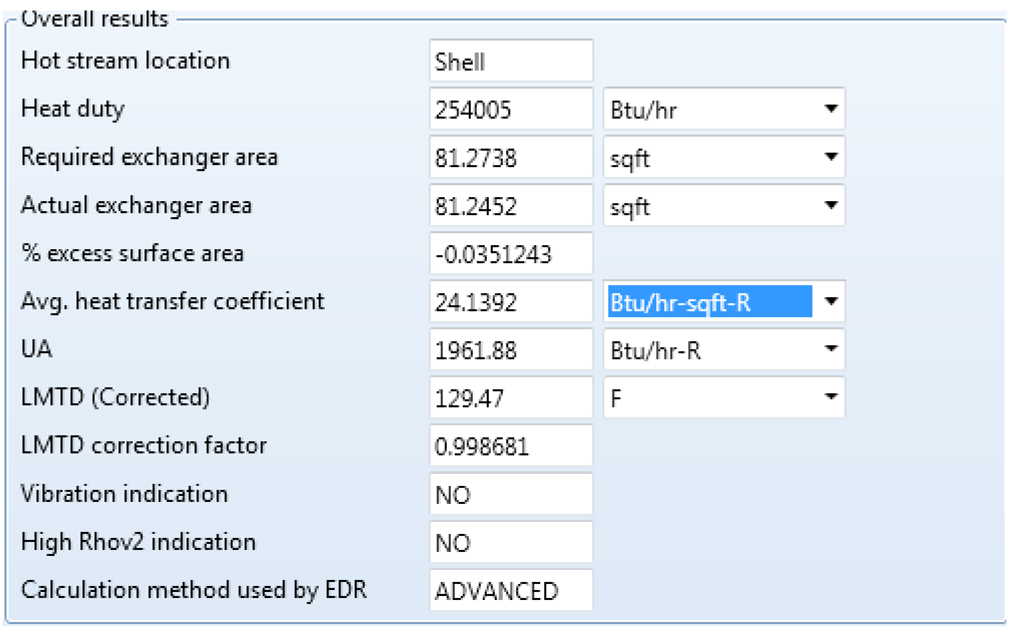


Figure A1-4: Aspen EDR Results H-102A

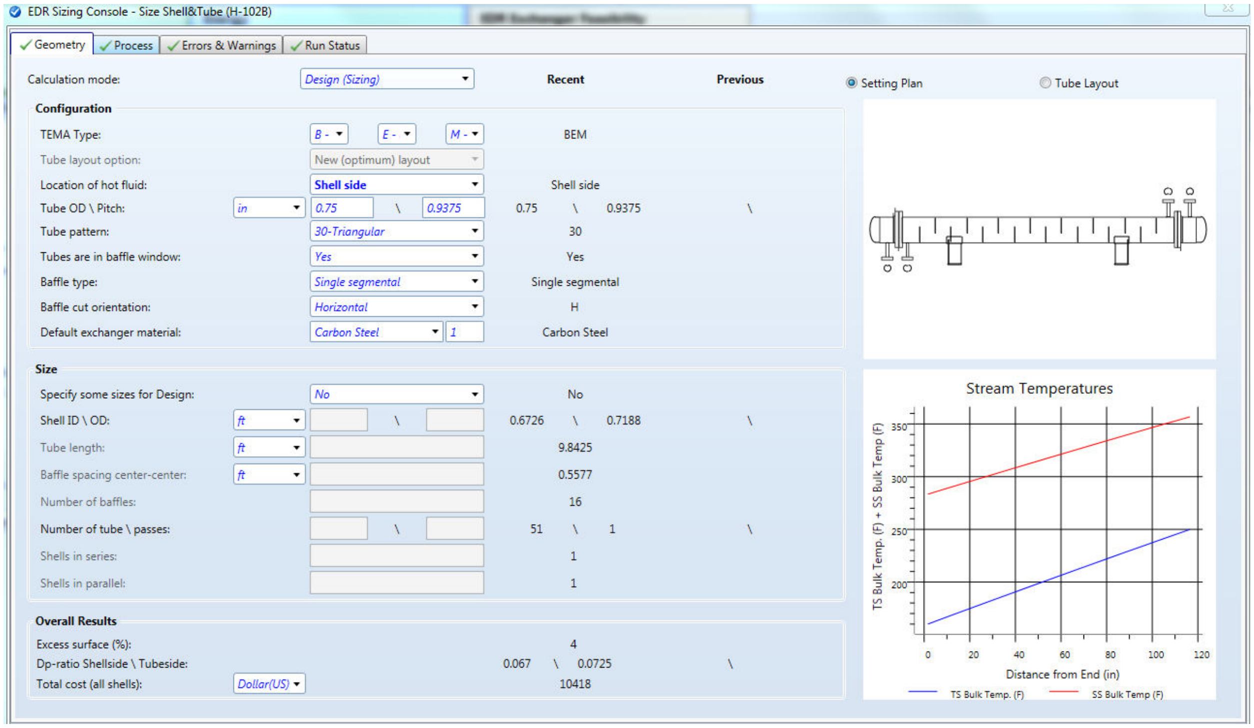


Figure A1-5: Aspen Sizing H-102B

Overall results		
Hot stream location	Shell	
Heat duty	305129	Btu/hr
Required exchanger area	95.9626	sqft
Actual exchanger area	96.0296	sqft
% excess surface area	0.0698761	
Avg. heat transfer coefficient	27.9863	Btu/hr-sqft-R
UA	2685.64	Btu/hr-R
LMTD (Corrected)	113.615	F
LMTD correction factor	0.999597	
Vibration indication	NO	
High Rhov2 indication	YES	
Calculation method used by EDR	ADVANCED	

Figure A1-6: Aspen EDR Results H-102B

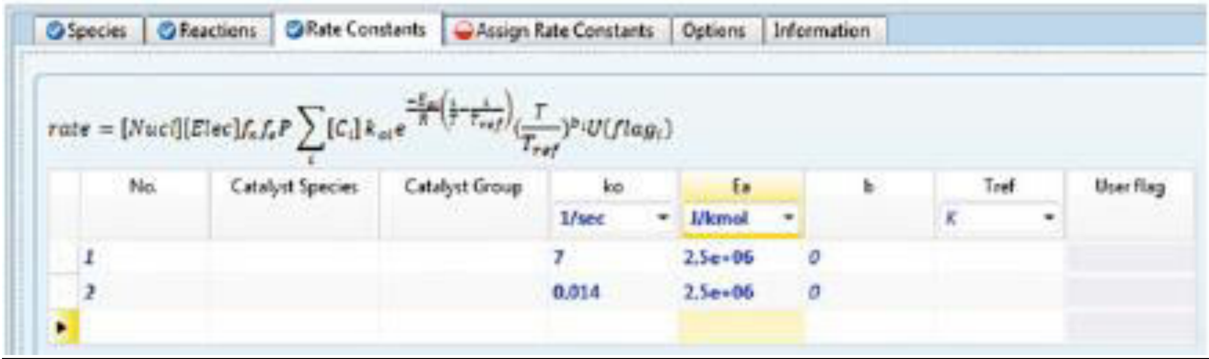


Figure A1-7: Aspen *Rate Constants* Window

(Chaves, López, Zapata, Robayo, & Niño, 2016)

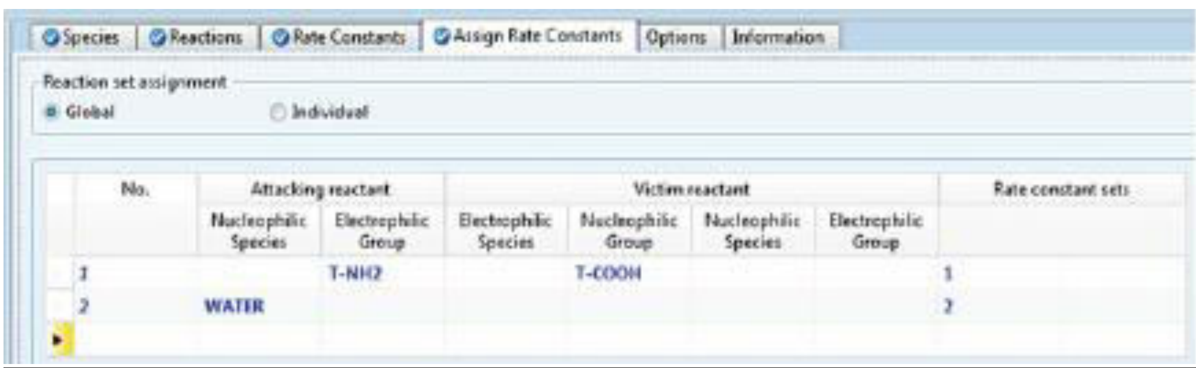


Figure A1-7: Aspen *Assign Rate Constants* Window

(Chaves, López, Zapata, Robayo, & Niño, 2016)

Stage	ADA	HMDA	H2O	Temperature F	Pressure psia
1	1.84983e-41	6.3226e-13	1	356.989	146.959
2	4.45067e-38	8.69532e-12	1	356.989	146.959
3	4.59179e-35	5.62194e-11	1	356.989	146.959
4	4.73477e-32	3.36328e-10	1	356.989	146.959
5	4.8822e-29	1.9873e-09	1	356.989	146.959
6	5.03422e-26	1.17182e-08	1	356.989	146.959
7	5.19097e-23	6.90727e-08	1	356.989	146.959
8	5.3526e-20	4.07122e-07	1	356.989	146.959
9	5.51925e-17	2.3996e-06	0.999998	356.989	146.959
10	5.69102e-14	1.41432e-05	0.999986	356.989	146.959
11	5.86769e-11	8.33542e-05	0.999917	356.99	146.959
12	6.04716e-08	0.000491078	0.999509	356.995	146.959
13	6.21537e-05	0.00288681	0.997051	357.024	146.959

Figure A1-8:

Appendix 2: Equipment Specification Sheets

Air Cooler								
Identification:	**Item**	Air Cooler						
	Item No		C-101		Date:	2-Mar-17		
	No. Required		1					
					By:	Caleb Woodall		
Function:	Condense water at overhead of enriching column for reflux to column.							
Operation:	Continuous							
Materials Handled:	Hot In:	Cold In:	Hot Out:	Cold Out:				
Quantity (lb/hr):	6094.33	2.40E+06	6094.33	2.40E+06				
Composition:								
Adipic Acid	trace	0	trace	0				
Hexamethylenediamine	trace	0	trace	0				
Water	1	0	1	0				
Nylon 6,6	0	0	0	0				
Air	0	1	0	1				
Temperature (F)								
Design Data:	Duty: -5269160 Btu/hr							
	Heat exchange area: 1615 ft^2							
	Heat transfer coefficient:							
	Material of construction: carbon steel							
Utilities: Air at specifications in cold stream information								
Controls:								
Tolerances:								
Comments and drawings: see PFD in Figure 6.1								

Figure A2-1: C-101 Specification Sheet

Extruder							
Identification:	**Item**	Extruder					
	Item No		E-101		Date:	2-Mar-17	
	No. Required		1				
					By:	Caleb Woodall	
Function:	Extrude Nylon 6,6 product						
Operation:	Continuous						
Materials Handled:	Feed:	Product:					
Quantity (lb/hr):	9636.27	9636.27					
Composition:							
Adipic Acid	1.4E-05	1.4E-05					
Hexamethylenediamine	7.4E-06	7.4E-06					
Water	0.00112	0.00112					
Nylon 6,6	0.99886	0.99886					
Air	0	0					
Temperature (F)	539.33	539.33					
Design Data:	Temperature: <515.9 F (melting point Nylon66)						
	Pressure: 14.6959 psia						
	Material of construction: Carbon steel						
	**More data unknown, this is only small approximation						
Utilities: electricity							
Controls:							
Tolerances:							
Comments and drawings: see PFD in Figure 6.1							

Figure A2-2: E-101 Specification Sheet

Heat Exchanger								
Identification:	**Item**	Heat Exchanger						
	Item No		H-101A		Date:	2-Mar-17		
	No. Required		1					
					By:	Caleb Woodall		
Function:	Preheat water and hexamethylenediamine solution before reaction							
Operation:	Continuous							
Materials Handled:	Hot In:	Cold In:	Hot Out:	Cold Out:				
Quantity (lb/hr):	3482.48	6904.85	3482.48	6904.85				
Composition:								
Adipic Acid	trace	0	trace	0				
Hexamethylenediamine	trace	0.715008	trace	0.71501				
Water	1	0.284992	1	0.28499				
Nylon 6,6	0	0	0	0				
Air	0	0	0	0				
Temperature (F)	214.351	77	147.786	135.008				
Design Data:	Duty: 241289 Btu/hr							
	Heat exchange area: 54.1822 sqft							
	Heat transfer coefficient: 69.942 Btu/hr-sqft-R							
	Material of construction: 25Cr, 12Ni steel							
	Location of hot fluid: shell side			Type: Shell and tube, floating head				
	Tube Length: 10.8268 ft							
	Number of tube/passes: 26/2			Shell ID/OD: 0.5339/0.5521 ft				
Utilities:								
Controls:								
Tolerances:								
Comments and drawings: see PFD in Figure 6.1 and Aspen data in Appenix 1								

Figure A2-3: H-101A Specification Sheet

Nonreactive Fired Heater								
Identification:	**Item**	Heater						
	Item No		H-101C		Date:	2-Mar-17		
	No. Required		1					
					By:	Caleb Woodall		
Function:	Preheat water and hexamethylenediamine solution before reaction							
Operation:	Continuous							
Materials Handled:	In:	Out:						
Quantity (lb/hr):	6904.85	6904.85						
Composition:								
Adipic Acid	0	0						
Hexamethylenediamine	0.71501	0.71501						
Water	0.28499	0.28499						
Nylon 6,6	0	0						
Air	0	0						
Temperature (F)	135.008	350.33						
Design Data:	Duty: 1019320 Btu/hr							
	Material of construction: 25Cr, 12Ni steel							
Utilities: electricity								
Controls:								
Tolerances:								
Comments and drawings: see PFD in Figure 6.1								

Figure A2-4: H-101C Specification Sheet

Heat Exchanger							
Identification:	**Item**	Heat Exchanger					
	Item No		H-102A		Date:	2-Mar-17	
	No. Required		1				
					By:	Caleb Woodall	
Function:	Preheat adipic acid before reaction						
Operation:	Continuous						
Materials Handled:	Hot In:	Cold In:	Hot Out:	Cold Out:			
Quantity (lb/hr):	3482.48	6214.01	3482.48	6214.01			
Composition:							
Adipic Acid	trace	0	trace	0			
Hexamethylenediamine	trace	1	trace	1			
Water	1	0	1	0			
Nylon 6,6	0	0	0	0			
Air	0	0	0	0			
Temperature (F)	214.351	77	214.351	158.984			
Design Data:	Duty: 253997 Btu/hr						
	Heat exchange area: 81.2452 sqft						
	Heat transfer coefficient: 24.1389 Btu/hr-sqft-R						
	Material of construction: carbon steel						
	Location of hot fluid: shell side			Type: Shell and tube, floating head			
	Tube Length: 8.3661 ft						
	Number of tube/passes: 51/1			Shell ID/OD: 0.6726/0.7188 ft			
Utilities:							
Controls:							
Tolerances:							
Comments and drawings: see PFD in Figure 6.1 and Aspen data in Appendix 1							

Figure A2-5: H-102A Specification Sheet

Heat Exchanger							
Identification:	**Item**	Heat Exchanger					
	Item No		H-102B		Date:	2-Mar-17	
	No. Required		1				
					By:	Caleb Woodall	
Function:	Preheat adipic acid before reaction						
Operation:	Continuous						
Materials Handled:	Hot In:	Cold In:	Hot Out:	Cold Out:			
Quantity (lb/hr):	3482.48	6214.01	3482.48	6214.01			
Composition:							
Adipic Acid	trace	0	trace	0			
Hexamethylenediamine	trace	1	trace	1			
Water	1	0	1	0			
Nylon 6,6	0	0	0	0			
Air	0	0	0	0			
Temperature (F)	356.989	158.984	281.205	251.477			
Design Data:	Duty: 305130 Btu/hr						
	Heat exchange area: 96.0296 sqft						
	Heat transfer coefficient: 27.9862 Btu/hr-sqft-R						
	Material of construction: carbon steel						
	Location of hot fluid: shell side			Type: Shell and tube, floating head			
	Tube Length: 8.3661 ft						
	Number of tube/passes: 51/1			Shell ID/OD: 0.6726/0.7188 ft			
Utilities:							
Controls:							
Tolerances:							
Comments and drawings: see PFD in Figure 6.1 and Aspen data in Appendix 1							

Figure A2-6: H-102B Specification Sheet

Nonreactive Fired Heater								
Identification:	**Item**	Heater						
	Item No		H-102C		Date:	2-Mar-17		
	No. Required		1					
					By:	Caleb Woodall		
Function:	Preheat adipic acid before reaction							
Operation:	Continuous							
Materials Handled:	In:	Out:						
Quantity (lb/hr):	6214.01	6214.01						
Composition:								
Adipic Acid	1	1						
Hexamethylenediamine	0	0						
Water	0	0						
Nylon 6,6	0	0						
Air	0	0						
Temperature (F)	251.477	350.33						
Design Data:	Duty: 347271 Btu/hr							
	Material of construction: carbon steel							
Utilities: electricity								
Controls:								
Tolerances:								
Comments and drawings: see PFD in Figure 6.1								

Figure A2-7: H-102C Specification Sheet

Pump							
Identification:	**Item**	Pump					
	Item No		P-CH101A		Date:	2-Mar-17	
	No. Required		1				
					By:	Caleb Woodall	
Function:	Pump condensate to water reserve						
Operation:	continuous						
Materials Handled:	Inlet:	Outlet:					
Quantity (lb/hr):	3482.48	3482.48					
Composition:							
Adipic Acid	trace	trace					
Hexamethylenediamine	trace	trace					
Water	1	1					
Nylon 6,6	0	0					
Air	0	0					
Temperature (F)	147.786	147.786					
Design Data:	Shaft power: 0.065533 kW						
	Material of construction: carbon steel						
	Pump type: positivie-displacement						
	Head differential: 40 ft						
Utilities: electricity							
Controls:							
Tolerances:							
Comments and drawings: See PFD in Figure 6.1							

Figure A2-8: P-CH101A Specification Sheet

Pump								
Identification:	**Item**	Pump						
	Item No		P-CH102A		Date:	2-Mar-17		
	No. Required		1					
					By:	Caleb Woodall		
Function:	Pump condensate to H-101A							
Operation:	continuous							
Materials Handled:	Inlet:	Outlet:						
Quantity (lb/hr):	3482.48	3482.48						
Composition:								
Adipic Acid	trace	trace						
Hexamethylenediamine	trace	trace						
Water	1	1						
Nylon 6,6	0	0						
Air	0	0						
Temperature (F)	214.351	214.351						
Design Data:	Shaft power: 0.016383 kW							
	Material of construction: carbon steel							
	Pump type: positivie-displacement							
	Head differential: 10 ft							
Utilities: electricity								
Controls:								
Tolerances:								
Comments and drawings: See PFD in Figure 6.1								

Figure A2-9: P-CH102A Specification Sheet

Pump							
Identification:	**Item**	Pump					
	Item No		P-CH102B		Date:	2-Mar-17	
	No. Required		1				
					By:	Caleb Woodall	
Function:	Pump condensate to H-102B						
Operation:	continuous						
Materials Handled:	Inlet:	Outlet:					
Quantity (lb/hr):	3482.48	3482.48					
Composition:							
Adipic Acid	trace	trace					
Hexamethylenediamine	trace	trace					
Water	1	1					
Nylon 6,6	0	0					
Air	0	0					
Temperature (F)	281.205	281.205					
Design Data:	Shaft power: 0.013107 kW						
	Material of construction: carbon steel						
	Pump type: positivie-displacement						
	Head differential: 10 ft						
Utilities: electricity							
Controls:							
Tolerances:							
Comments and drawings: See PFD in Figure 6.1							

Figure A2-10: P-CH102B Specification Sheet

Pump						
Identification:	**Item**	Pump				
	Item No	P-FH101A		Date:	2-Mar-17	
	No. Required	1				
				By:	Caleb Woodall	
Function:	Pump HMDA solution to H-101A					
Operation:	continuous					
Materials Handled:	Inlet:	Outlet:				
Quantity (lb/hr):	6904.85	6904.85				
Composition:						
Adipic Acid	0	0				
Hexamethylenediamine	0.71501	0.71501				
Water	0.28499	0.28499				
Nylon 6,6	0	0				
Air	0	0				
Temperature (F)	77	77				
Design Data:	Shaft power: 0.016242 kW					
	Material of construction: Ni-Cr alloy					
	Pump type: positivie-displacement					
	Head differential: 5 ft					
Utilities: electricity						
Controls:						
Tolerances:						
Comments and drawings: See PFD in Figure 6.1						

Figure A2-11: P-FH101A Specification Sheet

Pump							
Identification:	**Item**	Pump					
	Item No		P-FH101C		Date:	2-Mar-17	
	No. Required		1				
					By:	Caleb Woodall	
Function:	Pump HMDA solution to H-101C						
Operation:	continuous						
Materials Handled:	Inlet:	Outlet:					
Quantity (lb/hr):	6904.85	6904.85					
Composition:							
Adipic Acid	0	0					
Hexamethylenediamine	0.71501	0.71501					
Water	0.28499	0.28499					
Nylon 6,6	0	0					
Air	0	0					
Temperature (F)	135.008	135.008					
Design Data:	Shaft power: 0.016242 kW						
	Material of construction: Ni-Cr alloy						
	Pump type: positivie-displacement						
	Head differential: 5 ft						
Utilities: electricity							
Controls:							
Tolerances:							
Comments and drawings: See PFD in Figure 6.1							

Figure A2-12: P-FH101C Specification Sheet

Pump								
Identification:	**Item**	Pump						
	Item No		P-FH102A		Date:	2-Mar-17		
	No. Required		1					
					By:	Caleb Woodall		
Function:	Pump adipic acid to H-102A							
Operation:	continuous							
Materials Handled:	Inlet:	Outlet:						
Quantity (lb/hr):	6214.01	6214.01						
Composition:								
Adipic Acid	0	0						
Hexamethylenediamine	1	1						
Water	0	0						
Nylon 6,6	0	0						
Air	0	0						
Temperature (F)	77	77						
Design Data:	Shaft power: 0.014617 kW							
	Material of construction: carbon steel							
	Pump type: positivie-displacement							
	Head differential: 5 ft							
Utilities: electricity								
Controls:								
Tolerances:								
Comments and drawings: See PFD in Figure 6.1								

Figure A2-13: P-FH102A Specification Sheet

Pump								
Identification:	**Item**	Pump						
	Item No		P-FH102B		Date:	2-Mar-17		
	No. Required		1					
					By:	Caleb Woodall		
Function:	Pump adipic acid to H-102B							
Operation:	continuous							
Materials Handled:	Inlet:	Outlet:						
Quantity (lb/hr):	6214.01	6214.01						
Composition:								
Adipic Acid	0	0						
Hexamethylenediamine	1	1						
Water	0	0						
Nylon 6,6	0	0						
Air	0	0						
Temperature (F)	158.984	158.984						
Design Data:	Shaft power: 0.014617 kW							
	Material of construction: carbon steel							
	Pump type: positivie-displacement							
	Head differential: 5 ft							
Utilities: electricity								
Controls:								
Tolerances:								
Comments and drawings: See PFD in Figure 6.1								

Figure A2-14: P-FH102B Specification Sheet

Pump							
Identification:	**Item**	Pump					
	Item No		P-FH102C		Date:	2-Mar-17	
	No. Required		1				
					By:	Caleb Woodall	
Function:	Pump adipic acid to H-102C						
Operation:	continuous						
Materials Handled:	Inlet:	Outlet:					
Quantity (lb/hr):	6214.01	6214.01					
Composition:							
Adipic Acid	1	1					
Hexamethylenediamine	0	0					
Water	0	0					
Nylon 6,6	0	0					
Air	0	0					
Temperature (F)	251.477	251.477					
Design Data:	Shaft power: 0.014617 kW						
	Material of construction: carbon steel						
	Pump type: positivie-displacement						
	Head differential: 5 ft						
Utilities: electricity							
Controls:							
Tolerances:							
Comments and drawings: See PFD in Figure 6.1							

Figure A2-15: P-FH102C Specification Sheet

Pump						
Identification:	**Item**	Pump				
	Item No	P-FR1011		Date:	2-Mar-17	
	No. Required	1				
				By:	Caleb Woodall	
Function:	Pump HMDA solution to R-101					
Operation:	continuous					
Materials Handled:	Inlet:	Outlet:				
Quantity (lb/hr):	6904.85	6904.85				
Composition:						
Adipic Acid	0	0				
Hexamethylenediamine	0.71501	0.71501				
Water	0.28499	0.28499				
Nylon 6,6	0	0				
Air	0	0				
Temperature (F)	350.33	350.33				
Design Data:	Shaft power: 0.097452 kW					
	Material of construction: Ni-Cr alloy					
	Pump type: positivie-displacement					
	Head differential: 30 ft					
Utilities: electricity						
Controls:						
Tolerances:						
Comments and drawings: See PFD in Figure 6.1						

Figure A2-16: P-FR1011 Specification Sheet

Pump							
Identification:	**Item**	Pump					
	Item No		P-FR1012		Date:	2-Mar-17	
	No. Required		1				
					By:	Caleb Woodall	
Function:	Pump adipic acid to R-101						
Operation:	continuous						
Materials Handled:	Inlet:	Outlet:					
Quantity (lb/hr):	6214.01	6214.01					
Composition:							
Adipic Acid	1	1					
Hexamethylenediamine	0	0					
Water	0	0					
Nylon 6,6	0	0					
Air	0	0					
Temperature (F)	350.33	350.33					
Design Data:	Shaft power: 0.087702 kW						
	Material of construction: carbon steel						
	Pump type: positivie-displacement						
	Head differential: 30 ft						
Utilities: electricity							
Controls:							
Tolerances:							
Comments and drawings: See PFD in Figure 6.1							

Figure A2-17: P-FR1012 Specification Sheet

Pump								
Identification:	**Item**	Pump						
	Item No		P-FV1012		Date:	2-Mar-17		
	No. Required		1					
					By:	Caleb Woodall		
Function:	Pump water to V-101							
Operation:	continuous							
Materials Handled:	Inlet:	Outlet:						
Quantity (lb/hr):	1967.83	1967.83						
Composition:								
Adipic Acid	0	0						
Hexamethylenediamine	0	0						
Water	1	1						
Nylon 6,6	0	0						
Air	0	0						
Temperature (F)	77	77						
Design Data:	Shaft power: 0.004629 kW							
	Material of construction: carbon steel							
	Pump type: positivie-displacement							
	Head differential: 5 ft							
Utilities: electricity								
Controls:								
Tolerances:								
Comments and drawings: See PFD in Figure 6.1								

Figure A2-18: P-FV1012 Specification Sheet

Reactor							
Identification:	**Item**	Reactor					
	Item No		R-101		Date:	2-Mar-17	
	No. Required		1				
					By:	Caleb Woodall	
Function:	React ADA with HMDA to yield Nylon 6,6 oligomers						
Operation:	Continuous						
Materials Handled:	Feed 1:	Feed 2:	Feed 3:	Feed 4:	Product:	Vent:	
Quantity (lb/hr):	6904.85	6214.01	2374.3	414.49	10050.8	5856.77	
Composition:							
Adipic Acid	0	1	6.22E-05	trace	0.00069	2.5E-05	
Hexamethylenediamine	0.71502	0	0.002887	trace	0.00053	0.00117	
Water	0.28499	0	0.997048	1	0.03935	0.9988	
Nylon 6,6	0	0	0	trace	0.95942	trace	
Air	0	0	0	0	0	0	
Temperature (F)	350.33	350.33	357.024	539.33	431.33	431.33	
Design Data:	Duty: 8726270 Btu/hr						
	Volume: 63.5664 cuft						
	Temperature: 431.33 F						
	Pressure: 146.959 psia						
	Reactor Type: CSTR						
	Material of construction: Ni-Cr alloy						
Utilities: electricity							
Controls: Target specified temperature within 20F and specified pressure within 20 psia							
Tolerances:							
Comments and drawings: see PFD in Figure 6.1 and Aspen data in Appendix 1							

Figure A2-19: R-101 Specification Sheet

Reactor							
Identification:	**Item**	Reactor					
	Item No		R-102		Date:	2-Mar-17	
	No. Required		1				
					By:	Caleb Woodall	
Function:	React ADA with HMDA to yield high MW Nylon 6,6 polymer product						
Operation:	Continuous						
Materials Handled:	Feed 1:	Product:	Vent:				
Quantity (lb/hr):	10050.8	9636.27	414.494				
Composition:							
Adipic Acid	0.00069	1.38E-05	trace				
Hexamethylenediamine	0.00053	7.41E-06	trace				
Water	0.03935	0.001116	1				
Nylon 6,6	0.95942	0.998863	trace				
Air	0	0	0				
Temperature (F)	431.33	539.33	539.33				
Design Data:	Duty: 1046950 Btu/hr						
	Volume: 63.5664 cuft						
	Temperature: 539.33 F						
	Pressure: 14.6959 psia						
	Reactor Type: CSTR						
	Material of construction: Ni-Cr alloy						
Utilities: electricity							
Controls: Target specified temperature within 20F and specified pressure within 20 psia							
Tolerances:							
Comments and drawings: see PFD in Figure 6.1 and Aspen data in Appendix 1							

Figure A2-20: R-102 Specification Sheet

Enriching Column							
Identification:	**Item**	Enriching Column					
	Item No		T-101		Date:	2-Mar-17	
	No. Required		1				
					By:	Caleb Woodall	
Function:	Separate excess reactants from water byproduct stream						
Operation:	Continuous						
Materials Handled:	Feed:	Distillate:	Bottoms	Reflux:			
Quantity (lb/hr):	5856.77	6094.33	2374.3	2611.85			
Composition:							
Adipic Acid	2.5E-05	trace	6.2E-05	trace			
Hexamethylenediamine	0.00117	trace	0.00289	trace			
Water	0.9988	1	0.99705	1			
Nylon 6,6	trace	0	0	trace			
Air	0	0	0	0			
Temperature (F)	431.33	356.989	357.024	356.989			
Design Data:	Number of trays: 13						
	Pressure: 146.959 psia						
	Functional height: 26 ft						
	Material of construction: Ni-Cr alloy						
	Diameter: 1.3722 ft						
	Feed Stage: 13						
	Reflux ratio: 0.75			Tray spacing: 2 ft			
Utilities:							
Controls:							
Tolerances:							
Comments and drawings: see PFD in Figure 6.1 and column profiles in Appendix 1							

Figure A2-21: T-101 Specification Sheet

Process Vessel							
Identification:	**Item**	Vessel					
	Item No		V-101		Date:	2-Mar-17	
	No. Required		1				
					By:	Caleb Woodall	
Function:	Mix solid HMDA with liquid H2O to create HMDA solution						
Operation:	continuous						
Materials Handled:	Feed 1:	Feed 2:	Outlet:				
Quantity (lb/hr):	4937.02	1967.83	6904.85				
Composition:							
Adipic Acid	0	0	0				
Hexamethylenediamine	1	0	0.71501				
Water	0	1	0.28499				
Nylon 6,6	0	0	0				
Air	0	0	0				
Temperature (F)	77	77	77				
Design Data:	Volume: 0.0635664 cuft						
	Material of construction: Ni-Cr alloy						
	Height: 5 ft						
	Diameter: 4 ft						
Utilities:							
Controls:							
Tolerances:							
Comments and drawings: See PFD in Appendix Fig 6.1							

Figure A2-22: V-101 Specification Sheet

Appendix 3: Economic Spreadsheets

Table A3-1: Bare Module Cost Spreadsheet (1/2)

Equipment	Cbm eqn	Cbm (2016)	Cp0 k1	Cp0 K2	Cp0 k3	Capacity units A	A	Cp0	Fp C1	Fp C2	Fp C3
C-101	Cp0*(B1+B2*Fm*Fp)	$ 176,163.85	4.0336	0.2341	0.0497	m^2	150	60030.37	-0.125	0.15361	-0.02861
E-101		$ 467,424.98									
H-101a	Cp0*(B1+B2*Fm*Fp)	$ 172,608.40	4.8306	-0.8509	0.1634	m^2	5.03	20609.19	0.03881	-0.11272	0.08183
H-101b	-	-	-	-	-	-	-	-	-	-	-
H-101c	Cp0*Fbm*Fp*Ft	$ 1,912,162.06	7.3488	-1.1666	0.2028	kW	298.417	505557.4	0.1347	-0.2368	0.1021
H-102a	Cp0*(B1+B2*Fm*Fp)	$ 102,345.25	4.8306	-0.8509	0.1634	m^2	7.55	16199.52	0.03881	-0.11272	0.08183
H-102b	Cp0*(B1+B2*Fm*Fp)	$ 93,343.02	4.8306	-0.8509	0.1634	m^2	8.92	14774.62	0.03881	-0.11272	0.08183
H-102c	Cp0*Fbm*Fp*Ft	$ 1,892,614.33	7.3488	-1.1666	0.2028	kW	101.675	667185.6	0.1347	-0.2368	0.1021
PCH101A	Cp0*(B1+B2*Fm*Fp)	$ 16,881.53	3.4771	0.135	0.1438	kW	0.065533	3301.808	-0.245382	0.259016	-0.01363
PCH102A	Cp0*(B1+B2*Fm*Fp)	$ 25,310.27	3.4771	0.135	0.1438	kW	0.016383	4949.141	-0.245382	0.259016	-0.01363
PCH102B	Cp0*(B1+B2*Fm*Fp)	$ 25,315.08	3.4771	0.135	0.1438	kW	0.016383	4949.144	-0.245382	0.259016	-0.01363
PFH101A	Cp0*(B1+B2*Fm*Fp)	$ 37,221.57	3.4771	0.135	0.1438	kW	0.016242	4965.429	-0.245382	0.259016	-0.01363
PFH101C	Cp0*(B1+B2*Fm*Fp)	$ 37,015.11	3.4771	0.135	0.1438	kW	0.016242	4965.429	-0.245382	0.259016	-0.01363
PFH102A	Cp0*(B1+B2*Fm*Fp)	$ 20,742.47	3.4771	0.135	0.1438	kW	0.014617	5171.763	-0.245382	0.259016	-0.01363
PFH102B	Cp0*(B1+B2*Fm*Fp)	$ 20,709.70	3.4771	0.135	0.1438	kW	0.014617	5171.748	-0.245382	0.259016	-0.01363
PFH102C	Cp0*(B1+B2*Fm*Fp)	$ 20,681.27	3.4771	0.135	0.1438	kW	0.014617	5171.755	-0.245382	0.259016	-0.01363
PFR1011	Cp0*(B1+B2*Fm*Fp)	$ 34,565.53	3.4771	0.135	0.1438	kW	0.097452	3073.469	-0.245382	0.259016	-0.01363
PFR1012	Cp0*(B1+B2*Fm*Fp)	$ 15,995.57	3.4771	0.135	0.1438	kW	0.087702	3126.539	-0.245382	0.259016	-0.01363
PFV1012	Cp0*(B1+B2*Fm*Fp)	$ 35,389.42	3.4771	0.135	0.1438	kW	0.004629	8823.719	-0.245382	0.259016	-0.01363
R-101	Cp0*Fbm	$ 362,077.74	4.7116	0.4479	0.0004	m^3	1.8	66982.7	-	-	-
R-102	Cp0*Fbm	$ 362,077.74	4.7116	0.4479	0.0004	m^3	1.8	66982.7	-	-	-
S-101		$ 262,683.77	4.8509	-0.3973	0.1445	m^3	300	56677.47			
S-102		$ 262,683.77	4.8509	-0.3973	0.1445	m^3	300	56677.47			
S-103		$ 262,683.77	4.8509	-0.3973	0.1445	m^3	300	56677.47			
S-104		$ 367,806.37	4.8509	-0.3973	0.1445	m^3	600	72846.63			
T-101 Ni	Cp0*(B1+B2*Fm*Fp)	$ 63,454.00	3.4974	0.4485	0.1074	m^3	1.088819	3266.79	-	-	-
trays-sieve Ni	Cp0*Fbm*N*Fq	$ 106,403.16	2.9949	0.4465	0.3961	m^2	0.137394	802.3142	-	-	-
V-101 vertical ss	Cp0*(B1+B2*Fm*Fp)	$ 35,769.75	3.4974	0.4485	0.1074	m^3	1.8	4158.037	-	-	-

Table A3-2: Bare Module Cost Spreadsheet (2/2)

Equipment	P (bar)	D (m)	H (m)	Fp	Fp (vessel)	Fig A.18 ID	Fm	B1	B2	Fig A.19 ID	Fbm	N	Fq	Ft
C-101	10.1325	-	-	1.00126743	-	10	1	0.96	1.21	-	-	-	-	-
E-101														
H-101a	10.1325			1.019093141	-	6	2.7	1.63	1.66					
H-101b	-	-	-	-	-	-	-	-	-	-	-	-	-	
H-101c	10.1325	-	-	0.999578658	-	-	-	-	-	55	2.8			1
H-102a	10.1325			1.019093141	-	4	1.8	1.63	1.66					
H-102b	10.1325			1.019093141	-	4	1.8	1.63	1.66					
H-102c	10.1325	-	-	0.999578658	-	-	-	-	-	53	2.1			1
PCH101A	10.0772	-	-	1.001792751	-	32	1.4	1.89	1.35	-	-	-	-	-
PCH102A	10.0986	-	-	1.00228517	-	32	1.4	1.89	1.35	-	-	-	-	-
PCH102B	10.1151	-	-	1.002664255	-	32	1.4	1.89	1.35	-	-	-	-	-
PFH101A	1.01325	-	-	0.570293273	-	35	4.75	1.89	1.35	-	-	-	-	-
PFH101C	0.980737	-	-	0.565495307	-	35	4.75	1.89	1.35	-	-	-	-	-
PFH102A	1.01325	-	-	0.570293273	-	32	1.4	1.89	1.35	-	-	-	-	-
PFH102B	0.996368	-	-	0.567817354	-	32	1.4	1.89	1.35	-	-	-	-	-
PFH102C	0.98186	-	-	0.5656631	-	32	1.4	1.89	1.35	-	-	-	-	-
PFR1011	10.1325	-	-	1.003063469	-	35	4.75	1.89	1.35	-	-	-	-	-
PFR1012	10.1325	-	-	1.003063469	-	32	1.4	1.89	1.35	-	-	-	-	-
PFV1012	1.01325	-	-	0.570293273	-	32	1.4	1.89	1.35	-	-	-	-	-
R-101	-	1	2.291831181	-	-	-	-	-	-	-	4	-	-	
R-102	-	1	2.291831181	-	-	-	-	-	-	-	4	-	-	
S-101		8.305661184			1.276053048	18	1	1.49	1.52					
S-102		8.305661184			1.276053048	18	1	1.49	1.52					
S-103		8.305661184			1.276053048	18	1	1.49	1.52					
S-104		10.46447736			1.477765571	18	1	1.49	1.52					
T-101 Ni	10.1325	0.418252656	7.9248		0.938195798	22	7.1	2.25	1.82					
trays-sieve Ni		0.418252656	-	-	-	-	-	-	-	62	5.6	12	1.460365533	
V-101 vertical ss	1.013	1.2192	1.541816595	-	0.729481037	20	3.1	2.25	1.82					

Table A3-3 Discounted Cash Flow Rate of Return Calculation

Discount Rate	Taxation Rate	FCI	FCI 1st year	Land	Working Capital	Revenue	ComD	Salvage Value	Project Life	Start up Year
8.94%	48.89%	$ 10.51	$ 7.01	$ 4.20	$ 101.23	$ 114.04	$ 100.18	$ -	10	2.00

Yr	Investment	Land	Working Capital	Depreciation	FCI-dk	Revenue	ComD	After taxes	Cash Flow	Cumulative Cash Flow	Discounted Cash Flow	Discounted Cumulative Cash Flow	Positive Cumulative Discounted	Negative Cumulative Discounted
0	$ -	$ (4.20)	$ -	$ -	$ 10.51	$ -	$ -	$ -	$ (4.20)	$ (4.20)	$ (4.20)	$ (4.20)	$ -	$ (4.20)
1	$ (7.01)	$ -	$ -	$ -	$ 10.51	$ -	$ -	$ -	$ (7.01)	$ (11.21)	$ (6.43)	$ (10.63)	$ -	$ (10.63)
2	$ (104.73)	$ -	$ (101.23)	$ -	$ 10.51	$ -	$ -	$ -	$ (104.73)	$ (115.94)	$ (88.25)	$ (98.89)	$ -	$ (98.89)
3	$ -	$ -	$ -	$ 2.10	$ 8.41	$ 114.04	$ 100.18	$ 8.11	$ 8.11	$ (107.83)	$ 6.27	$ (92.61)	$ 6.27	$ (98.89)
4	$ -	$ -	$ -	$ 3.36	$ 5.05	$ 114.04	$ 100.18	$ 8.73	$ 8.73	$ (99.10)	$ 6.20	$ (86.42)	$ 12.47	$ (98.89)
5	$ -	$ -	$ -	$ 2.02	$ 3.03	$ 114.04	$ 100.18	$ 8.07	$ 8.07	$ (91.03)	$ 5.26	$ (81.15)	$ 17.73	$ (98.89)
6	$ -	$ -	$ -	$ 1.21	$ 1.82	$ 114.04	$ 100.18	$ 7.68	$ 7.68	$ (83.36)	$ 4.59	$ (76.56)	$ 22.33	$ (98.89)
7	$ -	$ -	$ -	$ 1.21	$ 0.61	$ 114.04	$ 100.18	$ 7.68	$ 7.68	$ (75.68)	$ 4.22	$ (72.35)	$ 26.54	$ (98.89)
8	$ -	$ -	$ -	$ 0.61	$ 0.00	$ 114.04	$ 100.18	$ 7.38	$ 7.38	$ (68.30)	$ 3.72	$ (68.63)	$ 30.26	$ (98.89)
9	$ -	$ -	$ -	$ -	$ -	$ 114.04	$ 100.18	$ 7.08	$ 7.08	$ (61.22)	$ 3.28	$ (65.35)	$ 33.54	$ (98.89)
10	$ -	$ -	$ -	$ -	$ -	$ 114.04	$ 100.18	$ 7.08	$ 7.08	$ (54.13)	$ 3.01	$ (62.34)	$ 36.55	$ (98.89)
11	$ -	$ -	$ -	$ -	$ -	$ 114.04	$ 100.18	$ 7.08	$ 7.08	$ (47.05)	$ 2.76	$ (59.57)	$ 39.31	$ (98.89)
12	$ 105.43	$ -	$ 101.23	$ -	$ -	$ 219.46	$ 100.18	$ 60.97	$ 166.40	$ 119.35	$ 59.57	$ (0.00)	$ 98.89	$ (98.89)

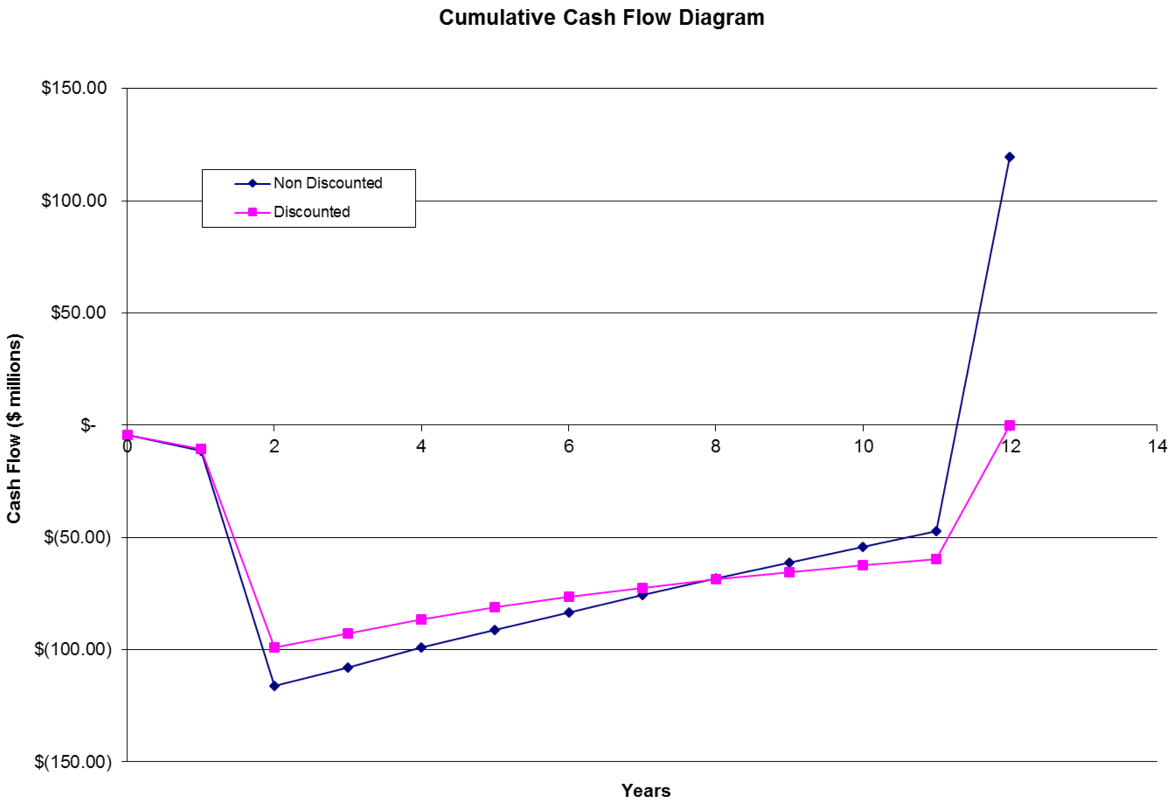


Figure A3-1: Cumulative Cash Flow Diagram

Appendix 4: Modified PFDs

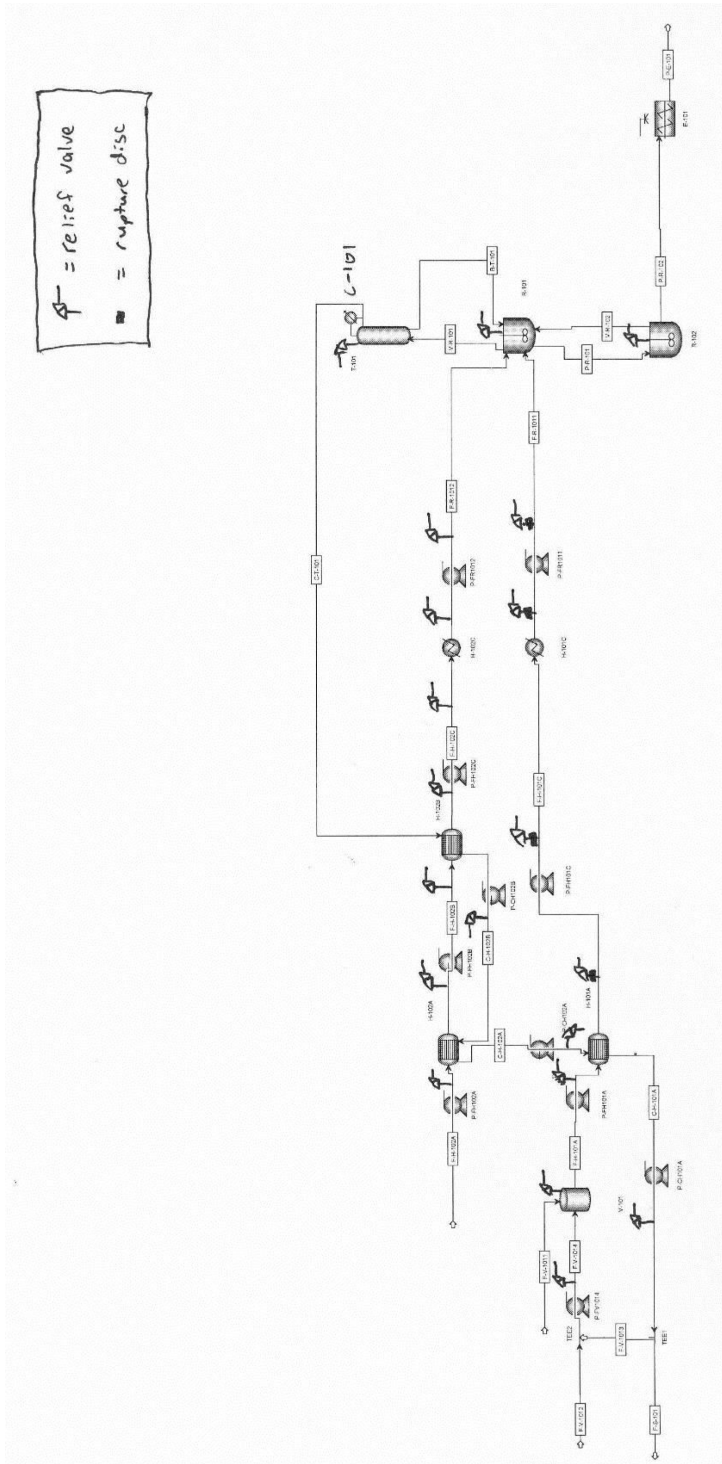


Figure A4-1: Relief Device Locations

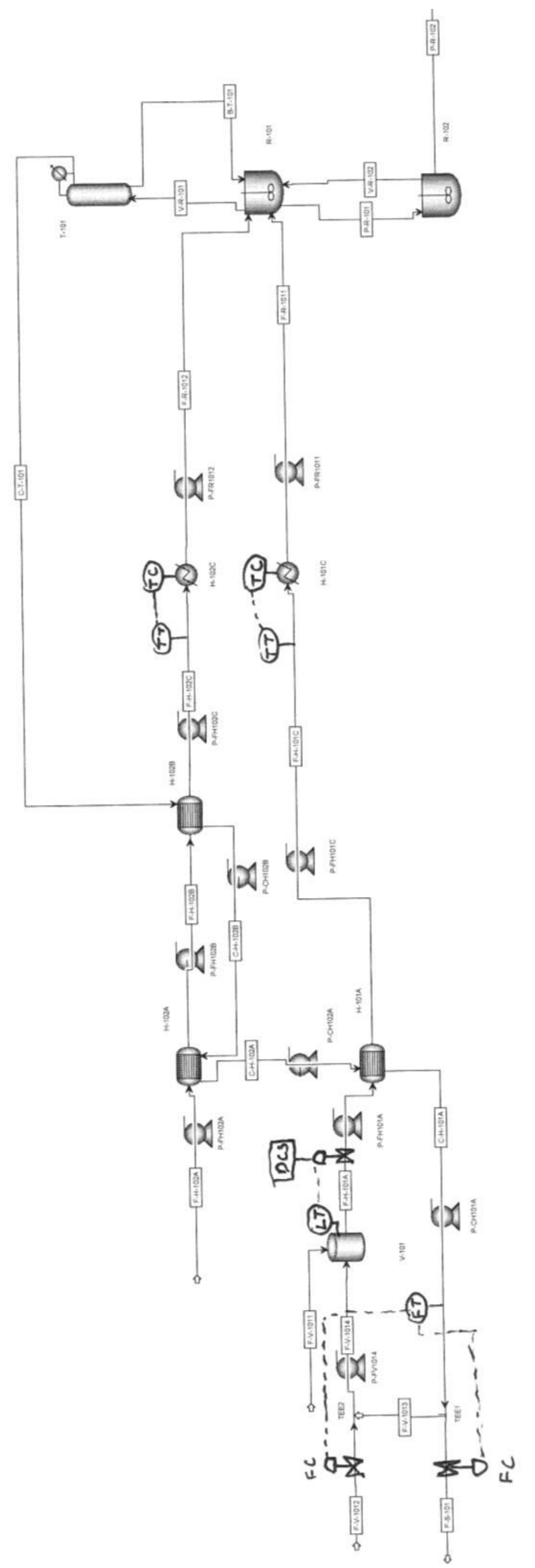


Figure A4-2: Process Control Scheme

Print

CAMEO Chemicals

Substances In This Report

1. HEXAMETHYLENEDIAMINE, SOLUTION
2. ADIPIC ACID
3. WATER

Contents

This report contains:

- Reaction hazard predictions associated with mixing these substances.
- Detailed information from the datasheet for each substance.

Chemical Reactivity

Substances In The Mix

1. HEXAMETHYLENEDIAMINE, SOLUTION
2. ADIPIC ACID
3. WATER

Summary of Hazard Predictions (for all pairs of sunstances)

- **Corrosive:** Reaction products may be corrosive
- **Generates gas:** Reaction liberates gaseous products and may cause pressurization
- **Generates heat:** Exothermic reaction at ambient temperatures (releases heat)
- **Toxic:** Reaction products may be toxic

Summary of Gas Predictions (for all pairs of sunstances)

May produce the following gases:

- Acid Fumes
- Base Fumes

Hazard Predictions (for each pair of substances)

ADIPIC ACID *mixed with*
HEXAMETHYLENEDIAMINE, SOLUTION

- **Corrosive:** Reaction products may be corrosive
- **Generates gas:** Reaction liberates gaseous products and may cause pressurization
- **Generates heat:** Exothermic reaction at ambient temperatures (releases heat)
- **Toxic:** Reaction products may be toxic
- **May produce the following gases:**
    - Acid Fumes
    - Base Fumes

WATER *mixed with*
HEXAMETHYLENEDIAMINE, SOLUTION

- **Corrosive:** Reaction products may be corrosive

WATER *mixed with*
ADIPIC ACID

- No known hazardous reaction

Chemical Datasheet

HEXAMETHYLENEDIAMINE, SOLUTION

Chemical Identifiers

CAS Number	UN/NA Number	DOT Hazard Label	USCG CHRIS Code
124-09-4	1783	Corrosive	none

NFPA 704

data unavailable

NIOSH Pocket Guide	International Chem Safety Card
none	HEXAMETHYLENEDIAMINE

General Description

A clear colorless liquid. Burns although some effort is required to ignite. Soluble in water. Corrosive to metals and tissue. Produces toxic oxides of nitrogen during combustion. Used to make nylon.

Hazards

Reactivity Alerts

none

Air & Water Reactions

Water soluble.

Fire Hazard

Excerpt from ERG Guide 153 [Substances - Toxic and/or Corrosive (Combustible)]:

Combustible material: may burn but does not ignite readily. When heated, vapors may form explosive mixtures with air: indoors, outdoors and sewers explosion hazards. Those substances designated with a (P) may polymerize explosively when heated or involved in a fire. Contact with metals may evolve flammable hydrogen gas. Containers may explode when heated. Runoff may pollute waterways. Substance may be transported in a molten form. (ERG, 2016)

Health Hazard

Excerpt from ERG Guide 153 [Substances - Toxic and/or Corrosive (Combustible)]:

TOXIC; inhalation, ingestion or skin contact with material may cause severe injury or death. Contact with molten substance may cause severe burns to skin and eyes. Avoid any skin contact. Effects of contact or inhalation may be delayed. Fire may produce irritating, corrosive and/or toxic gases. Runoff from fire control or dilution water may be corrosive and/or toxic and cause pollution. (ERG, 2016)

Reactivity Profile

HEXAMETHYLENEDIAMINE is hygroscopic. Can react with strong oxidizing materials. Incompatible with acids, acid chlorides and acid anhydrides. Also incompatible with ketones, aldehydes, nitrates, phenols, isocyanates, monomers and chlorinated compounds (NTP, 1992).

Belongs to the Following Reactive Group(s)

- Amines, Phosphines, and Pyridines
- Water and Aqueous Solutions

Potentially Incompatible Absorbents

Use caution: Liquids with this reactive group classification have been known to react with the absorbent listed below.

- Mineral-Based & Clay-Based Absorbents

Response Recommendations

Isolation and Evacuation

Excerpt from ERG Guide 153 [Substances - Toxic and/or Corrosive (Combustible)]:

As an immediate precautionary measure, isolate spill or leak area in all directions for at least 50 meters (150 feet) for liquids and at least 25 meters (75 feet) for solids.

SPILL: Increase, in the downwind direction, as necessary, the isolation distance shown above.

FIRE: If tank, rail car or tank truck is involved in a fire, ISOLATE for 800 meters (1/2 mile) in all directions; also, consider initial evacuation for 800 meters (1/2 mile) in all directions. (ERG, 2016)

Firefighting

Excerpt from ERG Guide 153 [Substances - Toxic and/or Corrosive (Combustible)]:

SMALL FIRE: Dry chemical, CO2 or water spray.

LARGE FIRE: Dry chemical, CO2, alcohol-resistant foam or water spray. Move containers from fire area if you can do it without risk. Dike fire-control water for later disposal; do not scatter the material.

FIRE INVOLVING TANKS OR CAR/TRAILER LOADS: Fight fire from maximum distance or use unmanned hose holders or monitor nozzles. Do not get water inside containers. Cool containers with flooding quantities of water until well after fire is out. Withdraw immediately in case of rising sound from venting safety devices or discoloration of tank. ALWAYS stay away from tanks engulfed in fire. (ERG, 2016)

Non-Fire Response

Excerpt from ERG Guide 153 [Substances - Toxic and/or Corrosive (Combustible)]:

ELIMINATE all ignition sources (no smoking, flares, sparks or flames in immediate area). Do not touch damaged containers or spilled material unless wearing appropriate protective clothing. Stop leak if you can do it without risk. Prevent entry into waterways, sewers, basements or confined areas. Absorb or cover with dry earth, sand or other non-combustible material and transfer to containers. DO NOT GET WATER INSIDE CONTAINERS. (ERG, 2016)

Protective Clothing

Excerpt from GUIDE 153 [Substances - Toxic and/or Corrosive (Combustible)]:

Wear positive pressure self-contained breathing apparatus (SCBA). Wear chemical protective clothing that is specifically recommended by the manufacturer. It may provide little or no thermal protection. Structural firefighters' protective clothing provides limited protection in fire situations ONLY; it is not effective in spill situations where direct contact with the substance is possible. (ERG, 2016)

DuPont Tychem® Suit Fabrics

Normalized Breakthrough Times (in Minutes)

Chemical	CAS Number	State	QC	SL	TF	TP	C3	BR	RC	TK	RF
Hexamethylenediamine, 1,6- (45° C)	124-09-4	Liquid			>480	>480		>480	>480	>480	>480
Hexamethylenediamine, 1,6- (50° C)	124-09-4	Liquid		80			45		80		

> indicates greater than.
A blank cell indicates the fabric has not been tested. The fabric may or may not offer barrier.

Special Warnings from DuPont

1. Serged and bound seams are degraded by some hazardous liquid chemicals, such as strong acids, and should not be worn when these chemicals are present.

2. CAUTION: This information is based upon technical data that DuPont believes to be reliable. It is subject to revision as additional knowledge and experience are gained. DuPont makes no guarantee of results and assumes no obligation or liability...

(DuPont, 2016)

First Aid

Excerpt from ERG Guide 153 [Substances - Toxic and/or Corrosive (Combustible)]:

Ensure that medical personnel are aware of the material(s) involved and take precautions to protect themselves. Move victim to fresh air. Call 911 or emergency medical service. Give artificial respiration if victim is not breathing. Do not use mouth-to-mouth method if victim ingested or inhaled the substance; give artificial respiration with the aid of a pocket mask equipped with a one-way valve or other proper respiratory medical device. Administer oxygen if breathing is difficult. Remove and isolate contaminated clothing and shoes. In case of contact with substance, immediately flush skin or eyes with running water for at least 20 minutes. For minor skin contact, avoid spreading material on unaffected skin. Keep victim calm and warm. Effects of exposure (inhalation, ingestion or skin contact) to substance may be delayed. (ERG, 2016)

Physical Properties

Chemical Formula: $C6H16N2$ (aqueous)

Flash Point: data unavailable

Lower Explosive Limit (LEL): data unavailable

Upper Explosive Limit (UEL): data unavailable

Autoignition Temperature: data unavailable

Melting Point: data unavailable

Vapor Pressure: data unavailable

Vapor Density (Relative to Air): data unavailable

Specific Gravity: data unavailable

Boiling Point: data unavailable

Molecular Weight: data unavailable

Water Solubility: data unavailable

Ionization Potential: data unavailable

IDLH: data unavailable

AEGLs (Acute Exposure Guideline Levels)

No AEGL information available.

ERPGs (Emergency Response Planning Guidelines)

No ERPG information available.

PACs (Protective Action Criteria)

No PAC information available.

Regulatory Information

EPA Consolidated List of Lists

No regulatory information available.

DHS Chemical Facility Anti-Terrorism Standards (CFATS)

No regulatory information available.

Chemical Datasheet

ADIPIC ACID

Chemical Identifiers

CAS Number	UN/NA Number	DOT Hazard Label	USCG CHRIS Code
124-04-9	3077	Class 9	ADA

NFPA 704

Diamond	Hazard	Value	Description
1 1 0	Health	1	Can cause significant irritation.
	Flammability	1	Must be preheated before ignition can occur.
	Instability	0	Normally stable, even under fire conditions.
	Special		

(NFPA, 2010)

NIOSH Pocket Guide	International Chem Safety Card
none	ADIPIC ACID

General Description

Adipic acid is a white crystalline solid. It is insoluble in water. The primary hazard is the threat to the environment. Immediate steps should be taken to limit its spread to the environment. It is used to make plastics and foams and for other uses.

Hazards

Reactivity Alerts

none

Air & Water Reactions

Dust may form explosive mixture with air (USCG, 1999). Insoluble in water.

Fire Hazard

Behavior in Fire: Melts and may decompose to give volatile acidic vapors of valeric acid and other substances. Dust may form explosive mixture with air. (USCG, 1999)

Health Hazard

Inhalation of vapor irritates mucous membranes of the nose and lungs, causing coughing and sneezing. Contact with liquid irritates eyes and has a pronounced drying effect on the skin; may produce dermatitis. (USCG, 1999)

Reactivity Profile

ADIPIC ACID is a carboxylic acid. Carboxylic acids donate hydrogen ions if a base is present to accept them. They react in this way with all bases, both organic (for example, the amines) and inorganic. Their reactions with bases, called "neutralizations", are accompanied by the evolution of substantial amounts of heat. Neutralization between an acid and a base produces water plus a salt. Carboxylic acids with six or fewer carbon atoms are freely or moderately soluble in water; those with more than six carbons are slightly soluble in water. Soluble carboxylic acid dissociate to an extent in water to yield hydrogen ions. The pH of solutions of carboxylic acids is therefore less than 7.0. Many insoluble carboxylic acids react rapidly with aqueous solutions containing a chemical base and dissolve as the neutralization generates a soluble salt. Carboxylic acids in aqueous solution and liquid or molten carboxylic acids can react with active metals to form gaseous hydrogen and a metal salt. Such reactions occur in principle for solid carboxylic acids as well, but are slow if the solid acid remains dry. Even "insoluble" carboxylic acids may absorb enough water from the air and dissolve sufficiently in it to corrode or dissolve iron, steel, and aluminum parts and containers. Carboxylic acids, like other acids, react with cyanide salts to generate gaseous hydrogen cyanide. The reaction is slower for dry, solid carboxylic acids. Insoluble carboxylic acids react with solutions of cyanides to cause the release of gaseous hydrogen cyanide. Flammable and/or toxic gases and heat are generated by the reaction of carboxylic acids with diazo compounds, dithiocarbamates, isocyanates, mercaptans, nitrides, and sulfides. Carboxylic acids, especially in aqueous solution, also react with sulfites, nitrites, thiosulfates (to give H_2S and SO_3), dithionites (SO_2), to generate flammable and/or toxic gases and heat. Their reaction with carbonates and bicarbonates generates a harmless gas (carbon dioxide) but still heat. Like other organic compounds, carboxylic acids can be oxidized by strong oxidizing agents and reduced by strong reducing agents. These reactions generate heat. A wide variety of products is possible. Like other acids, carboxylic acids may initiate polymerization reactions; like other acids, they often catalyze (increase the rate of) chemical reactions. Behavior in Fire: Melts and may decompose to give volatile acidic vapors of valeric acid and other substances.

Belongs to the Following Reactive Group(s)

- Acids, Carboxylic

Potentially Incompatible Absorbents

No information available.

Response Recommendations

Isolation and Evacuation

Excerpt from ERG Guide 171 [Substances (Low to Moderate Hazard)]:

As an immediate precautionary measure, isolate spill or leak area in all directions for at least 50 meters (150 feet) for liquids and at least 25 meters (75 feet) for solids.

SPILL: Increase, in the downwind direction, as necessary, the isolation distance shown above.

FIRE: If tank, rail car or tank truck is involved in a fire, ISOLATE for 800 meters (1/2 mile) in all directions; also, consider initial evacuation for 800 meters (1/2 mile) in all directions. (ERG, 2016)

Firefighting

Excerpt from ERG Guide 171 [Substances (Low to Moderate Hazard)]:

SMALL FIRE: Dry chemical, CO_2, water spray or regular foam.

LARGE FIRE: Water spray, fog or regular foam. Do not scatter spilled material with high-pressure water streams. Move containers from fire area if you can do it without risk. Dike fire-control water for later disposal.

FIRE INVOLVING TANKS: Cool containers with flooding quantities of water until well after fire is out. Withdraw immediately in case of rising sound from venting safety devices or discoloration of tank. ALWAYS stay away from tanks engulfed in fire. (ERG, 2016)

Non-Fire Response

Excerpt from ERG Guide 171 [Substances (Low to Moderate Hazard)]:

Do not touch or walk through spilled material. Stop leak if you can do it without risk. Prevent dust cloud. Avoid inhalation of asbestos dust.

SMALL DRY SPILL: With clean shovel, place material into clean, dry container and cover loosely; move containers from spill area.

SMALL SPILL: Pick up with sand or other non-combustible absorbent material and place into containers for later disposal.

LARGE SPILL: Dike far ahead of liquid spill for later disposal. Cover powder spill with plastic sheet or tarp to minimize spreading. Prevent entry into waterways, sewers, basements or confined areas. (ERG, 2016)

Protective Clothing

Normal protection against exposure to finely divided organic solids (rubber gloves, plastic goggles) (USCG, 1999)

DuPont Tychem® Suit Fabrics

No information available.

First Aid

INHALATION: remove victim to fresh air; get medical attention if irritation persists.

EYES: flush with water for at least 15 min.

SKIN: flush with water. (USCG, 1999)

Physical Properties

Chemical Formula: $C_6H_{10}O_4$

Flash Point: 376 ° F Combustible solid (USCG, 1999)

Lower Explosive Limit (LEL): 15 mg/l (dust) (USCG, 1999)

Upper Explosive Limit (UEL): 10 to 15 mg/l (dust) (USCG, 1999)

Autoignition Temperature: 788° F; 450° F (USCG, 1999)

Melting Point: 304 ° F (USCG, 1999)

Vapor Pressure: data unavailable

Vapor Density (Relative to Air): data unavailable

Specific Gravity: 1.36 at 68 ° F (USCG, 1999)

Boiling Point: data unavailable

Molecular Weight: 146.1 (USCG, 1999)

Water Solubility: data unavailable

Ionization Potential: data unavailable

IDLH: data unavailable

AEGLs (Acute Exposure Guideline Levels)

No AEGL information available.

ERPGs (Emergency Response Planning Guidelines)

No ERPG information available.

PACs (Protective Action Criteria)

No PAC information available.

Regulatory Information

EPA Consolidated List of Lists

Regulatory Name	CAS Number/ 313 Category Code	EPCRA 302 EHS TPQ	EPCRA 304 EHS RQ	CERCLA RQ	EPCRA 313 TRI	RCRA Code	CAA 112(r) RMP TQ
Adipic acid	124-04-9			5000 pounds			

(EPA List of Lists, 2015)

DHS Chemical Facility Anti-Terrorism Standards (CFATS)

No regulatory information available.

Chemical Datasheet

WATER

Chemical Identifiers

CAS Number	UN/NA Number	DOT Hazard Label	USCG CHRIS Code
7732-18-5	none	data unavailable	none

NFPA 704

data unavailable

NIOSH Pocket Guide	International Chem Safety Card
none	none

General Description

A clear, nontoxic liquid composed of hydrogen and oxygen, essential for life and the most widely used solvent. Include water in a mixture to learn how it could react with other chemicals in the mixture.

Hazards

Reactivity Alerts

none

Air & Water Reactions

No rapid reaction with air. No rapid reaction with water.

Fire Hazard

No information available.

Health Hazard

Water itself is nontoxic and is in fact essential for life. Solutes dissolved in water may be toxic, but those interactions are covered by the reactive groups that the solute belongs to.

Reactivity Profile

Water reacts with many substances, including but not limited to alkali metals, hydrides, strong halogenating agents, and chlorosilanes. These reactions can be hazardous and may result in flammable or toxic gas production, or generation of excessive heat that may cause pressurization to occur. Another reactive hazard is heat of mixing. Mixing substances such as sulfuric acid or sodium hydroxide with water may generate significant heat. Additionally, water is a good solvent for polar molecules, so it can form aqueous solutions if it comes into contact with such molecules.

Belongs to the Following Reactive Group(s)

- Water and Aqueous Solutions

Potentially Incompatible Absorbents

No information available.

Response Recommendations

Isolation and Evacuation

No information available.

Firefighting

No information available.

Non-Fire Response

No information available.

Protective Clothing

No information available.

DuPont Tychem® Suit Fabrics

No information available.

First Aid

No information available.

Physical Properties

Chemical Formula: H2O

Flash Point: data unavailable

Lower Explosive Limit (LEL): data unavailable

Upper Explosive Limit (UEL): data unavailable

Autoignition Temperature: data unavailable

Melting Point: 32 ° F

Vapor Pressure: data unavailable

Vapor Density (Relative to Air): data unavailable

Specific Gravity: 1

Boiling Point: 212 ° F at 760 mm Hg

Molecular Weight: data unavailable

Water Solubility: data unavailable

Ionization Potential: data unavailable

IDLH: data unavailable

AEGLs (Acute Exposure Guideline Levels)

No AEGL information available.

ERPGs (Emergency Response Planning Guidelines)

No ERPG information available.

PACs (Protective Action Criteria)

No PAC information available.

Regulatory Information

EPA Consolidated List of Lists

No regulatory information available.

DHS Chemical Facility Anti-Terrorism Standards (CFATS)

No regulatory information available.