Polymers, Inc.
Calvert City, Kentucky
Project Manager

To Whom It May Concern:

Our team has submitted our optimized design and financial projections for a grassroots nylon 6,6 manufacturing facility in Calvert City, Kentucky.

We have submitted a spiral-bound document containing the main body of our report, our process flow diagrams with control scheme, our equipment and financial tables, and an appendix containing any other relevant material to this project.

Per your request, economic analysis has been performed over the standard ten-year project life in order to identify the most profitable nylon 6,6 manufacturing process. We have closely examined different methods of nylon 6,6 production and have concluded that a melt-phase polymerization process resulting in nylon pellets is the most attractive choice from an economic, safety, and feasibility standpoint. This process has been optimized, a control strategy has been created, and health, safety, and the environment has been extensively considered.

We conclude that this process will require a capital investment of $2.26 million. Full-capacity annual operating costs will be $2.34 million. The payback period is 0.337 years and the discounted cash flow rate of return over a ten-year project life assuming a 15% internal rate of return is 333%.

If you have any other questions, please feel free to contact us.

Sincerely,

Process Engineering Team
Travis Diamond
Jacquelyn Lane
Dylan Oney
Nate Roper

9 March 2017

MANUFACTURING FACILITY FOR NYLON 6,6

AIChE Student Design Competition

March 9, 2017

EXECUTIVE SUMMARY

The nylon 6,6 polymerization process contained herein was made in accordance with the problem statement and standards put forth in the 2017 AIChE Student Design Competition. This design was created using Aspen Plus software, which was rigorously compared to an empirical model created in Microsoft Excel to ensure its validity. Various process design elements were considered, but the ultimate design was selected due to its merits from safety, economic, and practicality standpoints. The proposed design for converting aqueous adipic acid (ADA) and hexamethylenediamine (HMDA) utilizes two reaction stages in order to achieve 90% conversion of the feed materials. In order to promote high conversion of feed and keep the nylon in the melt phase, high temperatures and pressures are necessary. Regular maintenance and inspection will help to ensure that no equipment is damaged. These risks and others such as startup and shutdown, chemical hazards, loss of containment, emissions to air, and waste management have been carefully identified and mitigated through a series of active and passive safety measures.

Although spun nylon fiber has a higher sale price, it adds considerable complexity to the process and thus is inherently less safe. Instead, the nylon product is shaped into pellets using a pelletizer. This product will be sold for an estimated $1.18/lb based upon nylon market projections. In the future, it would be easy to add the equipment to turn the nylon pellets into fiber if further analysis deems it beneficial.

It was requested to design the process so that the process output could be turned down to 67% of its full capacity should demand for nylon 6,6 decrease. The process control scheme aids in this feat; by changing the temperature in the second reaction stage, the process will output the same quality nylon product at a 67% capacity.

The capital cost necessary to construct this grassroots process facility in Calvert City, Kentucky is estimated to be $2.26 million. A total of 29 operators will be needed for an annual cost of $1.89 million. If it is assumed that the plan is running at full capacity for a year, the annual utility costs are estimated to be around $450,000. However, the payback period is only 0.337 years as the project annual revenue is $106 million annually. Even if the case was run at 67% of the capacity, the process would still be immensely profitable. See the table below for more details.

	Capital costs	**Utility costs**	**Labor costs**	**Revenue**
Full Capacity case	$(2,260,000)	$(450,000)	$(1,890,000)	$106,000,000
Turndown case	$(2,260,000)	$(310,000)	$(1,890,000)	$70,000,000

Based upon these estimates and assuming a 10-year project life with a 40% tax rate, economic analysis was performed.

	NPV	**DCFROR**	**PWC**	**Payback Period**
Full Capacity case	$34,300,000	333%	$(2,370,000)	0.337 years
Turndown case	$20,300,000	212%	$(2,370,000)	0.514 years

Based upon these economic analyses, it has been concluded that this process is very desirable. It is recommended to move into the detailed design stage.

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INTRODUCTION

For this project, the design team is tasked with the preliminary design, optimization, and economic analysis of a nylon 6,6 production process from adipic acid (ADA) and hexamethylenediamine (HMDA) feed. This grassroots facility is to be located in the Calvert City, Kentucky area. In order to meet the growing nylon demand in the United States, this process must produce 85 million pounds of nylon 6,6 per year. In the instance that demand slows for any period of time, this process must also be able to be turned down to 67% of its full capacity. Safety and sustainability are of the utmost importance in the design of this production facility. Safety measures and a control strategy must be designed and discussed. The team is able to select the type of nylon production process (aqueous or melt phase polymerization) as well as the form in which the nylon (fiber or pellets) is sold. In-depth scientific research, computer-based process modeling, safety considerations, and economic analysis have been used to make each decision about the process. A discussion of each of these design considerations can be found in the body of this report.

Nylon 6,6 (also called nylon 66, polyamide 66, and PA 66) is a very versatile and widely-used polymer as it can be made to behave as both a plastic and a synthetic fiber. It was first created in 1934 in the laboratory of Wallace Hume Carothers, the father of synthetic polymer science. Donald Coffman, a member of Carothers' team pulled a sample of the fiber from an adipic acid and HMDA combination experiment. It was noted that this fiber was strong, elastic, and insoluble with a high melt temperature. This fiber came to be known as polyamide 66 because each carbon-containing unit was composed of six carbons. DuPont decided to manufacture these fibers under the name "Nuron", but was soon renamed to "Nylon" as it is known today. When it first hit the market, nylon was used for women's hosiery because of its high stretch and silk-like feel and appearance. By late 1941, nylon was used almost exclusively for military parachutes and harnesses during World War II.[1] Over the years, nylon 6,6 grew in popularity for clothing and home furnishings such as carpets and upholstery.[2] Most carpets are composed of nylon fiber because of its high abrasion resistance and ease of dyeing. Nylon fibers can also be found in toothbrush bristles and spandex-containing clothing like swimsuits and athletic shoes. Nylon 6,6 is often used in the rubber industry in the form of conveyer belts and tires due to its high melting point, dimensional stability, and moisture resistivity. Heavier aircraft and off-road vehicles contain nylon-reinforced tires, which results in safer air

[1] Carraher, Charles E. *Carraher's Polymer Chemistry*. 9th ed, pg 8-9

[2] Nexant CHEMSYSTEMS. "Nylon 6 and Nylon 6,6 Report Abstract." Web.

landings and road travel.[3] Recently, however, a higher proportion of nylon has been manufactured as engineering thermoplastics due to its broad range of useful properties such as chemical resistance, high melting point, and toughness which make it particularly well-suited for the electronics and automotive industries. Nylon thermoplastics are advantageous to use over metal parts due to their functional mechanical properties. These thermoplastics are lighter and less expensive than metal parts which aids in meeting environmental regulations for automotive emissions.[4] Some examples of thermoplastic applications include drive shafts, bearings, nuts, bolts, and even wheels.[5] According to the American Plastics Council, the 2010 US production of nylon thermoplastics was 1 trillion pounds and the production of nylon fiber was 1.3 trillion pounds.[6]

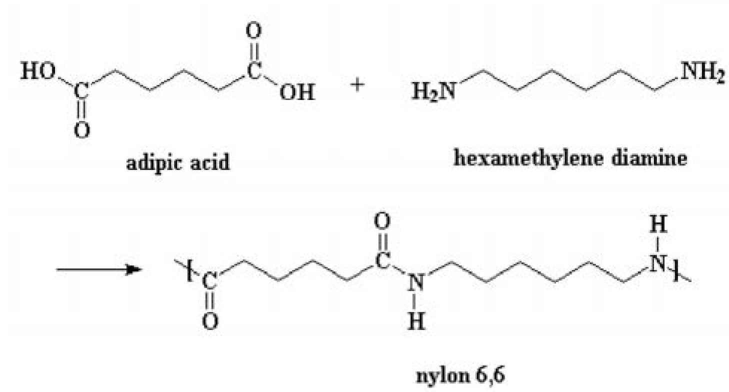

Figure 1: Nylon 6,6 condensation polymerization reaction

Nylon 6,6 is a polyamide, meaning that it is a long, synthetic chain with recurring amide groups that can alter its structural orientation to produce a strong, versatile filament.[7] This polyamide is produced through a step-growth polymerization condensation reaction of aqueous adipic acid and HMDA. In the absence of a catalyst, the step-growth process initiates when one adipic acid molecule donates a proton to the carbonyl oxygen on another adipic acid molecule. This protonated oxygen is now ready to react with the nitrogen of the HMDA creating an ammonium intermediate. After another electron rearrangement, the amide dimer is formed while a water molecule is expelled and regeneration of the acid catalyst occurs. This is a reversible reaction, thus the expelled water molecules must be boiled off at high temperatures in order to increase conversion. Dimers can react

[3] Bagwala, Mufaddal. "Preparation, Properties and Application of Nylon 6,6 Fibers." Web. pg. 3-4, 9-10
[4] Nexant. pg. 1-2
[5] Bagwala. pg. 10
[6] Carraher, pg. 15
[7] Bagwala. pg. 1-2

with other dimers or diacids to form trimers, tetramers, and oligomers. Longer such chains continue to form as water is expelled until the desired degree of polymerization or molecular weight for nylon 6,6 is achieved. Running this process at high temperatures and low pressures or under a slight vacuum at later stages aids in water removal. The reaction is terminated when water is no longer removed.[8]

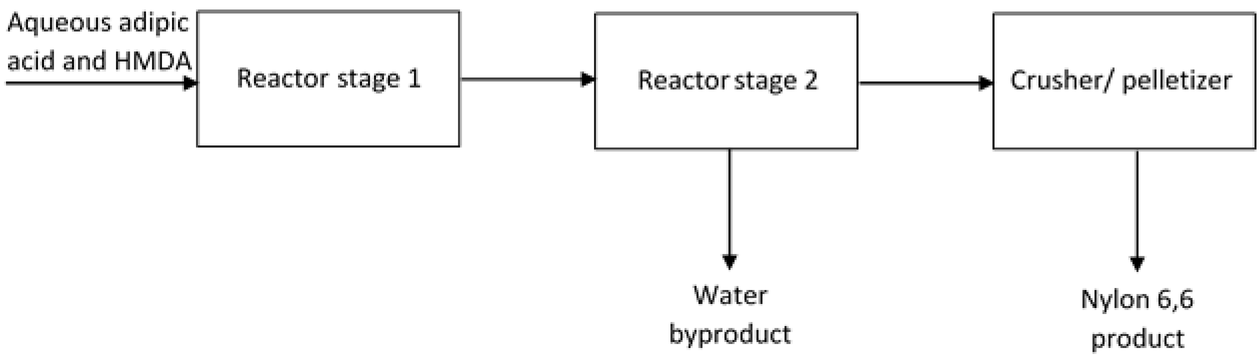

Figure 2: Block flow diagram for nylon 6,6 polymerization process

In order to create a continuous nylon 6,6 polymerization process, at least two reaction stages are necessary (see Figure 2). The aqueous adipic acid and HMDA feed must be mixed and reacted at high temperatures and pressures in either a continuous stirred tank reactor (CSTR) or plug flow reactor (PFR) in order to begin condensation polymerization. Water is formed as a byproduct of this reversible reaction and must be removed in order for the reaction to proceed. The pressure of the nylon solution needs to be lowered while keeping temperatures high in order to evaporate water from the solution. Pressure is reduced either through a series of throttling valves or the solution is flashed into a second reactor. This second reactor is a thin-film evaporator which is able to handle the high viscosity of the hot nylon and remove most of the water byproduct. After this second reactor, the nylon is at a high enough molecular weight to be used for thermoplastics or fiber. The nylon can either be extruded into sheets and cooled before crushing into chips or the molten nylon can be fed to a pelletizer which shapes the nylon before it is cooled and dried on a conveyor belt.

[8] "Making Nylon 6,6." University of Southern Mississippi, 2005. Web.

DESIGN BASIS

This process is required to produce at least 85 million pounds of nylon 6,6 from adipic acid and HMDA annually. The process must be capable of a turn-down case of 67% of its full capacity. The ideal molecular weight of nylon 6,6 product is between 18,000 and 20,000 grams per mole as anything below 18,000 g/mol will lack the characteristic strength of nylon and anything above 20,000 g/mol is very difficult to spin into fiber and can get caught in process equipment.[9] This grassroots facility must be located in the Calvert City, Kentucky area. In order for this process to be considered a favorable investment, the process must be profitable with at least a 15% return on investment. A 10-year project life and a tax rate of 40% have been assumed.

Table 1: Feed Component Prices (given)

Feed Component	**Price**	**Units**
Adipic acid (ADA)	$0.68	$/lb
Hexamethylenediamine (HMDA)	$1.13	$/lb
Water	$30.40	$/million lb

Pricing trends from PCI Wood Mackenzie, an analytics company, have been utilized to predict future nylon 6,6 sales prices.[10] See Table 2 below for the anticipated sale price of nylon pellets and nylon fiber.

Table 2: Nylon 6,6 Sale Price

Nylon 6,6 Form	**Price**	**Units**
Pellets	$1.18	$/lb
Fiber	$225	$/100 meters

Since this is the preliminary design stage, the design scheme for all supporting utilities such as electricity, cooling water, steam, etc. is not required; however, these things must also be taken into consideration from an economic standpoint. Table 3 contains the anticipated utility prices which are used to estimate manufacturing costs.

[9] Sinclair, Rose (ed.). *Textiles and Fashion: Materials, Design and Technology.* 2015. Print.

[10] PCI Wood Mackenzie. Polyamide/Nylon." *PCI Wood Mackenzie.* N.p., n.d. Web. 02 Mar. 2017.

Table 3: Assumed Utility Prices

Utility	Price	Units
Electricity	$0.07	$/kilowatt-hr
Fuel gas	$3.80	$/million Btu
Cooling water	$120	$/annual gpm

The limits of these utilities and other specifications for the process and the process location are given in Table 4.

Table 4: Utility and Process Specifications

Specification	Value	Units
Maximum ambient temperature	107	°F
Minimum ambient temperature	-9	°F
Absolute atmospheric pressure	14.13	psia
Cooling water supply temperature	87	°F
Cooling water return temperature	120	°F
Cooling water supply pressure	50	psig
Cooling water return pressure	35	psig
Cooling water fouling resistance	0.002	hr*°F*ft^2
Instrument air pressure	85	psig
Elevation above sea level	341	ft

TECHNICAL DISCUSSION

Design Philosophy

There are two main industrial nylon 6,6 production processes - aqueous phase polymerization and melt phase polymerization. Both processes begin with the creation of a nylon salt which is composed of a 1:1 stoichiometric molar ratio of aqueous adipic acid and HMDA. The aqueous phase process may be completed in an autoclave (batch process) or in three reactor stages (continuous process). Historically, autoclaves with a 3-4 hour residence time were employed, but the industry has trended toward continuous processes for productivity, consistency, and safety reasons.[11] The newer, three-

[11] Billmeyer, Fred W. *Textbook of Polymer Science.* New York, Wiley, 1962. Print. pg. 431

stage process requires the consecutive use of a reactive distillation column, a loop-type reactor or series of throttling valves, and a wiped-wall evaporator. In the reactive distillation column, the aqueous nylon salt flows in the top of the column above the reactor. This drives off excess water. In the reactor vessel below the column, temperatures are between 230°C and 290°C and pressures are above 250 psig. A partial reboiler maintains good circulation throughout the reactor and removes water produced by the condensation reaction. The oligomers travel out the bottom of the first reactor and travel to a loop-style reactor or a series of throttling valves to reduce the pressure and remove more water. In the final stage, a wiped-wall evaporator is used to finish the reaction at temperatures of up to 300°C and at slight vacuum pressure.[12] See Figure 3 for the process flow diagram (PFD) for this process.

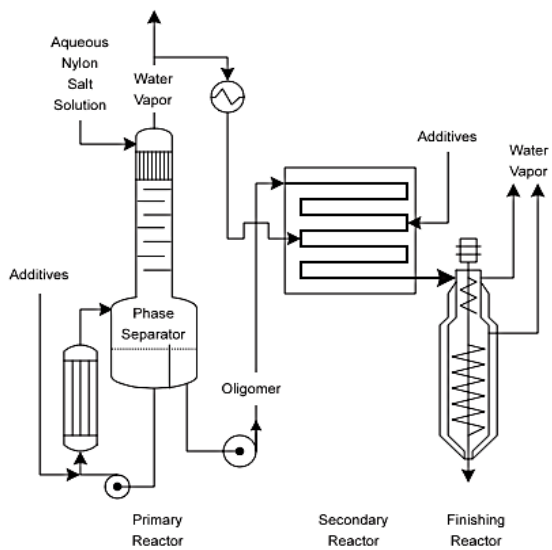

Figure 3: Process Flow Diagram for Aqueous Phase Nylon Polymerization

An alternative nylon 6,6 production process, melt-phase polymerization, has been developed more recently. The nylon salt solution is fed to a plug flow reactor (PFR) at temperatures near 275°C and pressures above 820 psig. At these high temperatures and pressures, the nylon salt is molten but does not boil. The residence time in this tubular reactor is usually between 15 and 30 minutes. The polymer solution is then throttled through a series of valves or a series of successively larger-diameter pipes. As the pressure is reduced, steam will be produced. Heating is necessary to keep the polymers from freezing and fouling the line. As in the aqueous phase polymerization, the final step involves the use of a wiped-wall evaporator which finishes the reaction around 300°C.[13]

[12] "Nylon 6,6 Step Growth Polymerization." *Aspen Polymers Handbook*, pg. 94–96
[13] *Aspen Polymers Handbook*, pg. 94–96.

Both the aqueous phase polymerization and melt phase polymerization processes result in the creation of nylon 6,6 ribbon, which travels on a conveyor belt as it cools. When it hardens, the ribbon is cut into chips, the finished product for plastics-grade nylon 6,6. Alternatively, the molten nylon may be fed into a pelletizer which turns the nylon into pellets before feeding them to a conveyor belt to cool and dry. In order to form nylon fiber, the chips or pellets are loaded into a hopper, melted via electric heater, forced through a spinneret (steel disk with small countersunk holes), and wound into fiber on large bobbins (see Figure 4). This spinning process can create, on average, 2500 feet of nylon fiber per minute.[14] The average ideal molecular weight for nylon fiber is between 18,000 and 20,000 grams/mole, but this molecular weight can be higher for thermoplastics depending upon the desired application.[15]

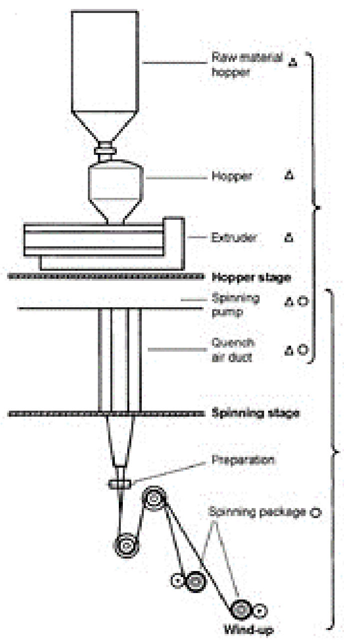

Figure 4: Melt Spinning Process to Make Nylon Fiber

Some of the main considerations for this project include choosing which of the two aforementioned nylon 6,6 production processes will be employed as well as whether the nylon will be sold as pellets or as a spun fiber. Both the aqueous phase polymerization and melt phase polymerization processes have been examined on a basis of design, economics, safety, and control. Based upon these analyses, the melt polymerization process has been chosen for several reasons: 1) it is more easily modeled as

[14] Billmeyer. pg. 431, 515
[15] Sinclair. pg. 100

a continuous process, 2) it requires a PFR reactor as opposed to a continuous-stirred tank reactor (CSTR), 3) higher conversion, and 4) Aspen Plus is better able to model polymerization in the melt phase than in the aqueous phase. The main drawback to the melt phase process is higher operating pressures, which will require additional safety measures.

We have examined the market for nylon pellets and nylon fiber in addition to the resultant revenue. The market for nylon fiber is larger than that of thermoplastics, but the thermoplastics market is projected to grow at a higher rate. Spinning the product into a fiber increases capital and operating costs, but also increases the sale price. The additional equipment required for fiber production, such as spinnerets, also creates more safety hazards such as operating temperatures of over 300°C. Furthermore, the spinning process requires frequent human input to load and unload the bobbins, thus the spinning process necessitates the hire of additional employees in order to operate the process. Selling the product as pellets decreases capital and operating costs, but results in a lower sales price. However, according to the principles of inherently safer design, less equipment also creates safer operating conditions. In the interest of safety and process simplification, it was decided to sell the nylon product as pellets.

In order to maintain the high temperatures at which the process operates and to avoid contamination of the product, the entire nylon 6,6 manufacturing process must occur indoors. It is anticipated that a warehouse-like building will be constructed in which the manufacturing process will take place, the excess reactants and product will be stored, and the control room will be located. This warehouse should be well insulated so as to minimize the effects of ambient temperature, which historically has ranged anywhere from -9°F in the winter and 107°F in the summer.[16]

Design Approach

The nylon production process was developed by first creating a simulation model with the chemical process simulation software Aspen Plus. Aspen Plus provided may advantages over hand calculations. The main advantages of using flowsheet simulation include bookkeeping of materials and energy, modeling complex physical interactions and phenomena, and iterative approaches using the power of the simulation engine. Disadvantages include difficulty for new users, inability to model unique unit operations, and the challenges inherent to the utilization of any rigorous simulation software.

[16] Intellicast. “Calvert City Historic Weather Averages in Kentucky.” *Intellicast*. Web.

These disadvantages were acknowledged and appropriate steps were taken to ensure accuracy in the design. One example of this is the sizing approach used for R-01, the PFR used for the first stage of the polymerization. The kinetics of the condensation polymerization taking place in this unit are complex and dependent on parameters not taken into account with a simple power law reaction model for a single reaction. To address these complexities, a kinetic and equilibrium model derived from experimental data by Steppan et al. in “A Kinetic and Equilibrium Model for Nylon 6,6 Polymerization” was used alongside a common reaction engineering approach, the Levenspiel plot, in order to model and size the PFR using Microsoft Excel.[17] Averaged kinetic and equilibrium parameters were then applied to a simplified reaction model in Aspen Plus to validate the developed model.

When attempting to model the more specialized unit operations, adequate research was required to find techniques to size these specialized pieces of equipment. Manufacturer’s catalogues were also utilized as a “sanity check”. One example of this is the design and sizing of R-02, the wiped film evaporator. The unit was modeled as a continuous stirred tank (CSTR) in Aspen so the extent of reaction and processing volume could be approximated. Sizing of the evaporator was done by using techniques described in “Design of Wiped Film Evaporator (WFE) System with Recovery of Working Fluid for Herbal Products” by Vijaykumar Patel and Alkesh Mavani.[18] Once this was done, a manufacturer’s catalog for WFE’s was used to verify that the identified dimensions were appropriate.

For most other process equipment sizing and design, Stephen Hall’s *Rules of Thumb for Chemical Engineers* was frequently referred to throughout the design of this process as it contains extensive heuristics tables and process approximations.

The PFD for the process at full capacity can be found in Figure 5 and the resultant stream table is in Table 5. The PFD for the 67% turndown case can be found in Figure 6 and the resultant stream table is in Table 6.

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[17] Steppan, D. D., M. F. Doherty, and M. F. Malone. “A Kinetic and Equilibrium Model for Nylon 6,6 Polymerization” *Journal of Applied Polymer Science.* pg. 2335-2344

[18] Patel, V. C., and Mavani, A. "Design of Wiped Film Evaporator (WFE) System with Recovery of Working Fluid for Herbal Products." *MIT International Journal of Mechanical Engineering*. Print. pg. 105-108

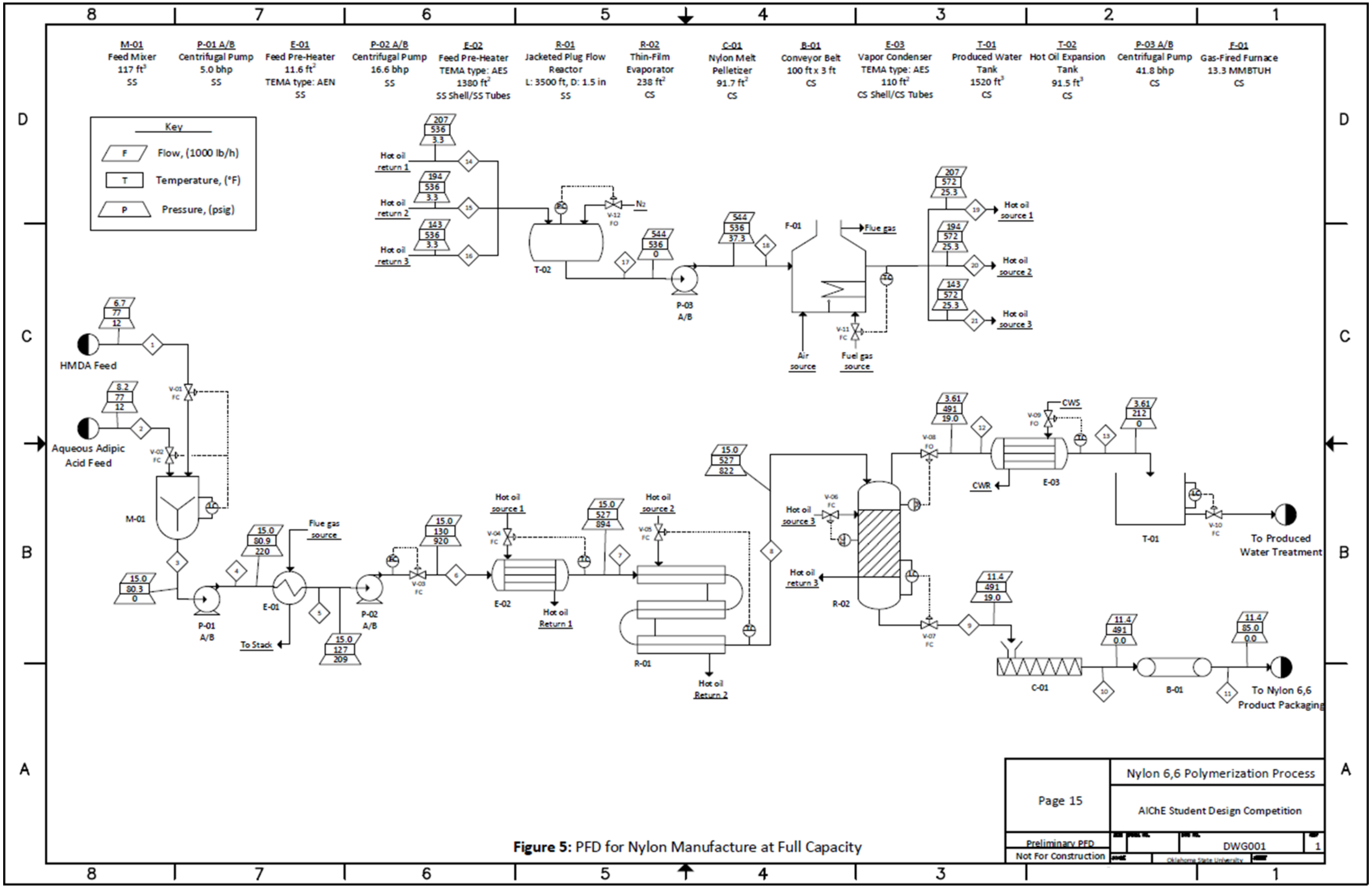

Figure 5: PFD for Nylon Manufacture at Full Capacity

Stream #		1	2	3	4	5	6	7	8	9	10	11	12
Stream Label		HMDA Feed	ADA Feed	To P-01	To E-01	To P-02	To E-02	To R-01	To R-02	To C-01	To B-01	To Packagin	To E-03
Vapor Fraction		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0
Pressure (psig)		12.0	12.0	0	221	209	920	894	822	19.0	0	0	19.0
Temperature (F)		77.0	77.0	80.3	80.9	127	130	527	527	491	491	85.0	491
Mass Flow (lb/hr)	H2O	905	905	1809	1809	1809	1809	1809	3289	21.6	21.6	21.6	3578
	ADA	-	7339	7339	7339	7339	7339	7339	591	9.9	9.9	9.9	1.9
	HMDA	5836	-	5836	5836	5836	5836	5836	470	4.0	4.0	4.0	28.1
	Nylon 6,6	-	-	-	-	-	-	-	10633	11340	11340	11340	-
	Duratherm	-	-	-	-	-	-	-	-	-	-	-	-
	Total	6740	8244	14984	14984	14984	14984	14984	14984	11375	11375	11375	3608
Volumetric Flow Rate (cft/hr)		120	114	235	235	240	240	311	302	209	160	160	59831
Density (lb/cft)		56.0	72.3	63.8	63.8	62.4	62.3	48.1	49.6	54.5	71.2	71.2	0.0603

Stream #		13	14	15	16	17	18	19	20	21
Stream Label		To T-01	HTF Return 1	HTF Return 2	HTF Return 3	To P-03	To F-01	HTF Source 1	HTF Source 2	HTF Source 3
Vapor Fraction		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pressure (psig)		0	3.3	3.3	3.3	0.0	37.3	25.3	25.3	25.3
Temperature (F)		212	280	280	280	280	280	300	300	300
Mass Flow (lb/hr)	H2O	3578	-	-	-	-	-	-	-	-
	ADA	1.9	-	-	-	-	-	-	-	-
	HMDA	28.1	-	-	-	-	-	-	-	-
	Nylon 6,6	-	-	-	-	-	-	-	-	-
	Duratherm	-	207460	193658	142630	543748	543548	207460	193658	142630
	Total	3608	207460	193658	142630	543748	543548	207460	193658	142630
Volumetric Flow Rate (cft/hr)		63.1	3566	3329	2452	9348	9344	3578	3340	2460
Density (lb/cft)		57.2	58.2	58.2	58.2	58.2	58.2	58.0	58.0	58.0

Table 5: Stream Table for Full Capacity

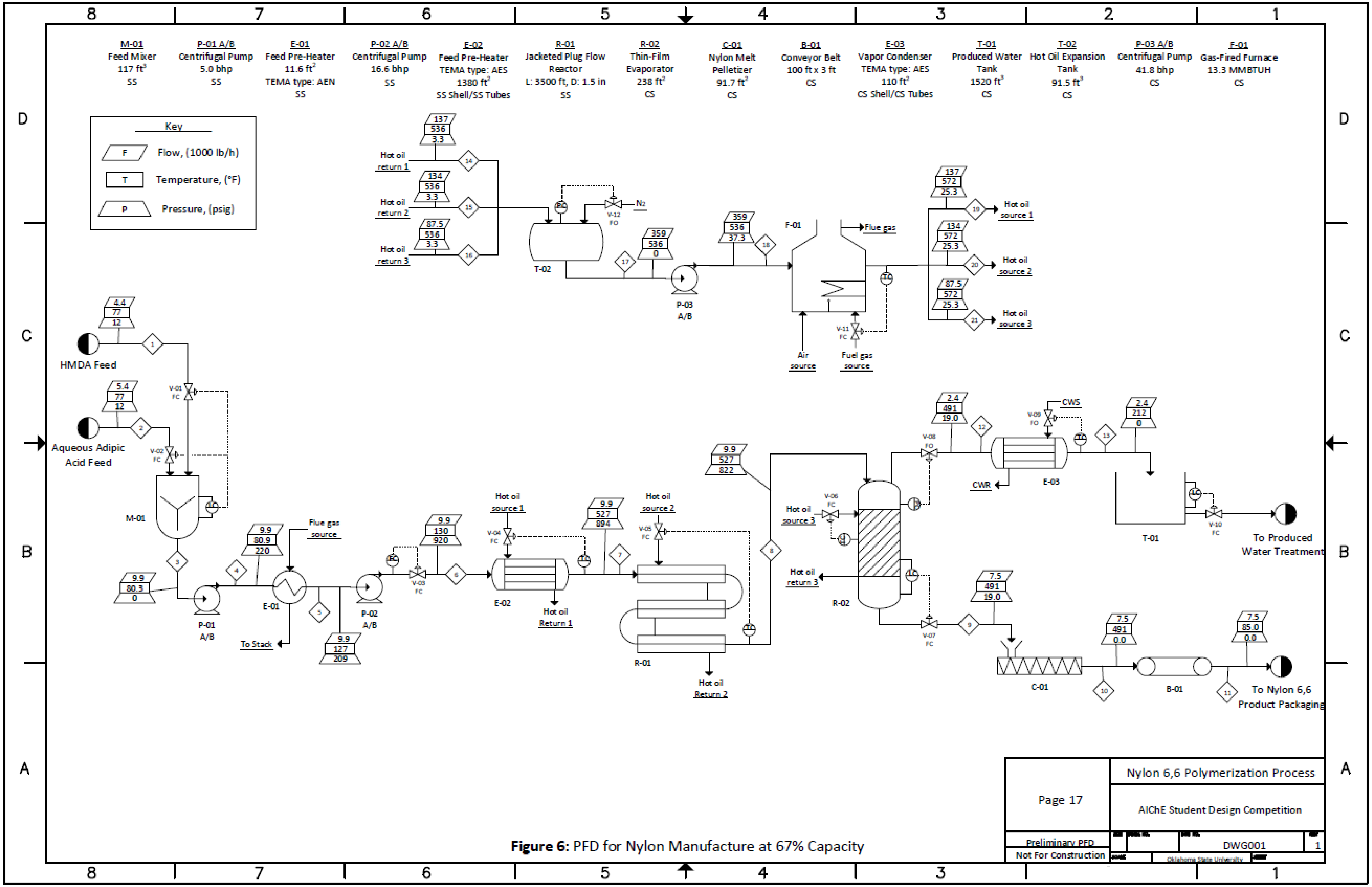

Figure 6: PFD for Nylon Manufacture at 67% Capacity

Stream #		1	2	3	4	5	6	7	8	9	10	11	12
Stream Label		HMDA Feed	ADA Feed	To P-01	To E-01	To P-02	To E-02	To R-01	To R-02	To C-01	To B-01	To Packaging	To E-03
Vapor Fraction		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0
Pressure (psig)		12.0	12.0	0.0	220	208	920	894	822	19.0	0.0	0.0	19.0
Temperature (F)		77.0	77.0	80.3	80.9	127	130	527	527	491	491	85.0	491
Mass Flow (lb/hr)	H2O	596	596	1193	1193	1193	1193	1193	2245	14.2	14.2	14.2	2362
	ADA	-	4837	4837	4837	4837	4837	4837	225	2.8	2.8	2.8	0.5
	HMDA	3846	-	3846	3846	3846	3846	3846	179	1.4	1.4	1.4	9.8
	Nylon 6,6	-	-	-	-	-	-	-	7228	7486	7486	7486	-
	Duratherm	-	-	-	-	-	-	-	-	-	-	-	-
	Total	4443	5434	9876	9876	9876	9876	9876	9876	7504	7504	7504	2372
Volumetric Flow Rate (cft/hr)		79	75.2	155	155	158	158	205	197	138	105	105	39469
Density (lb/cft)		56.0	72.3	63.8	63.8	62.4	62.3	48.1	50.1	54.5	71.2	71.2	0.0601

Stream #		13	14	15	16	17	18	19	20	21
Stream Label		To T-01	HTF Return 1	HTF Return 2	HTF Return 3	To P-03	To F-01	HTF Source 1	HTF Source 2	HTF Source 3
Vapor Fraction		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pressure (psig)		0.0	3.3	3.3	3.3	0.0	37.3	25.3	25.3	25.3
Temperature (F)		212	280	280	280	280	280	300	300	300
Mass Flow (lb/hr)	H2O	2362	-	-	-	-	-	-	-	-
	ADA	0.5	-	-	-	-	-	-	-	-
	HMDA	9.8	-	-	-	-	-	-	-	-
	Nylon 6,6	-	-	-	-	-	-	-	-	-
	Duratherm	-	136728	134464	87510	358702	358702	136728	134464	87510
	Total	2372	136728	134464	87510	358702	358702	136728	134464	87510
Volumetric Flow Rate (cft/hr)		41.4	2350	2312	1504	6166	6166	2358	2319	1509
Density (lb/cft)		57.3	58.2	58.2	58.2	58.2	58.2	58.0	58.0	58.0

Table 6: Stream Table for 67% Capacity

Description of Process

As can be see in the PFD for the process (Figure 5), HMDA and adipic acid for the process are shipped to the facility and stored in tanks (not shown) prior to being fed to the mixer, M-01, at atmospheric pressure and room temperature. From the mixer, the contents proceed to the first pump, P-01. P-01 is designed to increase the pressure of the reactant mixture from atmospheric to 220 psig. P-01 is able to handle a slight amount of undissolved solid which may be present in the solution after mixing. E-01 is downstream of P-01 and uses heat integration from the flue gas of F-01. E-01 is designed to increase the temperature to ensure that any leftover solid adipic acid dissolves. The reactant solution proceeds to the multi-stage pump, P-02 where the pressure is then increased to 920 psig. The preliminary design calls for four stages to P-02 in order to reach the desired pressure. A second heat exchanger, E-02, follows P-02 and utilizes a synthetic high temperature fluid (HTF) in order to heat the reactant solution to 527°F. After the system has reached 527°F, it is ready to enter the plug flow reactor, R-01. R-01 is jacketed because heat, also in the form of HTF, must be added for the reaction to proceed. R-01 is designed to be composed of 3,500 feet of 1.5-inch diameter pipe looped back and forth in order to reach the desired conversion over the 8.4 minutes that it takes fluid to pass through the reactor. The majority of the polymerization occurs in R-01 as above 90% of the nylon by mass produced by the process is polymerized this first reactor. The average molecular weight of the nylon 6,6 leaving R-01 is 1,440 g/mol. Since nylon 6,6 is formed through a condensation polymerization reaction, water is a byproduct of the reaction. The newly formed nylon and the water byproduct flow towards the thin-film evaporator R-02, (sometimes referred to as wiped film evaporator or WFE) where the remainder of the polymerization occurs. Since the nylon solution has a pressure of 826 psig as it leaves R-01, it does not need to be pumped in order to reach R-02. The solution is flashed upon entry to R-02 in order to lower the solution pressure and separate the water from the nylon. The removal of water causes the reaction to proceed and the nylon will continue to make longer and longer chains. The thin film evaporator also relies upon HTF in order to keep the reactor at elevated temperatures to evaporate the water byproduct and prevent the nylon from freezing and fouling any lines or equipment. The evaporated water is then condensed in E-03 using cooling water before proceeding to T-01 where it is stored until a truck takes it to a produced water treatment plant. T-01 was designed with a holdup time of 1 day. The nylon 6,6 product exits out the bottom of the WFE and is then pelletized by C-01 and cooled and dried on conveyer belt B-01. It is then moved to nylon 6,6 product storage.

Duratherm S is the HTF chosen as a heat transfer medium in this process. Duratherm S was chosen over comparable synthetic hot oils because of its additives. The corrosion inhibitors, suspension agents, and metal deactivators are critical components in protecting the equipment from damage or blockage. It is also inherently safer than other oils because of its higher flashpoint. The HTF is stored in the expansion tank, T-02, where it is then pumped by P-03 to the fired heater, F-01. This fired heater uses fuel gas to heat the oil and send it to E-02, R-01, and R-02. The Duratherm is returned to T-02 after it has been utilized in these three locations.

Turndown Case

In the instance of a decreased nylon 6,6 demand, the plant managers may want to reduce the overall nylon production to 67% of the typical plant production capacity. Clearly, the process equipment has been designed, sized, and optimized to run at full capacity. Thus, one of the main considerations is that only two-thirds of the volumetric flow that the equipment was sized for will be flowing through the process. The biggest concern is with the PFR, R-01. It was sized for a specific conversion at full capacity, so at lower capacities a higher conversion and molecular weight number (MWN) are reached. This is undesirable because if maximum conversion is reached, the nylon oligomer will react with itself (polycondensation), forming longer polymer chains. The larger and longer these chains become, the more viscous the nylon solution becomes, making it very difficult to pump and increasing the likelihood of line and equipment fouling. Furthermore, longer oligomer chains will be fed to the evaporator R-02, which will likely result in a nylon product that has a MWN that is above 20,000 g/mol. This is not ideal for most nylon 6,6 products, particularly those that will be spun and used for fabric. The best way to prevent this from occurring is to control temperature in R-02. If the temperature in R-02 is decreased, then water is vaporized at a slower rate, resulting in a slower polycondensation of the nylon to higher MWN product. It is recommended that in the future design steps that work be done towards developing a calibration curve relating exiting molecular weight to temperature of the WFE. The temperature of the unit will then be able to be adjusted conviently depending on process demands. Doing this during the turndown case will limit the amount of hot oil flowing to the reactor so that approximately the same conversion and MWN is reached regardless of process operating volumetric flow rate. Thus, the turndown 67% capacity process should still be fed a proportional amount (67%) of feed materials, despite the fact that a higher conversion will be reached in R-01.

Process Control

Table 7 below describes each of the control valves in the process. They can be found on the PFDs using the same nomenclature. Fail open or fail closed are safety mechanisms to minimize hazards such as runaway reactions, under pressurization, overheating, etc. Each control valve stem position (percent open) is based on a level, temperature, or pressure control sensor. As the set points are changed, the stem position on the corresponding valve will change to accommodate the set point. All descriptions in the table are based upon an emergency failure scenario.

Table 7: Description of Control Valves

Control Valve	Fail Open or Fail Closed	Description
V-01	Fail Closed	Fails closed to prevent process from initiating. Percent open adjusts based upon level control in M-01. Connected with a constant ratio to V-02.
V-02	Fail Closed	Fails closed to prevent process from initiating. Percent open adjusts based upon level control in M-01. Connected with a constant ratio to V-01
V-03	Fail Closed	Fails closed to prevent entrance to E-02. Percent open based upon flow control sensor downstream of P-01.
V-04	Fail Closed	Fails closed to prevent overheating. Percent open based on temperature control sensor of E-02 product stream.
V-05	Fail Closed	Fails closed to prevent overheating. Percent open based on temperature control sensor of R-01 product stream.
V-06	Fail Open	Fails closed to prevent overheating. Percent open based on temperature control sensor in thin-film evaporator.
V-07	Fail Closed	Fails closed to force toxic HDMA and ADA vapors into condenser. Percent open based on level control sensor on R-02 product stream.
V-08	Fail Open	Fails open to prevent over-pressurization of R-02. Percent open based on pressure control sensor on R-02.
V-09	Fail Open	Fails open to prevent overheating. Percent open based on temperature control sensor on E-03 product stream.
V-10	Fail Closed	Fails closed to prevent product from going to water treatment. Percent open based on level control sensor on T-01.
V-11	Fail Closed	Fails closed to prevent fuel gas from entering F-01. Percent open based on temperature control sensor on hot oil source line
V-12	Fail Open	Fails open to prevent vacuum formation and P-03 cavitation. Percent open based on pressure control sensor on T-02.

Kinetic and Thermodynamic Parameters

Considerable effort was taken in modeling the condensation polymerization reaction occurring in the PFR, R-01. A single reaction rate constant was deemed inadequate to describe the complex system of reactions occurring in the PFR. It was decided that the best approach would be to model the reaction in Microsoft Excel using empirical relations found from established experiments. The Levenspiel plot technique (more information in "Equipment Lists, Sizing, and Selection") could then be used to find the volume of reactor required. A reactor with appropriate dimensions could then be designed. These reactor dimensions were used to model the reactor in Aspen Plus software, using the averaged kinetic parameters developed in the Microsoft Excel model. The conversion output from Aspen Plus was found to be similar to the original conversion specified in the Excel model, thus validating the Aspen Plus in its ability to model this complex polymerization reaction.

Reaction kinetics were modeled based upon the work of Steppan et al., who developed an empirical equation describing the apparent 2nd order reaction rate constant as a function of water mole fraction.[19] Rates for the forward and reverse reaction are combined into a single rate. This is only valid when large stresses are not put on one side of the reversible chemical equation. This empirical model was utilized in the model developed in Excel. Each iteration of the model would calculate a new reaction rate constant based upon the new conditions. This reaction rate constant and the new concentrations of the reactants were used to find the reaction rate for that iteration. Approximately 500 iterations were performed for each PFR design to ensure precision.

Similar to reaction kinetics, thermodynamics influenced multiple aspects of design. The extent of polymerization in the first reactor is limited by thermodynamic equilibrium. The large operating pressure, while required to achieve the high rate of reaction needed for a continuous process, prevents any water from vaporizing. As the condensation polymerization reactions are reversible, the increase in water production leads to a shift in equilibrium away from the desired product, nylon 6,6. This is one of the main drivers for designing a second reaction stage. The agitated wiped film evaporator (WFE), is ideal for the second reaction stage because of its effectiveness in separating water from the R-01 product stream. As water is removed from the reaction system, equilibrium shifts towards the formation of more water and nylon 6,6. In the WFE there remains very little ADA and HMDA, so polycondensation, or growth of the polymer chains, takes place. Because Le Chatlier's Principle influences the reaction in the WFE, it is important to consider both the forward and reverse

[19] Steppan, D. D., M. F. Doherty, and M. F. Malone. pg. 2335-2344

reactions explicitly. Kinetic data for this reaction set is given by Kevin Seavey and Y. Liu in *Step-growth Polymerization Process Modeling and Product Design*.[20] This results in a nylon 6,6 product with the molecular weight falling within the desired range (18,000 to 20,000 g/mol).

Equipment Lists, Sizing, and Selection

The following tables include all of the equipment and some important specifications. Beneath each table is a detailed description of the equipment selection and sizing techniques. The spreadsheets attached in Appendix A show more detailed calculations of the values obtained in the tables below. Any equipment that encounters high concentrations of HDMA or adipic acid is constructed from stainless steel because these reactants are corrosive and thus incompatible with carbon steel. Equipment used for nylon 6,6, hot oil, or water uses carbon steel to lower capital costs.

The Duratherm HTF loop is required for heat exchange due to high process temperatures that are impossible to reach via high-pressure steam. The economics associated with this decision are discussed in the "Economic Analysis" section of this report.

Table 8: Process Vessel Details and Specifications

Vessels	Type	Volume (ft^3)	Design Temperature (°F)	Design Pressure (psig)	MOC
M-01	Mixer	117	130	50	SS
T-01	Atmospheric Tank	1520	260	50	CS
T-02	Hot Oil Expansion Tank	165	590	55	CS

M-01 was sized as a horizontal process vessel with an impeller. It is assumed that the tank is well mixed. It is designed for a holdup time of 30 minutes. T-01 was sized to accommodate a holdup time of 1 day to allow for truck pickup and delivery of the water to a treatment facility. These holdup times should be sufficient in the case that something downstream results in a process bottleneck. T-02 was sized using expansion tank heuristics from Hall's *Rules of Thumb for Chemical Engineers*. Using heuristics from Richard Turton et al. textbook *Analysis, Synthesis, and Design of Chemical Processes*, the volume of oil required to fill E-02 and R-01 was calculated. Dimensions of the WFE

[20] Seavey, Kevin, and Y. A. Liu. *Step-growth Polymerization Process Modeling and Product Design*. Hoboken, NJ: Wiley, 2008. Print. pg. 604-610

were compared to those of commercially available units to determine the volume of the jacket surrounding the unit. 100 feet of 7-inch diameter pipe between units was used to conservatively determine the volume of HTF in transit. Heuristics from Hall were used to calculate the normal liquid volume in the expansion tank and the total volume.

Table 9: Centrifugal Pump Details and Specifications

Centrifugal Pump	**Efficiency (%)**	**Power (bhp)**	**Design Temperature (°F)**	**Design Pressure (psig)**	**MOC**
P-01	75	5.0	130	270	SS
P-02	75	17	180	970	SS
P-03	75	42	590	90	CS

All three pumps were sized based upon differential pressure and flow rate requirements and typical pump efficiencies. The first pump provides adequate head so as to avoid vaporization of the feed when it is preheated in the economizer E-01. In the case that there are undissolved solids in the solution, it is recommended to use a radial impeller.[21] For this reason, P-01 utilizes a radial impeller to handle the excess solids. P-02 does not, and more importantly, it is a multistage pump with impellers in series. Multistage pumps are not recommended for liquids containing solids. This is why E-01, which will heat the solution and increase solid solubility, is located prior to P-02. This multistage configuration for P-02 is required because of the large amount of head that must be provided to the process fluid. The third pump serves as a recirculation pump for the hot oil used for heating throughout the process. P-03 requires a larger amount of power than the previous two pumps because of the high volumetric flow rate required for the hot oil loop.

The following pressure drops were assumed:

- 2 psi per 100ft of line including the PFR,
- 10-15 psi for control valves depending on flow rate,
- 10 psi for HTF fluid through equipment, and
- 9 psi for process fluid through equipment.

[21] Hall. pg. 102-117

Conservative efficiencies were assumed to be 75% for the pump and 80% for the motor. A high-pressure differential was designed for P-02 as the reactants need to be at a pressure of above 900 psig before entering R-01.

Table 10: Heat Exchanger Details and Specifications

Heat Exchanger	Area (ft^2)	Duty (MMBTUH)	Design Temperature (°F)	Design Pressure (psig)	MOC Shell/Tubes	TEMA Type
E-01	171	0.386	440	270	SS	AEN
E-02	541	3.95	620	970	SS	AES
E-03	110	-3.94	540	70	CS	AES

The placement of E-01 was chosen to reduce the amount of undissolved solids going through the high-pressure differential pump, P-02. The heat increases solubility of the ADA and HMDA, and the turbulent nature of flow provides mixing. This was necessary in order to protect the equipment from damage. Additionally, E-01 incorporates heat integration from the fired heater flue gas, making the process more efficient. For all three heat exchangers, necessary heat duties (Q) were taken from Aspen. These were then used to calculate heat exchanger area using typical overall heat transfer coefficient (U) values found in Turton et al. as well as the log mean temperature difference (LMTD). As mentioned before, stainless steel was used for E-01 and E-02 due to the corrosive nature of HDMA and adipic acid. An AEN heat exchanger type was utilized for E-01 because the temperature change of the process fluid is small enough for fixed tubes (46.8°F). Higher process fluid temperature changes in E-02 (397°F) and E-03 (279°F) require a floating head type (AES) in order to account for thermal expansion.

Table 11: Reactor Details and Specifications

Reactor	Type	Length (ft)	Diameter (in)	Area (ft^2)	Design Temperature (°F)	Design Pressure (psig)	MOC
R-01	Jacketed PFR	3,500	1.5	N/A	580	945	SS
R-02	Thin-Film Evaporator	N/A	N/A	238	580	875	SS

Due to the positive order kinetics of this melt-phase polymerization reaction, a PFR is better suited than a CSTR for this process. This is shown below in the Levenspiel Plot generated from the Excel Model, shown below in Figure 7. In the Levenspiel plot technique, volume of the PFR reactor is found by integrating for the area under the reaction curve, shown by the diagonal black lines. The required volume for a CSTR to achieve the same conversion is found by calculating the area enclosed by the horizontal and vertical bars. To minimize capital investment, a PFR type reactor is the logical choice. The PFR, R-01, is simply a pipe with a jacket added in order to heat the tubular reactor to the desired temperature. This is almost exactly like a double pipe heat exchanger, thus R-01 has been sized as a double pipe heat exchanger.

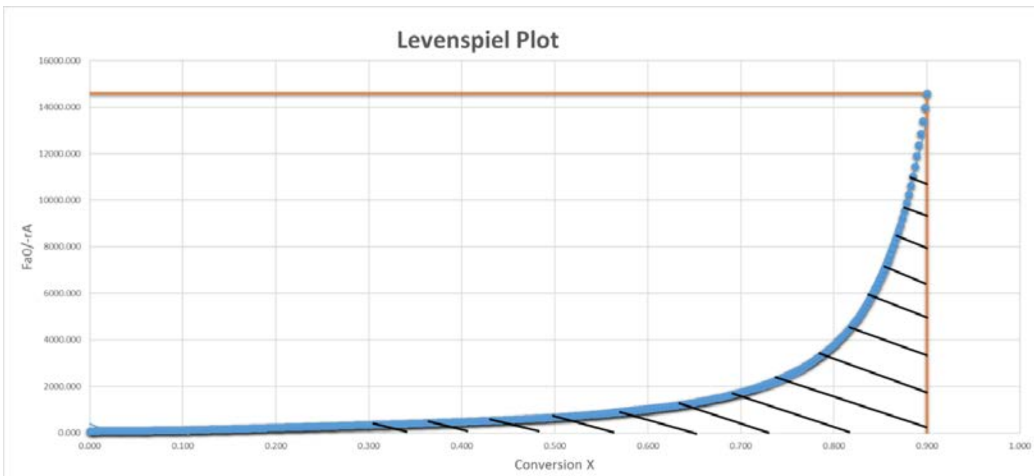

Figure 7: Levenspiel plot used to determine type of reactor

It was observed that in a small PFR that low conversion was being achieved and resulting in the waste of unreacted feed materials. The tradeoff between the capital cost of the PFR versus the recurring cost of the raw materials was explored during design. Conversion was the variable connecting these two. A larger conversion required a larger reactor (higher capital cost), but lower raw material cost (recurring). Smaller conversion yields opposite effect. Ultimately, it was found that the price of raw materials had a much greater effect economically than the size of the reactor over a 10-year project life. So it was decided to increase reactor volume. The diameter of R-01 was sized based on a desired velocity of 4 - 8 ft/s. The length was then optimized to get high conversion at low cost. 90% conversion gives a feasible (albeit long) 3500-foot length with minimal unreacted products. However, because the diameter is only 1.5 inch, the PFR is able to snake back and forth while not taking up too much space and allowing for more efficient heating. R-01 was designed to withstand temperatures over 550 °F and pressures over 900 psig. These high temperatures and pressures are necessary for the condensation polymerization reaction to proceed.

Wiped thin-film evaporators (WFEs) are preferred for high viscosity liquids, particularly when water is present. Thus, a WFE was chosen for the second reaction stage, R-02. The working principle of a WFE is that the thin film created by the agitator allows for the high heat flux that is required for water to overcome the relatively large activation energy for diffusion (58kJ/mol) in order for the water to evaporate nearly fully from the nylon product.[22] There is a low concentration of water in the nylon solution and a high concentration of water in the vapor leaving the WFE, thus significant energy is required to move the water against the concentration gradient. As water diffuses out and vaporizes, Le Chatlier's principle dictates that the condensation polymerization must proceed forward, driving the conversion and molecular weight up. It is important to note that any unreacted ADA and HMDA left with water out the vapor outlet, so no new short chain oligomers are formed in R-02.

The WFE diameter was sized based upon the desired water vapor flowrate of 6.5 ft/s[23] and the specified film thickness (0.5 in) of nylon 6,6 in the evaporator from Seavey and Liu.[24] R-02 is modeled as a CSTR in Aspen because a CSTR most closely resembles a thin-film evaporator. The Aspen model outputs a liquid volume and the WFE must have this same volume of liquid in it at a given time. Since the film thickness and diameter of the WFE is known, the cross sectional area of the liquid film is able to be calculated. This liquid film cross sectional area was used to calculate the heat transfer area. The height was found using the cross-sectional area and the liquid volume. Since the WFE was modeled as a CSTR in Aspen, the height of the design WFE was specified so that the volume of fluid in the design WFE matched the volume of fluid in the simulated CSTR. The process fluid was flashed into R-02 to lower the pressure, which aids in the evaporation process. Throttling valves were found to result in two-phase flow so flashing was seen as the better alternative.

Residence time in a WFE is generally short to protect the nylon product from excessive exposure to heat and potential thermal degradation. The residence time obtained in Aspen is not accurate because of the specified CSTR model. In a CSTR, most of the fluid is not in contact with the wall of the reactor, whereas in a WFE the surface area of fluid exposed to the heat flux is very large, thus the residence time should be much shorter for the reasons mentioned above.

[22] Mark, James E., and Brent D. Viers. *The Polymer Data Handbook*. Print. pg. 189
[23] Patel and Mavani. pg. 105-108
[24] Seavey and Liu. pg. 604-610

Table 12: Fired Heater Details and Specifications

Fired Heater	Firing Rate (MMBTU/hr)	Design Temperature (°F)	Design Pressure (psig)	MOC
F-01	13.3	800	90	CS

The steps taken to find the heat duty for the process can be found belo The volume of Duratherm S required to fill the three units, transfer piping, and expansion tank were calculated. The required mass flow rate needed to achieve the desired heat transfer in each of the units was calculated using the Aspen simulation and the properties of Duratherm S from the Duratherm Heat Transfer Fluids website. The recirculating pump was sized by noting the pressure drops that occur through each vessel and through the connecting process lines. According to the recommendation from Hall's textbook, the pressure of the expansion vessel was set at 16 psia, which is 15 psi above the vapor pressure of the heat transfer fluid. The total required duty to heat the Duratherm S from 536°F degrees (estimated temperature inside the expansion tank) to 572°F was used to size and cost the fired heater. The duty provided by the fired heater was approximated by dividing the total required process duty by the thermal efficiency of a typical fired heater (0.78).[25]

As a measure of heat integration, the flue gas from the heater is used to preheat the process feed. From the heater efficiency, the flue gas temperature was estimated to be 200°C.[26] A typical heat capacity for flue gas was used to estimate the amount of heat transferred to the process for a given temperature change of flue gas. Combustion calculations, along with mass and volume flow approximations of flue gas can be found in Appendices A and C.

Table 13: Miscellaneous Equipment Details and Specifications

Other Equipment	Type	Width (ft)	Length (ft)	Area (ft^2)	Design Temperature (°F)	Design Pressure (psig)	MOC
C-01	Nylon Melt Pelletizer	1.1	26.4	91.2	541	69	CS
B-01	Conveyor Belt	3	100	300	135	50	CS

[25] Turton et al. pg. 395
[26] Hall. pg. 169

The nylon 6,6 melt pelletizer, C-01, was sized using a graph from extrusionists.com.[27] The melt is fed to C-01 where a screw pushes it through an extruder where a blade cuts the melt into pellets. These pellets then fall to conveyor belt, B-01 for cooling. Other manufacturing possibilities exist such as spinning the nylon 6,6. It was found that a melt pelletizer is inherently safer because it is less complex, and it does not regularly require an operator to load the fiber onto a spinneret. The flowrate was extrapolated and a corresponding diameter was found for C-01. An industry heuristic from the aforementioned source was then used to find the length. B-01, was designed for a 1-inch depth of pellets on the belt. The area required was calculated based upon the cooling time, belt velocity, and the volumetric flowrate of the pellets.

SAFETY, HEALTH, AND ENVIRONMENTAL CONSIDERATIONS

Safety Concerns

A prerequisite for the process design is the safety of people, the environment, and the process equipment. The health and safety of all employees and citizens in the vicinity of the grassroots manufacturing facility is paramount. Compliance with the Occupational Safety and Health Administration's (OSHA) Process Safety Management (PSM) is mandatory for the process facility due to high quantities of adipic acid and HMDA.[28] According to the OSHA Process Safety Management Guidelines, "process safety management is the proactive identification, evaluation, and mitigation or prevention of chemical releases that could occur as a result of failures in processes, procedure, or equipment".[29] In order to maintain compliance with OSHA's PSM, companies are required to identify and control hazards and train their workforce how to properly operate equipment, be mindful of abnormalities, and handle emergencies. Information compiled in the PSM is also important for contractors working with the process, those performing the process start-up, insurance and enforcement officials, and emergency preparedness personnel.

A preliminary Process Hazard Analysis (PHA) has been completed in an attempt to identify, evaluate, and mitigate the hazards associated with the polymerization and pelletizing of nylon. The main

[27] Brink, Ted. "Extrusion Processes." *The Extrusionists*. Web.
[28] Hall, Stephen. *Rules of Thumb for Chemical Engineers*. 2012. pg. 322
[29] U.S. Department of Labor. OSHA. *Process Safety Management Guidelines for Compliance*. 1994. Web.

hazards that have been identified include high operating pressures, high operating temperatures, chemical hazards, and loss of containment due to internal defects or to external factors.

High Pressures

High-pressures may be found at the discharge of P-02, throughout R-01, and in the pipes prior to R-02. In R-02, the high pressure solution is flashed in order to reduce pressure and aid in water separation. All lines, process vessels, and reactors have been designed to withstand pressures of 50 psig above the normal operating pressures, but this is not sufficient pressure control. All process vessels are equipped with pressure relief valves that vent high-pressure vapors to a flare with a knock-out drum for nylon because it releases a toxic smoke when burned. Routine inspection and proper maintenance will minimize fouling through these valves.[30] Pressure imbalances for any reason can result in backflow and result in high pressures in unexpected areas, thus check valves should be installed and process lines should be properly instrumented to detect conditions that indicate backflow.[31] Furthermore, should these pressure relief valves be needed, it is important that all personnel are wearing proper ear protection as rupture causes damaging levels of noise.

High Temperatures

Elevated temperatures are found throughout the process in order to result in melt-phase polymerization of nylon. In particular, the reactors and HTF loop are maintained at temperatures above 500°F. After the nylon is formed, high temperatures must be maintained to keep the nylon in the molten state. If the nylon freezes, it can foul lines and equipment, posing a large hazard to the process. All lines and process vessels are to be insulated. This helps to reduce heat loss to the environment and serves as a first line of protection for personnel against burns. The WFE is very sensitive to pressure changes. For this reason, special care should be taken by the control engineers involved in the detailed design process. Operators should be adequately trained to deal with changes in the process temperatures, especially as they concern the WFE. All personnel should wear burn protection gloves and long sleeves.

[30] Cheremisinoff, Rosenfeld, and Davletshin. *Responsible Care: A New Strategy for Pollution Prevention and Waste Reduction through Environmental Management*. 2008. pg. 253-256
[31] Hall. pg. 328-331

Chemical Hazards

It is important to understand the chemicals in the process and the risk they pose to health, safety, equipment, and the environment. Safety data sheets (SDS) have been referenced to collect the following hazards associated with the chemicals in this process:

Table 14: Chemical Hazards

Component	**Hazards according to SDS**
Adipic acid	Corrosive, causes serious eye damage, harmful to aquatic life, thermal decomposition can lead to release of irritating gases and vapors, combustible dust[32]
Hexamethylenediamine (HMDA)	Corrosive, causes severe eye and skin burns, causes digestive and respiratory tract burns, thermal decomposition can lead to release of irritating gases and vapors[33]
Nylon 6,6	Can burn in fire with dense toxic smoke, avoid breathing vapors or mist, molten plastic may cause severe burns, relatively stable in solid form[34]
Duratherm S (HTF)	Non-regulated material, avoid release to environment, flash point: 324°C, autoignition temperature: 437°C[35]

Due to the fact that adipic acid and HMDA cause serious eye damage, all personnel are required to wear protective eyewear. Since adipic acid dust is combustible and HMDA causes skin, respiratory tract, and digestive tract burns, personnel are required to wear protective and fire-resistant clothing.

Fire Hazards

Nylon 6,6 is flammable and adipic acid dust is highly combustible, indicating the need for design elements to prevent fires and, in the case that fire does occur, control it. Three elements are required for combustion: oxygen, a fuel source, and a source of ignition. These three elements are commonly referred to as the "fire triangle". If only one of these elements is taken away, combustion cannot occur. Any chemical in the process system (with the exception of water) could be a fuel source for a fire.

[32] Fisher Science Education. "Adipic Acid Material Safety Data Sheet (MSDS)." 20 Jan. 2015. Web.
[33] Fisher Science Education. "Hexamethylenediamine Material Safety Data Sheet (MSDS)." (2014): n.pag. *Fisher Scientific.* 24 Jan. 2014. Web. 27 Feb. 2017.
[34] Edinburgh Plastics, Inc. "Material Safety Data Sheet." *Plastics Design.* 2 Oct. 2007. Web.
[35] "Duratherm S." *Duratherm Heat Transfer Fluids.* Duratherm, 20 Dec. 2016. Web.

Common ignition sources include but are not limited to a spark, electrical arc, cigarette, static discharge, or a hot piece of equipment. Although the process equipment will be purged with nitrogen during start-up and the process is designed to avoid oxygen contamination, according to Nicholas Cheremisinoff in *Responsible Care*, controlling the source of ignition is often the easiest and safest way to avoid combustion. It is recommended that all unnecessary heat sources be turned off and sources of static electricity, such as cell phones, be left in cars and away from the operating area. In the case that a fire does occur, it is recommended to emergency shutdown all heat, electrical, and fuel sources. A water sprinkler system will be installed for the purpose of putting out fires by limiting heat.[36]

<u>Loss of containment</u>

All efforts will be made to avoid loss of containment. Most emissions in chemical systems are a result of storage vessel filling and emptying. Since the process feeds are relatively stable in the aqueous phase, they can be stored in open tanks inside the process warehouse. Because the process will be indoors, loss of containment via loading and unloading of storage vessels will be mitigated. In order to prevent loss of containment elsewhere in the process, pumps are to have mechanical seals at the point of contact between the moving shafts and the stationary casing to prevent leakage or emissions. Liquid and vapor leaks can occur at any pipe flange or valve. This emission is reduced through regular inspection and proper maintenance.[37] In the case of large-scale loss of containment, the process should be quickly shut down and/or isolation valves be closed to isolate the area with emissions in order to minimize losses and contamination. The process will be indoors and as such will have proper ventilation systems including fume hoods and exhaust fans. Should loss of containment take place, the gases will be discharged safely through these additions. Furthermore, the emergency preparedness plan must be clearly communicated with all emergency response crews and personnel.

<u>Other Potential Hazards</u>

One potential hazard could be overheating the process fluid. If for some reason the flowrate is slowed or halted, the amount of heat transfer to the process fluid will increase and could potentially overheat. This risk is mitigated through the use of controls on all heat transfer systems as described previously. Overheating could cause damage to the equipment and maybe even loss of containment.

[36] Cheremisinoff, Rosenfeld, and Davletshin. pg. 247-253
[37] Hall. pg. 334-336

This is also true for the Duratherm S HTF. For loss of flow, a switch is in place to shut down F-01 in order to prevent overheating. The sensors on flowrates are extremely important to prevent this from happening. The amount of cooling water, HTF, or flue gas used correlates to the amount of process fluid going through the system. There is also an inherent risk with using Duratherm S as a heating medium. As mentioned before, Duratherm S was chosen over other oils because of its higher flashpoint; however, leaks could result in fire. Once exposed to air, the hot oil may smoke a little as it is being oxidized. This is not the biggest danger though. It is important to use nonporous insulation near areas such as valves and flanges which are prone to leaks. Porous insulation such as mineral wool or fiberglass will absorb the oil and leave it unreacted with oxygen. This unreacted oil poses a catastrophic risk as it has the potential to burst into flames if the oxygen supply were to abruptly increase. Furthermore, it is necessary to provide suitable ventilation at all times so unreacted vapor is not accumulating in the event of low volume leaks. Finally, it is important to regularly perform fluid analysis to check for oxidation or contamination of Duratherm S.[38] Duratherm Heat Transfer Fluids will do used oil analysis on the system annually upon request.

Startup and Shutdown Considerations

Exact startup and shutdown instructions are beyond the scope of this project; however, there are a few important things to mention. Initially, the process fluid will be too viscous to reach its target flow rate. Because of this, it is important to gradually heat the process fluid. At slower flow rates it is easy to overheat the process fluid and damage the equipment due to the increased heat transfer. Damage of the equipment can be very dangerous and very costly. Damaged equipment can cause loss of containment, which is dangerous with process fluids of such high temperature and pressure. Therefore, during startup it is necessary to gradually increase the applied heat until the flow rate has increased to full capacity.

When shutting down, it is necessary to turn off the heat exchangers before the pumps to allow cooling to take place. This avoids damage to the equipment because this prevents the hot fluid from being trapped in the system and thermally degrading the equipment.

Environmental Concerns

Environmental aspect (EA) refers to the issues that a management needs to address for a process including public safety, worker protection, property damage, compliance, emissions, and waste

[38]"10 Tips: Hot Oil Systems." *Industrial Thermal Fluid Heating*. Process Heating RSS. Web.

management. An environmental management system (EMS) is a list of prioritized EAs for a particular business or industry and the plan to address these issues. The International Standards Organization (ISO) standard 14001 is commonly used to "find a common basis for managing the environment affected by a business's operations". According to ISO 14001, the most significant EAs to consider for a business's EMS are emissions to air, waste management, releases to water bodies, contamination of land, and use of raw materials and natural resources.[39]

As for the project, nylon 6,6 itself is not very reactive and also not very harmful. However, it is very difficult to recycle or repurpose. Furthermore, if burned, it produces hazardous smoke containing hydrogen cyanide and nitrous oxide.[40] Making the monomer, adipic acid, has a significant impact on the environment because it produces nitrous oxide. Although the design does not include manufacturing the adipic acid, by buying this reactant it will still increase the amount of nitrous oxide introduced into the atmosphere. Nitrous oxide is a greenhouse gas that is 310 times more potent than carbon dioxide and is a major cause of climate change.[41] As of 1991, the production of nylon, and the subsequent production of nitrous oxide, has accounted for 10% of the increase in the atmospheric N_2O.

Emissions to Air

In order to minimize any emissions to air, plans have been made to equip all process equipment with pressure relief valves that vent to a flare system which includes a knock-out drum to prevent nylon from being burned. It is anticipated that the flare system will only be utilized in cases of over-pressurization or in an emergency. Pumps are designed to have mechanical seals. Regular inspection of all valves and flanges is recommended. Fired heater, F-01, will produce some carbon emissions as it requires fuel gas. From hand calculations, it was found that the emissions meet environmental standards. Additionally, the flue gas is repurposed as a heating source for E-01 before going out the stack.

Waste Management

In order to optimize this project from an economics standpoint, conversion was varied in order to find the optimal PFR reactor size and volume of raw materials. As conversion increases, reactor size increases, but less raw materials are needed in order to achieve the desired nylon 6,6 molecular

[39] Cheremisinoff, Rosenfeld, and Davletshin. pg. 1-5
[40] Anne, Patty and Anne, Leigh. https://oecotextiles.wordpress.com/2012/06/05/nylon-6-and-nylon-66/
[41] "Nitrous Oxide" http://apps.sepa.org.uk/spripa/Pages/SubstanceInformation.aspx?pid=8

weight. As conversion decreases, reactor size decreases, but more raw materials are needed and thus more waste is produced. The leftover reactants cannot be recycled in the process; that would be like trying to un-bake a cake. A produced water solution will be separated from the nylon solution in the wiped-wall thin film evaporator. This produced water solution will be sent to a treatment facility.

Releases to Water Bodies

All cooling water output from the process heat exchangers will be monitored to ensure no nylon or reactant presence. The facility will recycle all cooling water and only release water once the EPA requirements are met.

Contamination of Land

The creation of containment troughs around the processing facility is recommended in order to prevent potentially-contaminated rainwater and other drainage from escaping into the Calvert City drainage system or the nearby river.

Use of Raw Materials and Natural Resources

A high volume of adipic acid and HMDA are utilized for this process. These raw materials are almost exclusively used to make nylon. The process utilizes a synthetic HTF, Duratherm S. This fluid gets recycled and reused throughout the process. It is anticipated to have a 10-year life and Duratherm Heat Transfer Fluids will do a used oil analysis to help identify when it should be replaced. Additional energy and cooling water are needed for this process.

ECONOMIC ANALYSIS

Capital Cost Estimates

As aforementioned, a hurdle rate or ROR of 15% and an effective tax rate of 40% is assumed. An assumption is made that 100% of the capital costs will be incurred in 2017 with production beginning in the subsequent year. A modified accelerated cost recovery system (MACRS) depreciation over 10 years is used based upon the United States tax code 13.3.[42] Turton et.al "Chapter 7: Estimation of Capital Costs" is used as a guide for the capital cost estimation. The process equipment estimates and values from this book are for US dollars in 2001, thus all values need to be escalated to US dollars in 2017, which is year 0 for the economic analysis. This is done using the Chemical Engineering Plant

[42] "Publication 946, How To Depreciate Property." IRS. Web.

Cost Index (CEPCI).[43] By graphing all values from 1990 to 2016 and fitting the data with a polynomial trend line, the CEPCI value for 2017 (see Figure 8) is aproximated. The polynomial trend line function predicted the 2017 CEPCI value to be 542.34.

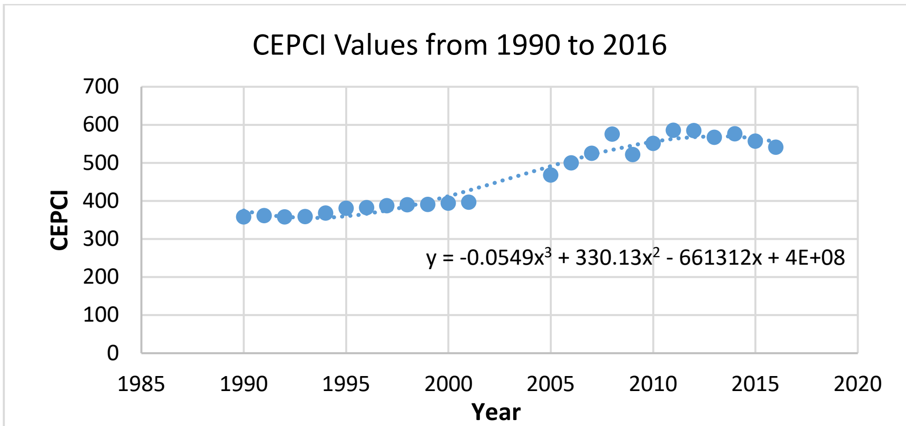

Figure 8: Historical CEPCI Values

Using equations 14, 15, and 16, found in Appendix D, the grassroots cost, in 2017 dollars, was calculated for each piece of equipment in the process. The grassroots cost refers to a completely new facility in which construction is started on undeveloped land. Since the process is beginning on from essentially ground zero, there are additional cost factors that are added in order to account for contingency and contractor fee costs and auxiliary facilities costs such as site development, auxiliary buildings, and off-sites and utilities.[44] The grassroots cost is calculated from the bare module cost via equations 15 and 16. The bare module cost takes into account the size, pressure, and materials of construction. Other variables are specific to each type of equipment and can be found in Turton et al. The sizing and costing variables for each piece of equipment can be found in Appendix A. The total capital costs associated with the proposed nylon 6,6 polymerization process can be found in Table 15. Please note that a backup pump has been included for each required pump in the process.

Table 15 shows the estimated capital costs for the process. The capital costs are the same for both the full capacity and turn-down case, as the process equipment remains unchanged regardless of the volumetric flow rate. The spreadsheets attached in Appendix A show more detailed cost calculations.

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[43] "Economic Indicators - CEPCI." *Chemical Engineering*. Oct. 2016. Web.
[44] Turton, pg. 175, 193

Table 15: Capital Costs

Equipment	Capital Costs
M-01 (Mixer)	$74,000
P-01 (Centrifugal Pump 1)	$67,900
E-01 (Economizer)	$201,500
P-02 (Centrifugal Pump 2)	$132,200
E-02 (Feed Heater)	$290,400
R-01 (PFR)	$66,600
R-02 (Thin-Film Evaporator)	$875,800
E-03 (Condenser)	$150,700
T-01 (Water Holdup)	$185,500
C-01 (Screw Conveyor)	$42,900
B-01 (Belt conveyor)	$247,700
P-03 (HTF Circulation Pump)	$97,700
T-02 (HTF Expansion Tank)	$50,500
HTF total	$117,800
TOTAL CAPITAL COSTS	**$2,258,000**

Please refer to Appendix A for exact costing and sizing for each piece of equipment.

Revenue and Operating Expense Estimates

Revenue and operating expenses are both dependent on the amount of nylon 6,6 product produced by the process system. The assumed service factor is 0.90, which means that the process is on line for 90% of each year. The 10% of the year that the process is offline is used for routine maintenance, cleaning, and inspection. Although downtime reduces utility use and raw material costs, it also reduces total revenue. Furthermore, start-up can be quite challenging, so it is important to keep the process running as much as possible. Utility costs are assumed to be relatively constant from year-to-year based upon past data and long-term negotiations; however, uncertainty in the utility prices has been taken into account in the sensitivity analysis.[45] If there are any variations in the utility costs, it will be reflected in the nylon 6,6 sale price. The washout assumption was made for both raw material costs and in product revenue changes because the Consumer Price Index (CPI) and Producers Price Index (PPI) for polymers have been nearly constant since 1990.[46] All other annual costs were estimated using the following heuristics from Turton et al:

[45] "Electric Power Monthly with Data for August 2016." U.S. Energy Information Administration, Oct. 2016. Web.

[46] "Producer Price Index by Commodity for Rubber and Plastic Products." Federal Reserve Bank of St. Louis. Web.

- Maintenance is expected to be 4% of the fixed capital plant cost,
- Insurance is estimated to be 3.2% of the fixed capital plant cost,
- Plant overhead – the costs associated with operations of auxiliary facilities supporting the manufacturing process (i.e. accounting services, fire protection services, payroll and employee benefits, general engineering, etc.) – is estimated to be 70.8% of the labor cost and 3.6% of the fixed capital plant cost,
- Administration costs are estimated to be 17.7% of the labor cost and 0.9% of the fixed capital plant cost,
- Laboratory costs (to ensure quality control) are estimated to be 10% of the labor cost, and
- Operating supply costs and other miscellaneous expenses (i.e. lubricants, protective clothing, filters) are 0.9% of the fixed capital plant cost.[47]

Raw material costs were estimated using the quote provided by Invista. The amount of raw material required was estimated on the basis of 85 MMlb/yr of nylon 6,6 production with an assumed overall conversion of 90%. This assumption is based on the fact that the PFR was sized in the Excel model to achieve 90% conversion. Even if 90% conversion is not quite reached in the first stage, the evaporator will provide some additional conversion while driving up the molecular weight. Annual nylon 6,6 production rate and the expected annual revenue in 2017 dollars is given.

Table 16: Nylon 6,6 Yearly Production and Associated Revenue

Flow	MMlb/yr	Annual Revenue
Nylon 6,6 (full capacity)	89.7	$ 106,000,000
Nylon 6,6 (67% capacity)	59.2	$ 69,800,000

Required utilities include fuel gas for the fired heater F-01, electricity for the pumps, cooling water for the condenser E-03, and treatment for wastewater coming out of the condenser. Duty for each utility was calculated within the Aspen Plus simulation, and then the associated costs were estimated using prices from a Phillips 66 Design Project Statement.[48]

Table 17 below shows each utility and the cost per year. More detailed calculations of these values can be found in Appendix A.

[47] Turton, pg. 206
[48] Phillips 66, Oct. 21, 2016. *Proposed Ponca City Propylene Fractionation System* [Memorandum].

Table 17: Annual Utility Costs

Utilities	Full Capacity Case ($/yr)	Turndown Case ($/yr)
78% efficient Fuel Gas	397,600	262,300
Electricity	32,600	32,600
Cooling Water	24,900	16,400
Treatment	800	500
TOTAL UTILITY COSTS	455,000	311,300

Labor costs for operation were estimated as a function of unit operations (from procedure in Chapter 8.2 in Turton et al). A competitive salary of $65,000 was estimated for each operator. Maintenance costs, incurred annually, were estimated to be 6% of the total capital investment.

Table 18: Annual Cost of Labor

Cost of Operating Labor		
N_{np}	6	# of equipment
N_{OL}	6.27	# of operators per shift
N_{OLT}	29	# of operators to cover 3 shifts
W	$65,000	Wage average per 2080 hour year
Operating Labor	$1,885,000	Operating labor/year

DCFROR Analysis

A project hurdle rate of 15% was assumed for the project along with a 10 year project evaluation life. 10 year MACRS was used to depreciate equipment. Tax rate was assumed to be 40%. Since this is a grassroots plant, the grassroots factor from Turon et al was applied to all equipment costed. Equipment costs presented are grassroots costs (used costing factors from Turton). Production was assumed to start at the beginning of 2018. Table 19 below presents the findings of the analysis, which evaluated both the full production and turndown capacities.

Table 19: Economic Analysis for Full-Capacity and Turndown Cases

	NPV ($)	DCFROR	PWC	Payback Period
Full Capacity	$ 34,300,000	333%	$ (2,370,666)	0.337 years
Turndown Capacity	$ 20,300,000	212%	$ (2,370,666)	0.514 years

A cash flow timeline was generated for the 10 year evaluation life for both the full capacity and turndown cases, which is shown below in Tables 20 and 21.

Table 20: 10-year Cash Flow Table for Full Capacity Process

Full Capacity

Minimum rate of return, i		0.15
Total Capital Costs	$	2,257,777
Nylon 66 Price ($/lb)	$	1.18
ADA Price ($/lb)	$	0.68
HMDA Price ($/lb)	$	1.13
H2O Price ($/lb)	$	0.00003
Operating Cost	$	455,085
Raw Material Cost	$	91,538,899
10 Year MACRS		

	0	1	2	3	4	5	6	7	8	9	10
End of Year	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Production Nylon 66 Chips (lb)	-	89,682,077	89,682,077	89,682,077	89,682,077	89,682,077	89,682,077	89,682,077	89,682,077	89,682,077	89,682,077
x Sales Price ($/pound)	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.18
Sales Revenue	-	105,765,801	105,765,801	105,765,801	105,765,801	105,765,801	105,765,801	105,765,801	105,765,801	105,765,801	105,765,801
Net Revenue	-	105,765,801	105,765,801	105,765,801	105,765,801	105,765,801	105,765,801	105,765,801	105,765,801	105,765,801	105,765,801
- Raw Material Cost	-	(91,538,899)	(91,538,899)	(91,538,899)	(91,538,899)	(91,538,899)	(91,538,899)	(91,538,899)	(91,538,899)	(91,538,899)	(91,538,899)
- Operating Costs	-	(455,085)	(455,085)	(455,085)	(455,085)	(455,085)	(455,085)	(455,085)	(455,085)	(455,085)	(455,085)
- Labor Costs	-	(1,885,000)	(1,885,000)	(1,885,000)	(1,885,000)	(1,885,000)	(1,885,000)	(1,885,000)	(1,885,000)	(1,885,000)	(1,885,000)
- Depreciation	-	(225,778)	(406,400)	(325,120)	(260,096)	(208,167)	(166,398)	(147,884)	(147,884)	(148,110)	(147,884)
- Maintenance	-	(135,467)	(135,467)	(135,467)	(135,467)	(135,467)	(135,467)	(135,467)	(135,467)	(135,467)	(135,467)
- Loss Forward	-	(2,370,666)									
- Writeoff	-										(74,055)
Taxable Income	-	9,154,907	11,344,950	11,426,230	11,491,254	11,543,183	11,584,952	11,603,466	11,603,466	11,603,240	11,529,411
- Tax @ 40%	-	(3,661,963)	(4,537,980)	(4,570,492)	(4,596,502)	(4,617,273)	(4,633,981)	(4,641,386)	(4,641,386)	(4,641,296)	(4,611,764)
Net Income	-	5,492,944	6,806,970	6,855,738	6,894,753	6,925,910	6,950,971	6,962,080	6,962,080	6,961,944	6,917,647
+ Depreciation	-	225,778	406,400	325,120	260,096	208,167	166,398	147,884	147,884	148,110	147,884
+ Loss Forward	-	2,370,666									
+ Writeoff	-										74,055
- Construction Cost	-										
- Working Capital (5% tot. Cap)	(112,889)										
- Fixed Capital	(2,257,777)										
Cash Flow	(2,370,666)	8,089,388	7,213,370	7,180,858	7,154,849	7,134,077	7,117,369	7,109,964	7,109,964	7,110,054	7,139,586
Discount factor ($P/F_{i^*,n}$)	1.00	0.87	0.76	0.66	0.57	0.50	0.43	0.38	0.33	0.28	0.25
Discounted Cash Flow	(2,370,666)	7,034,250	5,454,344	4,721,531	4,090,808	3,546,897	3,077,035	2,672,899	2,324,260	2,021,121	1,764,796
NPV @ i^*=	34,337,276										
DCFROR=	333%										

Table 21: 10-year Cash Flow Table for 67% Capacity Process

Design Project

Minimum rate of return, i	0.15
Total Capital Costs	$ 2,257,777
Nylon 66 Price ($/lb)	$ 1.18
ADA Price ($/lb)	$ 0.68
HMDA Price ($/lb)	$ 1.13
H2O Price ($/lb)	$ 0.00003
Operating Cost	$ 311,301
Raw Material Cost	$ 60,337,032
10 Year MACRS	

	0	1	2	3	4	5	6	7	8	9	10
End of Year	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Production Nylon 66 Chips (lb)	-	59,161,536	59,161,536	59,161,536	59,161,536	59,161,536	59,161,536	59,161,536	59,161,536	59,161,536	59,161,536
x Sales Price ($/pound)	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.18
Sales Revenue	-	69,771,658	69,771,658	69,771,658	69,771,658	69,771,658	69,771,658	69,771,658	69,771,658	69,771,658	69,771,658
Net Revenue	-	69,771,658	69,771,658	69,771,658	69,771,658	69,771,658	69,771,658	69,771,658	69,771,658	69,771,658	69,771,658
- Raw Material Cost	-	(60,337,032)	(60,337,032)	(60,337,032)	(60,337,032)	(60,337,032)	(60,337,032)	(60,337,032)	(60,337,032)	(60,337,032)	(60,337,032)
- Operating Costs	-	(311,301)	(311,301)	(311,301)	(311,301)	(311,301)	(311,301)	(311,301)	(311,301)	(311,301)	(311,301)
- Labor Costs	-	(1,885,000)	(1,885,000)	(1,885,000)	(1,885,000)	(1,885,000)	(1,885,000)	(1,885,000)	(1,885,000)	(1,885,000)	(1,885,000)
- Depreciation	-	(225,778)	(406,400)	(325,120)	(260,096)	(208,167)	(166,398)	(147,884)	(147,884)	(148,110)	(147,884)
- Maintenance	-	(135,467)	(135,467)	(135,467)	(135,467)	(135,467)	(135,467)	(135,467)	(135,467)	(135,467)	(135,467)
- Loss Forward	-	(2,370,666)									
- Writeoff	-										(74,055)
Taxable Income	-	4,506,415	6,696,459	6,777,739	6,842,763	6,894,692	6,936,461	6,954,974	6,954,974	6,954,749	6,880,919
- Tax @ 40%	-	(1,802,566)	(2,678,584)	(2,711,096)	(2,737,105)	(2,757,877)	(2,774,584)	(2,781,990)	(2,781,990)	(2,781,899)	(2,752,368)
Net Income	-	2,703,849	4,017,875	4,066,643	4,105,658	4,136,815	4,161,876	4,172,985	4,172,985	4,172,849	4,128,552
+ Depreciation	-	225,778	406,400	325,120	260,096	208,167	166,398	147,884	147,884	148,110	147,884
+ Loss Forward	-	2,370,666									
+ Writeoff	-										74,055
- Construction Cost	-										
- Working Capital (5% tot. Cap)	(112,889)										
- Fixed Capital	(2,257,777)										
Cash Flow	(2,370,666)	5,300,293	4,424,275	4,391,763	4,365,754	4,344,982	4,328,275	4,320,869	4,320,869	4,320,959	4,350,491
Discount factor ($P/F_{i^*, n}$)	1.00	0.87	0.76	0.66	0.57	0.50	0.43	0.38	0.33	0.28	0.25
Discounted Cash Flow	(2,370,666)	4,608,950	3,345,388	2,887,656	2,496,134	2,160,224	1,871,233	1,624,375	1,412,500	1,228,286	1,075,375
NPV @ i^*=	20,339,453										
DCFROR=	212%										

The plant is designed to be able to operate at turndown case, resulting in roughly 67% production capacity of nylon 6,6. To briefly examine the profitability of the plant in a constantly changing market, two hypothetical economic cases were considered.

For Case 1 the plant would operate at full capacity for the first 3 years, then at turndown capacity for the next 7 years due to a change in market demand of nylon 6,6. This would result in decreased sales revenue but with reduced raw material and utility costs for the process, but all other costs would remain the same. For Case 2 the plant would only operate at full capacity for the first operating year, then it would operate at turndown capacity for the remainder of the 10 year evaluation.
As expected, the NPV and DCFROR are still favorable. Results are shown in the Table 21 below.

Table 22: Hypothetical Case Economic Analysis

	NPV ($)	DCFROR
Case 1	$ 26,700,000	331%
Case 2	$ 22,800,000	303%

Sensitivity Analysis
A sensitivity analysis was done using tornado charts, all of which are shown below. Similar trends can be established between the full capacity and turndown cases for both the NPV and DCFROR analysis. Both operation situations yield a positive net present value, even when the worst case is considered.

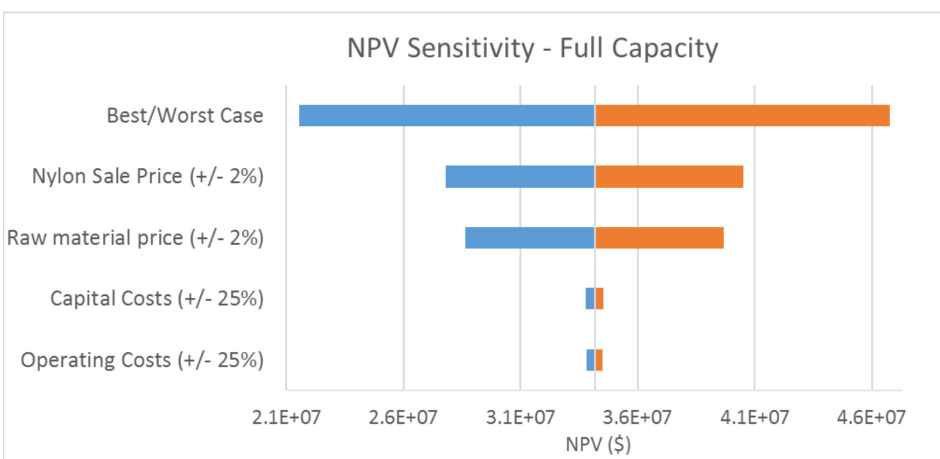

Figure 9: Full Capacity NPV Tornado Chart

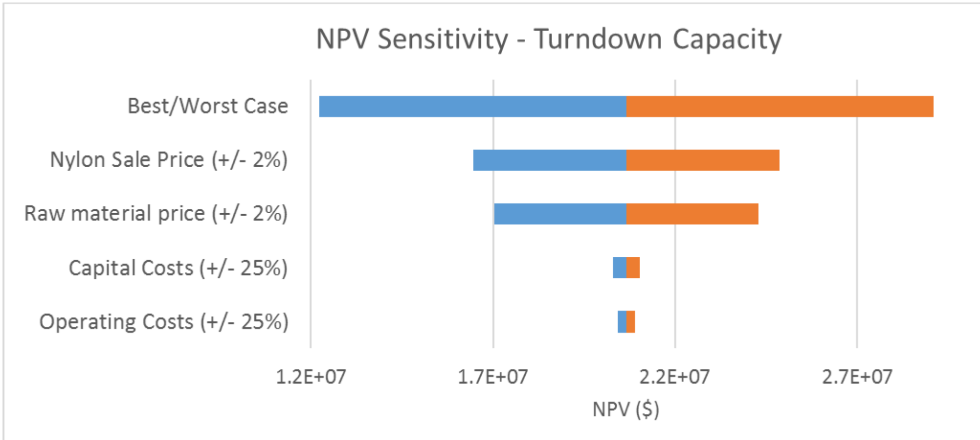

Figure 10: Full Capacity DCFROR Tornado Chart

Market conditions will play the largest role in the profitability of the process. As can be seen, a 2 percent price variation in raw material or nylon will have a much larger impact on the project NPV compared to a 25 percent variation in either capital or operating costs.

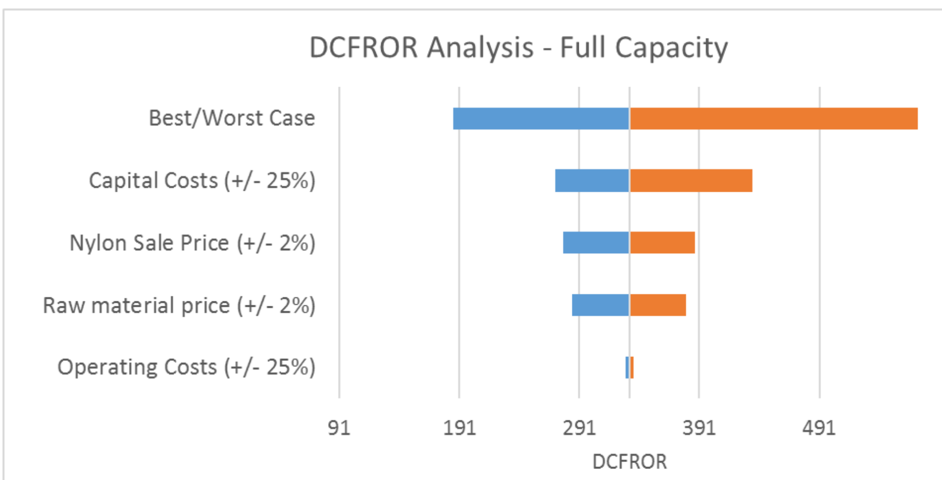

Figure 11: Turndown NPV Tornado Chart

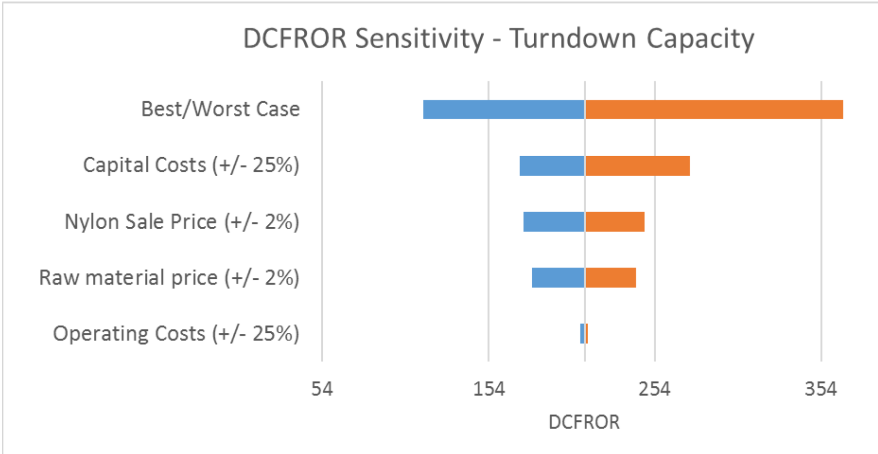

Figure 12: Turndown DCFROR Tornado Chart

CONCLUSIONS

Based upon this design, adipic acid and hexamethyenediamine are combined to produce nylon 6,6 pellets. This process was designed to meet the requirement that 85 million pounds of nylon 6,6 be produced annually. In fact, conservative sizing estimates were used such that the process is capable of producing 90 million pounds of nylon with a service factor of 0.90. The results shown in this report have been verified by Aspen Plus and vigorous hand calculations using Microsoft Excel as show in Appendix B.

The aforementioned economic analysis shows that the proposed process is quite profitable. Even in the 67% capacity turndown case, the NPV is positive. Evaluated over a 10-year project life, the full-scale process has an NPV of $34,300,000, and the turndown case has an NPV of $20,300,000.

RECOMMENDATIONS

We suggest that this grassroots manufacturing plant be located in the industrial park in Calvert City, Kentucky. A 30-acre plot of undeveloped, unrestricted land located has been found at 150 Industrial Pkwy, Calvert City. The land is about a mile away from the Tennessee River and is posted for

$80,000.[49] This plot of land is large enough for the process, extra storage, any necessary administration buildings, and employee parking. Furthermore, should the company expand into other manufacturing processes, there is enough land to do so.

In order to maintain the high temperatures at which the process operates and to avoid contamination of the product, the entire nylon 6,6 manufacturing process must occur indoors. It is anticipated that a warehouse-like building will be constructed in which the manufacturing process will take place, the excess reactants and product will be stored, and the control room will be located. This warehouse should be well-insulated so as to minimize the effects of ambient temperature, which historically has ranged anywhere from -9°F in the winter and 107°F in the summer.[50]

Further consideration should be taken for the produced water waste stream in the process. In the current design, this waste is sent to a water treatment facility and associated costs are considered. Moving forward, it may be beneficial to treat this water onsite and send it to the nearby river if the EPA standards can be met.

For the turndown case, changes may be necessary for the temperature set point on the WFE. Because a higher conversion is reached in the PFR, the molecular weight number of the nylon may be too high (above 20,000) exiting the WFE. This can be avoided by slightly lowering the temperature set point in the WFE. This will prevent the viscosity from becoming too high to finish the processing. This would require an empirical relationship between the amount of flow and the average molecular weight to be developed. If the viscosity can be measured directly, development of this empirical relationship can be avoided as the temperature would be lowered if the viscosity set point was exceeded.

The proposed process produces nylon chips. This design was chosen because it is inherently safer than the design for producing fiber due to the simplification from reduced equipment and steps. Furthermore, it requires less human input and allows us to hire fewer employees to run the process. If further evaluation finds that the reduced simplicity of the nylon fiber-spinning process is worth the additional revenue, the plant can be retrofitted with little effort.

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Based upon the conclusion of this report, it is the recommendation of the authors that the design of this process move from preliminary design to the detailed design phase.

ACKNOWLEDGEMENTS

Several software and resources have been employed in order to complete this process. Due to its capabilities to model the series of complex reactions taking place during condensation polymerization, Aspen Plus has been utilized. Most calculations for capital and operating costs have been derived from Richard Turton's textbook *Analysis, Synthesis, and Design of Chemical Processes.* The equipment and sizing information has been documented in Microsoft Excel. The process PFDs and Piping and Instrumentation Diagrams (P&IDs) have been created using Microsoft Visio. All other resources can be found in the "References" section of this report.

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Appendix A: Equipment Costing and Sizing Tables

The following tables are from the spreadsheet used for costing and sizing of equipment for the full capacity case (p. 51-57). The turndown case tables begin on page 57.The tables used for the same pieces of equipment are grouped together. Grass Roots Cost is calculated as the capital cost.

M-01	
Purchase Cost, Cp (2001)	$18,598.10
Base Purchase Cost, Cpo (2001)	$5,999.39
Installed Cost, CBM (2001)	$37,208.21
Volume (m^3)	3.324
K1	3.5565
K2	0.3776
K3	0.0905
Design Pressure, barg	3.44
Pressure Factor, Fp	1
D (m)	1.1215
P operating (barg)	0
C3	0
FM, from Figure A.18	3.1
FBM	6.202
B1	1.49
B2	1.52
Purchase Cost, Cp (2016)	$25,603.08
Base Purchase Cost, Cpo (2016)	$8,259.06
Installed Cost, CBM (2016)	$51,222.67
2017 CEPCI (extrapolated)	542.4
2001 CEPCI	394

Total Costs for M-01		
Purchase Cost	$	25,603.08
Installed Cost	$	51,222.67
Grass Roots Cost	$	74,028.90

P-01 (Centrifugal Pump 1)	
Purchase Cost, Cp (2001)	$8,293.32
Base Purchase Cost, Cpo (2001)	$2,955.61
Installed Cost, CBM (2001)	$16,782.08
Shaft Power, kW	3.75
K1	3.3892
K2	0.0536
K3	0.1538
Design Pressure, barg	18.65
Pressure Factor, Fp	1.275435684
C1	-0.3935
C2	0.3957
C3	-0.00226
FM, from Figure A.18	2.2
FBM	5.678043983
B1	1.89
B2	1.35
Purchase Cost, Cp (2016)	$11,416.99
Base Purchase Cost, Cpo (2016)	$4,068.84
Installed Cost, CBM (2016)	$23,103.04
2017 CEPCI (extrapolated)	542.4
2001 CEPCI	394

Total Costs for P-01		
Purchase Cost	$	11,416.99
Installed Cost	$	23,103.04
Grass Roots Cost 2 pumps	$	67,909.66

P-01 Electricity		
Motor efficiency		0.8
Purchase hp (kW)		4.69
Cost ($/yr)	$	2,586.94

E-01 (Economizer)	
Purchase Cost, Cp (2001)	46072.85118
Base Purchase Cost, Cpo (	15718.4086
Installed Cost, CBM (2001	102101.939
Area cacl from below (m^2	15.85407803
K1	4.3247
K2	-0.303
K3	0.1634
Design Pressure, barg	18.65
Pressure Factor, Fp	1.065868975
C1	0.03881
C2	-0.11272
C3	0.08183
FM, from Figure A.18	2.75
FBM	6.495691872
B1	1.63
B2	1.66
Purchase Cost, Cp (2016)	63426.17888
Base Purchase Cost, Cpo (	21638.74321
Installed Cost, CBM (2016	140558.6084
2017 CEPCI (extrapolated)	542.4
2001 CEPCI	394

Total Costs for E-01		
Purchase Cost	$	63,426.18
Installed Cost	$	140,558.61
Grass Roots Cost	$	201,454.89

E-01 Flue Calc	
Qprocess (kJ/hr)	10921237.28
Heater eff	0.78
Qreq (kJ/hr)	14073759.38
Gas HV (kJ/lb)	21100.00
NG (lg/hr)	667.00
NG (mol/hr)	18909.53
Combustion products	
CO2 (mol/hr)	18909.53
CO2 (kg/hr)	832.02
H2O (mol/hr)	37819.06
H2O (kg/hr)	680.74
N2 (mol/hr)	136148.61
N2 (kg/hr)	3812.16
Total flue mass (kg/hr)	5324.92
Cp (kJ/kg*K)	1.09
dT flue ©	70.00
Qflue (kJ/hr)	406291.67

E-01 Area Calculation	
Flue Tin (K)	473
Flue Tout (K)	403
Feed Tin (K)	305
Feed Tout (K)	331
ΔTlm (K)	118.6432885
U (W/m^2*K)	60
Q (W)	1.13E+05
Area (m^2)	15.85407803

P-02 (Centrifugal Pump 2)	
Purchase Cost, Cp (2001)	$19,733.87
Base Purchase Cost, Cpo (2001)	$4,281.04
Installed Cost, CBM (2001)	$34,731.90
Shaft Power, kW	12.39
K1	3.3892
K2	0.0536
K3	0.1538
Design Pressure, barg	66.88
Pressure Factor, Fp	2.095270388
C1	-0.3935
C2	0.3957
C3	-0.00226
FM, from Figure A.18	2.2
FBM	8.112953052
B1	1.89
B2	1.35
Purchase Cost, Cp (2016)	$27,166.63
Base Purchase Cost, Cpo (2016)	$5,893.50
Installed Cost, CBM (2016)	$47,813.67
2017 CEPCI (extrapolated)	542.4
2001 CEPCI	394

Total Costs for P-02		
Purchase Cost	$	27,166.63
Installed Cost	$	47,813.67
Grass Roots Cost 2 pumps	$	132,229.85

P-02 Electricity		
Motor efficiency		0.8
Purchase hp (kW)		15.49
Cost ($/yr)	$	8,547.24

E-02 (Feed Heater)	
Purchase Cost, Cp (2001)	70880.82075
Base Purchase Cost, Cpo (2001)	20206.90966
Installed Cost, CBM (2001)	150599.4252
Area calc from below, (m^2)	50.31054569
K1	4.8306
K2	-0.8509
K3	0.3187
Design Pressure, barg	66.88
Pressure Factor, Fp	1.275546056
C1	0.03881
C2	-0.11272
C3	0.08183
FM, from Figure A.18	2.75
FBM	7.452867744
B1	1.63
B2	1.66
Purchase Cost, Cp (2016)	97578.0639
Base Purchase Cost, Cpo (2016)	27817.83705
Installed Cost, CBM (2016)	207322.6605
2017 CEPCI (extrapolated)	542.4
2001 CEPCI	394

Total Costs for E-02		
Purchase Cost	$	97,578.06
Installed Cost	$	207,322.66
Grass Roots Cost	$	290,401.08

E-02 Area	
DOW Therm G Tin (K)	573
DOW Therm G Tout (K)	553
Feed Tin (K)	327
Feed Tout (K)	548
ΔTlm (K)	91.29478456
U (W/m^2*K)	280
Q (W)	1157458.788
Area (m^2)	50.31054569

E-02 HTF Flow	
Q (kJ/hr)	4166851.638
Cp (kJ/kg*K)	2.214
m (kg/hr)	94102.34
rho (kg/L)	0.89
m (gpm)	465.5281554

E-02 HTF Volume	
Area (ft^2)	541.54
Pipe D (in)	1.52
# of 16' segments	85.05
Vtubes (ft^3)	17.14870988
Shell D (ft)	2.5
Vtot (ft^3)	78.53981634
Vfluid (gal)	459.2373997
Cost ($)	$22,961.87

R-01 (PFR)	
Purchase Cost, Cp (2001)	15976.69873
Base Purchase Cost, Cpo (2001)	5166.135683
Installed Cost, CBM (2001)	33752.95912
Area, m^2	127.6902847
K1	3.3444
K2	0.2745
K3	-0.0472
Design Pressure, barg	66.88
Pressure Factor, Fp	1.124575308
C1	0.6072
C2	-0.912
C3	0.3327
FM, from Figure A.18	2.75
FBM	6.533502252
B1	1.74
B2	1.55
Purchase Cost, Cp (2016)	22014.59325
Base Purchase Cost, Cpo (2016)	7118.515387
Installed Cost, CBM (2016)	46508.83631
2017 CEPCI (extrapolated)	542.9
2001 CEPCI	394

Total Costs for R-01 (PFR)		
Purchase Cost	$	22,014.59
Installed Cost	$	46,508.84
Grass Roots Cost	$	66,590.38

R-01 Area	
D (in)	1.50E+00
L (ft)	3500
A (m^2)	127.69

R-01 HTF Flow	
Q (kJ/hr)	3889649.819
Cp (kJ/kg*K)	2.214
m (kg/hr)	87842.14
rho (kg/L)	0.89
m (gpm)	434.5586698

R-01 HTF Volume	
Area (ft^2)	1374.45
Inner Pipe OD (in)	1.66
Outer Pipe ID (in)	2.16
A2 (ft^2)	0.025399798
A1 (ft^2)	0.015029467
Vannulus (ft^3)	36.29616165
Vfluid (gal)	271.5141631
Cost ($)	$13,575.71

R-02 (Evaporator)	
Base Purchase Cost, Cpo (2001)	150001.4354
Installed Cost, CBM (2001)	330003.1579
Area calc from below, (m^2)	22.1
K1	5
K2	0.149
K3	-0.0134
Design Pressure, barg	5.778
Pressure Factor, Fp	1
C1	0
C2	0
C3	0
FBM	2.2
Base Purchase Cost, Cpo (2016)	206499.438
Installed Cost, CBM (2016)	454298.7635
2017 CEPCI (extrapolated)	542.4
2001 CEPCI	394

Total Costs for R-02		
Installed Cost	$	454,298.76
Grass Roots Cost	$	875,764.12

R-02 Area Calculation	
Vapor Volumetric Flow (m3/s)	0.4706
Diameter (m)	0.774071398
Film Thickness (m)	0.0127
Liquid Volume (m3)	0.295708
Height (m)	9.734483699
Area (m2)	22.89570585

R-02 HTF Flow	
Q (kJ/hr)	2864735.825
Cp (kJ/kg*K)	2.214
m (kg/hr)	64695.93
rho (kg/L)	0.89
m (gpm)	320.05

R-02 HTF Volume	
Area (ft^2)	246.45
Vfluid (gal)	317.93
Cost ($)	$15,896.39

E-03 (Condenser)	
Purchase Cost, Cp (2001)	19800.37797
Base Purchase Cost, Cpo (2001)	19800.37797
Installed Cost, CBM (2001)	65143.24352
Area cacl from below (m^2)	10.1902958
K1	4.8306
K2	-0.8509
K3	0.3187
Design Pressure, barg	4.75
Pressure Factor, Fp	1
C1	0
C2	0
C3	0
FM, from Figure A.18	1
FBM	3.29
B1	1.63
B2	1.66
Purchase Cost, Cp (2016)	27258.18531
Base Purchase Cost, Cpo (2016)	27258.18531
Installed Cost, CBM (2016)	89679.42966
2017 CEPCI (extrapolated)	542.4
2001 CEPCI	394

Total Costs for E-03		
Purchase Cost	$	27,258.19
Installed Cost	$	89,679.43
Grass Roots Cost	$	150,661.44

E-03 Area Calculation	
CW Tin (K)	303
CW Tout (K)	322
Feed Tin (K)	528
Feed Tout (K)	373
ΔTlm (K)	-125.9981501
U (W/m^2*K)	900
Q (W)	-1155563
Area (m^2)	10.1902958

E-03 CW	
Q (kJ/hr)	-4160025
Cp (kJ/kg*K)	4.184
m (kg/hr)	52329.99495
Cost ($/yr)	$24,883.41

T-01	
Purchase Cost, Cp (2001)	25935.00687
Base Purchase Cost, Cpo (2001)	25935.00687
Installed Cost, CBM (2001)	78064.37067
Volume (m^3)	42.87
K1	3.5565
K2	0.3776
K3	0.0905
Design Pressure, barg	3.447
Pressure Factor, Fp	1
D (m)	2.63
P operating (barg)	0
FM, from Figure A.18	1
FBM	3.01
B1	1.49
B2	1.52
Purchase Cost, Cp (2016)	35703.42062
Base Purchase Cost, Cpo (2016)	35703.42062
Installed Cost, CBM (2016)	107467.2961
2017 CEPCI (extrapolated)	542.4
2001 CEPCI	394

Total Costs for T-01		
Purchase Cost	$	35,703.42
Installed Cost	$	107,467.30
Grass Roots Cost	$	185,543.54

C-01 (Screw Conveyor)	
Purchase Cost, Cp (2001)	10599.55142
Base Purchase Cost, Cpo (2001)	10599.55142
Installed Cost, CBM (2001)	11659.50656
Area (m2)	8.523039311
K1	3.6062
K2	0.2659
K3	0.1982
Design Pressure, barg	6.89476
Pressure Factor, Fp	1
FM, from Figure A.18	1
FBM	1.1
Purchase Cost, Cp (2016)	14591.86977
Base Purchase Cost, Cpo (2016)	14591.86977
Installed Cost, CBM (2016)	16051.05674
2017 CEPCI (extrapolated)	542.4
2001 CEPCI	394

Total Costs for C-01		
Purchase Cost	$	14,591.87
Installed Cost	$	16,051.06
Grass Roots Cost	$	42,943.87

C-01 Sizing	
flow (kg/hr)	5159.72
flow (kg/hr)	5159.720003
D (mm)	336.2146929
A (m^2)	8.523039311

B-01 (Belt Conveyor)	
Purchase Cost, Cp (2001)	57655.22411
Base Purchase Cost, Cpo (2001)	57655.22411
Installed Cost, CBM (2001)	72069.03013
Area (m2)	27.870912
K1	4.0637
K2	0.2584
K3	0.155
Design Pressure, barg	1
Pressure Factor, Fp	1
C1	0
C2	0
C3	0
FM, from Figure A.18	1
FBM	1.25
Purchase Cost, Cp (2016)	79371.04963
Base Purchase Cost, Cpo (2016)	79371.04963
Installed Cost, CBM (2016)	99213.81204
2017 CEPCI (extrapolated)	542.4
2001 CEPCI	394

Total Costs for B-01		
Purchase Cost	$	79,371.05
Installed Cost	$	99,213.81
Grass Roots Cost	$	247,637.67

B-01 Sizing	
Operating flow (ft^3/hr)	208.857
Belt Width (ft)	3.0
Height of solid (ft)	0.125
Belt vel (ft/min)	9.282533333
Belt Length Total (ft)	100
A (m^2)	27.870912

P-03 (HTF Circulation Pump)	
Purchase Cost, Cp (2001)	6489.570414
Base Purchase Cost, Cpo (2001)	6489.570414
Installed Cost, CBM (2001)	21026.20814
Shaft Power, kW	31.14
K1	3.3892
K2	0.0536
K3	0.1538
Design Pressure, barg	6.02
Pressure Factor, Fp	1
C1	0
C2	0
C3	0
FM, from Figure A.18	1
FBM	3.24
B1	1.89
B2	1.35
Purchase Cost, Cp (2016)	8933.865463
Base Purchase Cost, Cpo (2016)	8933.865463
Installed Cost, CBM (2016)	28945.7241
2017 CEPCI (extrapolated)	542.4
2001 CEPCI	394

Total Costs for P-03		
Purchase Cost	$	8,933.87
Installed Cost	$	28,945.72
Grass Roots Cost 2 pumps	$	97,704.33

P-03 Electricity		
Motor efficiency		0.8
Purchase hp (kW)		38.93
Cost ($/yr)	$	21,481.93

Appendix A: Equipment Costing and Sizing Tables

The following tables are from the spreadsheet used for costing and sizing of equipment for the turndown (67% capacity) case. The tables used for the same pieces of equipment are grouped together.

T-02 (HTF Expansion Tank)	
Purchase Cost, Cp (2001)	7062.316541
Base Purchase Cost, Cpo (2001)	7062.316541
Installed Cost, CBM (2001)	21257.57279
Volume (m^3)	4.652144092
K1	3.5565
K2	0.3776
K3	0.0905
Design Pressure, barg	4.55
Pressure Factor, Fp	1
D (m)	1.03
p operating (barg)	1.3
C3	0
FM, from Figure A.18	1
FBM	3.01
B1	1.49
B2	1.52
Purchase Cost, Cp (2016)	9722.336274
Base Purchase Cost, Cpo (2016)	9722.336274
Installed Cost, CBM (2016)	29264.23218
2017 CEPCI (extrapolated)	542.4
2001 CEPCI	394

Total Costs for Expansion Tank		
Purchase Cost	$	9,722.34
Installed Cost	$	29,264.23
Grass Roots Cost	$	50,525.04

Transfer Line/T-02 Sizing	
Transfer Line Sizing	
Pipe size (in)	7
Total Mass flow (cfs)	2.595833333
Velocity (ft/s)	9.712998813
Length (ft)	500
Transfer Piping (gal)	999.5977319
Cost ($)	$49,979.89
T-02 Sizing	
Volume sys (no tank) (gal)	2048.28
Volume sys (no tank) (m^3)	7.753573486
Vtank (gal)	307.2415522
Cost ($)	$15,362.08

M-01 (67%)	
Purchase Cost, Cp (2001)	$18,598.10
Base Purchase Cost, Cpo (2001)	$5,999.39
Installed Cost, CBM (2001)	$37,208.21
Volume (m^3)	3.324
K1	3.5565
K2	0.3776
K3	0.0905
Design Pressure, barg	3.44
Pressure Factor, Fp	1
D (m)	1.1215
P operating (barg)	0
C3	0
FM, from Figure A.18	3.1
FBM	6.202
B1	1.49
B2	1.52
Purchase Cost, Cp (2016)	$25,603.08
Base Purchase Cost, Cpo (2016)	$8,259.06
Installed Cost, CBM (2016)	$51,222.67
2017 CEPCI (extrapolated)	542.4
2001 CEPCI	394

Total Costs for M-01 (67%)		
Purchase Cost	$	25,603.08
Installed Cost	$	51,222.67
Grass Roots Cost	$	74,028.90

P-01 (Centrifugal Pump 1) (67%)	
Purchase Cost, Cp (2001)	$8,293.32
Base Purchase Cost, Cpo (2001)	$2,955.61
Installed Cost, CBM (2001)	$16,782.08
Shaft Power, kW	3.75
K1	3.3892
K2	0.0536
K3	0.1538
Design Pressure, barg	18.65
Pressure Factor, Fp	1.275435684
C1	-0.3935
C2	0.3957
C3	-0.00226
FM, from Figure A.18	2.2
FBM	5.678043983
B1	1.89
B2	1.35
Purchase Cost, Cp (2016)	$11,416.99
Base Purchase Cost, Cpo (2016)	$4,068.84
Installed Cost, CBM (2016)	$23,103.04
2017 CEPCI (extrapolated)	542.4
2001 CEPCI	394

Total Costs for P-01 (67%)		
Purchase Cost	$	11,416.99
Installed Cost	$	23,103.04
Grass Roots Cost for 2 pumps	$	67,909.66

P-01 Electricity (67%)		
Motor efficiency		0.8
Purchase hp (kW)		4.69
Cost ($/yr)	$	2,586.94

E-01 (Economizer) (67%)	
Purchase Cost, Cp (2001)	46072.85118
Base Purchase Cost, Cpo (2001)	15718.4086
Installed Cost, CBM (2001)	102101.939
Area cacl from below (m^2)	15.85407803
K1	4.3247
K2	-0.303
K3	0.1634
Design Pressure, barg	18.65
Pressure Factor, Fp	1.065868975
C1	0.03881
C2	-0.11272
C3	0.08183
FM, from Figure A.18	2.75
FBM	6.495691872
B1	1.63
B2	1.66
Purchase Cost, Cp (2016)	63426.17888
Base Purchase Cost, Cpo (2016)	21638.74321
Installed Cost, CBM (2016)	140558.6084
2017 CEPCI (extrapolated)	542.4
2001 CEPCI	394

Total Costs for E-01 (67%)		
Purchase Cost	$	63,426.18
Installed Cost	$	140,558.61
Grass Roots Cost	$	201,454.89

E-01 Area Calculation (67%)	
Flue Tin (K)	473
Flue Tout (K)	403
Feed Tin (K)	305
Feed Tout (K)	331
ΔTlm (K)	118.6432885
U (W/m^2*K)	60
Q (W)	1.13E+05
Area (m^2)	15.85407803

E-01 Flue Calc (67%)	
Qprocess (kJ/hr)	10921237.28
Heater eff	0.78
Qreq (kJ/hr)	14073759.38
Gas HV (kJ/lb)	21100.00
NG (lg/hr)	667.00
NG (mol/hr)	18909.53
Combustion products	
CO2 (mol/hr)	18909.53
CO2 (kg/hr)	832.02
H2O (mol/hr)	37819.06
H2O (kg/hr)	680.74
N2 (mol/hr)	136148.61
N2 (kg/hr)	3812.16
Total flue mass (kg/hr)	5324.92
Cp (kJ/kg*K)	1.09
dT flue ©	70.00
Qflue (kJ/hr)	406291.67

P-02 (Centrifugal Pump 2) (67%)	
Purchase Cost, Cp (2001)	$19,733.87
Base Purchase Cost, Cpo (2001)	$4,281.04
Installed Cost, CBM (2001)	$34,731.90
Shaft Power, kW	12.39
K1	3.3892
K2	0.0536
K3	0.1538
Design Pressure, barg	66.88
Pressure Factor, Fp	2.095270388
C1	-0.3935
C2	0.3957
C3	-0.00226
FM, from Figure A.18	2.2
FBM	8.112953052
B1	1.89
B2	1.35
Purchase Cost, Cp (2016)	$27,166.63
Base Purchase Cost, Cpo (2016)	$5,893.50
Installed Cost, CBM (2016)	$47,813.67
2017 CEPCI (extrapolated)	542.4
2001 CEPCI	394

Total Costs for P-02 (67%)		
Purchase Cost	$	27,166.63
Installed Cost	$	47,813.67
Grass Roots Cost for 2 pumps	$	132,229.85

P-02 Electricity (67%)		
Motor efficiency		0.8
Purchase hp (kW)		15.49
Cost ($/yr)	$	8,547.24

E-02 (Feed Heater) (67%)	
Purchase Cost, Cp (2001)	70880.82075
Base Purchase Cost, Cpo (2001)	20206.90966
Installed Cost, CBM (2001)	150599.4252
Area calc from below, (m^2)	50.31054569
K1	4.8306
K2	-0.8509
K3	0.3187
Design Pressure, barg	66.88
Pressure Factor, Fp	1.275546056
C1	0.03881
C2	-0.11272
C3	0.08183
FM, from Figure A.18	2.75
FBM	7.452867744
B1	1.63
B2	1.66
Purchase Cost, Cp (2016)	97578.0639
Base Purchase Cost, Cpo (2016)	27817.83705
Installed Cost, CBM (2016)	207322.6605
2017 CEPCI (extrapolated)	542.4
2001 CEPCI	394

Total Costs for E-02 (67%)		
Purchase Cost	$	97,578.06
Installed Cost	$	207,322.66
Grass Roots Cost	$	290,401.08

E-02 Area (67%)	
DOW Therm G Tin (K)	573
DOW Therm G Tout (K)	553
Feed Tin (K)	327
Feed Tout (K)	548
ΔTlm (K)	91.29478456
U (W/m^2*K)	280
Q (W)	1157458.788
Area (m^2)	50.31054569

E-02 HTF Volume (67%)	
Area (ft^2)	541.54
Pipe D (in)	1.52
# of 16' segments	85.05
Vtubes (ft^3)	17.14870988
Shell D (ft)	2.5
Vtot (ft^3)	78.53981634
Vfluid (gal)	459.2373997
Cost ($)	$22,961.87

E-02 HTF Flow (67%)	
Q (kJ/hr)	2746191.617
Cp (kJ/kg*K)	2.214
m (kg/hr)	62018.78
rho (kg/L)	0.89
m (gpm)	306.809464

R-01 (PFR) (67%)	
Purchase Cost, Cp (2001)	15976.69873
Base Purchase Cost, Cpo (2001)	5166.135683
Installed Cost, CBM (2001)	33752.95912
Area, m^2	127.6902847
K1	3.3444
K2	0.2745
K3	-0.0472
Design Pressure, barg	66.88
Pressure Factor, Fp	1.124575308
C1	0.6072
C2	-0.912
C3	0.3327
FM, from Figure A.18	2.75
FBM	6.533502252
B1	1.74
B2	1.55
Purchase Cost, Cp (2016)	22014.59325
Base Purchase Cost, Cpo (2016)	7118.515387
Installed Cost, CBM (2016)	46508.83631
2017 CEPCI (extrapolated)	542.9
2001 CEPCI	394

Total Costs for R-01 (PFR) (67%)		
Purchase Cost	$	22,014.59
Installed Cost	$	46,508.84
Grass Roots Cost	$	66,590.38

R-01 Area (67%)	
D (in)	1.50E+00
L (ft)	3500
A (m^2)	127.69

R-01 HTF Volume (67%)	
Area (ft^2)	1374.45
Inner Pipe OD (in)	1.66
Outer Pipe ID (in)	2.16
A2 (ft^2)	0.025399798
A1 (ft^2)	0.015029467
Vannulus (ft^3)	36.29616165
Vfluid (gal)	271.5141631
Cost ($)	$13,575.71

R-01 HTF Flow (67%)	
Q (kJ/hr)	2700714.088
Cp (kJ/kg*K)	2.214
m (kg/hr)	60991.74
rho (kg/L)	0.89
m (gpm)	301.7286328

R-02 (Evaporator) (67%)	
Base Purchase Cost, Cpo (2001)	150001.4354
Installed Cost, CBM (2001)	330003.1579
Area calc from below, (m^2)	22.1
K1	5
K2	0.149
K3	-0.0134
Design Pressure, barg	5.778
Pressure Factor, Fp	1
C1	0
C2	0
C3	0
FBM	2.2
Base Purchase Cost, Cpo (2016)	206499.438
Installed Cost, CBM (2016)	454298.7635
2017 CEPCI (extrapolated)	542.4
2001 CEPCI	394

Total Costs for R-02 (67%)		
Installed Cost	$	454,298.76
Grass Roots Cost	$	875,764.12

R-02 Area Calculation (67%)	
Vapor Volumetric Flow (m3/s)	0.4706
Diameter (m)	0.774071398
Film Thickness (m)	0.0127
Liquid Volume (m3)	0.295708
Height (m)	9.734483699
Area (m2)	22.89570585

R-02 HTF Volume (67%)	
Area (ft^2)	246.45
Vfluid (gal)	317.93
Cost ($)	$15,896.39

R-02 HTF Flow (67%)	
Q (kJ/hr)	1757641.98
Cp (kJ/kg*K)	2.214
m (kg/hr)	39693.81
rho (kg/L)	0.89
m (gpm)	196.37

E-03 (Condenser) (67%)	
Purchase Cost, Cp (2001)	19800.37797
Base Purchase Cost, Cpo (2001)	19800.37797
Installed Cost, CBM (2001)	65143.24352
Area cacl from below (m^2)	10.1902958
K1	4.8306
K2	-0.8509
K3	0.3187
Design Pressure, barg	4.75
Pressure Factor, Fp	1
C1	0
C2	0
C3	0
FM, from Figure A.18	1
FBM	3.29
B1	1.63
B2	1.66
Purchase Cost, Cp (2016)	27258.18531
Base Purchase Cost, Cpo (2016)	27258.18531
Installed Cost, CBM (2016)	89679.42966
2017 CEPCI (extrapolated)	542.4
2001 CEPCI	394

Total Costs for E-03 (67%)		
Purchase Cost	$	27,258.19
Installed Cost	$	89,679.43
Grass Roots Cost	$	150,661.44

E-03 Area Calculation (67%)	
CW Tin (K)	303
CW Tout (K)	322
Feed Tin (K)	528
Feed Tout (K)	373
ΔTlm (K)	-125.9981501
U (W/m^2*K)	900
Q (W)	-1155563
Area (m^2)	10.1902958

E-03 CW (67%)	
Q (kJ/hr)	-2742641
Cp (kJ/kg*K)	4.184
m (kg/hr)	34500.36036
Cost ($/yr)	$16,405.25

T-01 (67%)	
Purchase Cost, Cp (2001)	25935.00687
Base Purchase Cost, Cpo (2001)	25935.00687
Installed Cost, CBM (2001)	78064.37067
Volume (m^3)	42.87
K1	3.5565
K2	0.3776
K3	0.0905
Design Pressure, barg	3.447
Pressure Factor, Fp	1
D (m)	2.63
P operating (barg)	0
FM, from Figure A.18	1
FBM	3.01
B1	1.49
B2	1.52
Purchase Cost, Cp (2016)	35703.42062
Base Purchase Cost, Cpo (2016)	35703.42062
Installed Cost, CBM (2016)	107467.2961
2017 CEPCI (extrapolated)	542.4
2001 CEPCI	394

Total Costs for T-01 (67%)		
Purchase Cost	$	35,703.42
Installed Cost	$	107,467.30
Grass Roots Cost	$	185,543.54

C-01 (Screw Conveyor) (67%)	
Purchase Cost, Cp (2001)	10599.55142
Base Purchase Cost, Cpo (2001)	10599.55142
Installed Cost, CBM (2001)	11659.50656
Area (m2)	8.523039311
K1	3.6062
K2	0.2659
K3	0.1982
Design Pressure, barg	6.89476
Pressure Factor, Fp	1
FM, from Figure A.18	1
FBM	1.1
Purchase Cost, Cp (2016)	14591.86977
Base Purchase Cost, Cpo (2016)	14591.86977
Installed Cost, CBM (2016)	16051.05674
2017 CEPCI (extrapolated)	542.4
2001 CEPCI	394

Total Costs for C-01 (67%)		
Purchase Cost	$	14,591.87
Installed Cost	$	16,051.06
Grass Roots Cost	$	42,943.87

C-01 Sizing (67%)	
flow (kg/hr)	5159.72
flow (kg/hr)	5159.720003
D (mm)	336.2146929
A (m^2)	8.523039311

B-01 (Belt Conveyor) (67%)	
Purchase Cost, Cp (2001)	57655.22411
Base Purchase Cost, Cpo (2001)	57655.22411
Installed Cost, CBM (2001)	72069.03013
Area (m2)	27.870912
K1	4.0637
K2	0.2584
K3	0.155
Design Pressure, barg	1
Pressure Factor, Fp	1
C1	0
C2	0
C3	0
FM, from Figure A.18	1
FBM	1.25
Purchase Cost, Cp (2016)	79371.04963
Base Purchase Cost, Cpo (2016)	79371.04963
Installed Cost, CBM (2016)	99213.81204
2017 CEPCI (extrapolated)	542.4
2001 CEPCI	394

Total Costs for B-01 (67%)		
Purchase Cost	$	79,371.05
Installed Cost	$	99,213.81
Grass Roots Cost	$	247,637.67

B-01 Sizing (67%)	
Operating flow (ft^3/hr)	208.857
Belt Width (ft)	3.0
Height of solid (ft)	0.125
Belt vel (ft/min)	9.282533333
Belt Length Total (ft)	100
A (m^2)	27.870912

P-03 (HTF Circulation Pump) (67%)	
Purchase Cost, Cp (2001)	6489.570414
Base Purchase Cost, Cpo (2001)	6489.570414
Installed Cost, CBM (2001)	21026.20814
Shaft Power, kW	31.14
K1	3.3892
K2	0.0536
K3	0.1538
Design Pressure, barg	6.02
Pressure Factor, Fp	1
C1	0
C2	0
C3	0
FM, from Figure A.18	1
FBM	3.24
B1	1.89
B2	1.35
Purchase Cost, Cp (2016)	8933.865463
Base Purchase Cost, Cpo (2016)	8933.865463
Installed Cost, CBM (2016)	28945.7241
2017 CEPCI (extrapolated)	542.4
2001 CEPCI	394

Total Costs for P-03 (67%)		
Purchase Cost	$	8,933.87
Installed Cost	$	28,945.72
Grass Roots Cost for 2 pumps	$	97,704.33

P-03 Electricity (67%)		
Motor efficiency		0.8
Purchase hp (kW)		38.93
Cost ($/yr)	$	21,481.93

T-02 (HTF Expansion Tank) (67%)	
Purchase Cost, Cp (2001)	7062.316541
Base Purchase Cost, Cpo (2001)	7062.316541
Installed Cost, CBM (2001)	21257.57279
Volume (m^3)	4.652144092
K1	3.5565
K2	0.3776
K3	0.0905
Design Pressure, barg	4.55
Pressure Factor, Fp	1
D (m)	1.03
p operating (barg)	1.3
C3	0
FM, from Figure A.18	1
FBM	3.01
B1	1.49
B2	1.52
Purchase Cost, Cp (2016)	9722.336274
Base Purchase Cost, Cpo (2016)	9722.336274
Installed Cost, CBM (2016)	29264.23218
2017 CEPCI (extrapolated)	542.4
2001 CEPCI	394

Total Costs for Expansion Tank (67%)		
Purchase Cost	$	9,722.34
Installed Cost	$	29,264.23
Grass Roots Cost	$	50,525.04

Transfer Line/T-02 Sizing (67%)	
Transfer Line Sizing	
Pipe size (in)	7
Total Mass flow (cfs)	2.595833333
Velocity (ft/s)	9.712998813
Length (ft)	500
Transfer Piping (gal)	999.5977319
Cost ($)	$49,979.89
T-02 Sizing	
Volume sys (no tank) (gal)	2048.28
Volume sys (no tank) (m^3)	7.753573486
Vtank (gal)	307.2415522
Cost ($)	$15,362.08

Appendix B: Verification of Aspen PFR Simulation

The spreadsheet on the following page is used to verify the estimated kinetic parameters used in the Aspen simulation. The Aspen results and the results from this sheet are different only to the degree of rounding error.

	MOL/HR						L/HR	MOL/L					N/A	L/MOL/HR	N/A	N/A	MOL/L/HR	HR/MOL/L	L
iteration	**mol ADA**	**mol HMDA**	**mol H2O**	**mol Nylon**	**K_{rxn}**	**total mol**	**Volume**	**C(ADA)**	**C(HMDA)**	**C(H2O)**	**C(NYL)**	**C(TOT)**	**X(H2O)**	**k**	**K LIMIT**	**X (conv)**	**-rA**	**1/-rA**	**Fa0/-ra**
FEED	22778	22778	45556	0	0.000	91112	6417	3.549	3.549	7.099	0.000	7.099	0.500	20.36	1950.46	0.000	256.53	0.004	89
1	22578	22578	45956	200	0.018	91312	6408	3.524	3.524	7.172	0.031	7.047	0.503	20.14	1952.78	0.009	250.01	0.004	91
2	22378	22378	46356	400	0.037	91512	6398	3.498	3.498	7.245	0.063	6.995	0.507	19.88	1955.06	0.018	243.24	0.004	94
3	22178	22178	46756	600	0.057	91712	6388	3.472	3.472	7.319	0.094	6.943	0.510	19.60	1957.29	0.026	236.22	0.004	96
4	21978	21978	47156	800	0.078	91912	6379	3.445	3.445	7.393	0.125	6.891	0.513	19.29	1959.48	0.035	228.94	0.004	99
5	21778	21778	47556	1000	0.100	92112	6369	3.419	3.419	7.467	0.157	6.839	0.516	18.94	1961.63	0.044	221.43	0.005	103
6	21578	21578	47956	1200	0.124	92312	6360	3.393	3.393	7.541	0.189	6.786	0.519	18.56	1963.74	0.053	213.69	0.005	107
7	21378	21378	48356	1400	0.148	92512	6350	3.367	3.367	7.615	0.220	6.733	0.523	18.15	1965.81	0.061	205.76	0.005	111
8	21178	21178	48756	1600	0.174	92712	6340	3.340	3.340	7.690	0.252	6.680	0.526	17.72	1967.85	0.070	197.67	0.005	115
9	20978	20978	49156	1800	0.201	92912	6331	3.314	3.314	7.765	0.284	6.627	0.529	17.26	1969.84	0.079	189.48	0.005	120
10	20778	20778	49556	2000	0.230	93112	6321	3.287	3.287	7.840	0.316	6.574	0.532	16.77	1971.80	0.088	181.24	0.006	126
11	20578	20578	49956	2200	0.260	93312	6311	3.260	3.260	7.915	0.349	6.521	0.535	16.27	1973.72	0.097	173.01	0.006	132
12	20378	20378	50356	2400	0.291	93512	6302	3.234	3.234	7.991	0.381	6.467	0.538	15.77	1975.61	0.105	164.87	0.006	138
13	20178	20178	50756	2600	0.324	93712	6292	3.207	3.207	8.067	0.413	6.414	0.542	15.25	1977.47	0.114	156.89	0.006	145
14	19978	19978	51156	2800	0.359	93912	6282	3.180	3.180	8.143	0.446	6.360	0.545	14.75	1979.29	0.123	149.12	0.007	153
15	19778	19778	51556	3000	0.395	94112	6273	3.153	3.153	8.219	0.478	6.306	0.548	14.25	1981.08	0.132	141.63	0.007	161
16	19578	19578	51956	3200	0.434	94312	6263	3.126	3.126	8.296	0.511	6.252	0.551	13.76	1982.83	0.140	134.47	0.007	169
17	19378	19378	52356	3400	0.474	94512	6253	3.099	3.099	8.372	0.544	6.198	0.554	13.30	1984.56	0.149	127.68	0.008	178
18	19178	19178	52756	3600	0.516	94712	6244	3.072	3.072	8.449	0.577	6.143	0.557	12.86	1986.25	0.158	121.29	0.008	188
19	18978	18978	53156	3800	0.561	94912	6234	3.044	3.044	8.527	0.610	6.088	0.560	12.44	1987.92	0.167	115.31	0.009	198
20	18778	18778	53556	4000	0.608	95112	6224	3.017	3.017	8.604	0.643	6.034	0.563	12.06	1989.56	0.176	109.75	0.009	208
21	18578	18578	53956	4200	0.657	95312	6215	2.989	2.989	8.682	0.676	5.979	0.566	11.71	1991.17	0.184	104.59	0.010	218
22	18378	18378	54356	4400	0.708	95512	6205	2.962	2.962	8.760	0.709	5.923	0.569	11.38	1992.75	0.193	99.84	0.010	228
23	18178	18178	54756	4600	0.762	95712	6196	2.934	2.934	8.838	0.742	5.868	0.572	11.09	1994.30	0.202	95.46	0.010	239
24	17978	17978	55156	4800	0.819	95912	6186	2.906	2.906	8.916	0.776	5.813	0.575	10.82	1995.83	0.211	91.43	0.011	249
25	17778	17778	55556	5000	0.879	96112	6176	2.878	2.878	8.995	0.810	5.757	0.578	10.59	1997.33	0.220	87.73	0.011	260
26	17578	17578	55956	5200	0.942	96312	6167	2.850	2.850	9.074	0.843	5.701	0.581	10.38	1998.81	0.228	84.32	0.012	270
27	17378	17378	56356	5400	1.008	96512	6157	2.822	2.822	9.153	0.877	5.645	0.584	10.19	2000.26	0.237	81.18	0.012	281
28	17178	17178	56756	5600	1.077	96712	6147	2.794	2.794	9.233	0.911	5.589	0.587	10.02	2001.69	0.246	78.27	0.013	291
29	16978	16978	57156	5800	1.150	96912	6138	2.766	2.766	9.312	0.945	5.532	0.590	9.88	2003.09	0.255	75.58	0.013	301
30	16778	16778	57556	6000	1.227	97112	6128	2.738	2.738	9.392	0.979	5.476	0.593	9.75	2004.47	0.263	73.08	0.014	312
31	16578	16578	57956	6200	1.307	97312	6118	2.710	2.710	9.472	1.013	5.419	0.596	9.64	2005.83	0.272	70.75	0.014	322
32	16378	16378	58356	6400	1.392	97512	6109	2.681	2.681	9.553	1.048	5.362	0.598	9.54	2007.17	0.281	68.56	0.015	332
33	16178	16178	58756	6600	1.482	97712	6099	2.653	2.653	9.634	1.082	5.305	0.601	9.45	2008.48	0.290	66.50	0.015	343
34	15978	15978	59156	6800	1.576	97912	6089	2.624	2.624	9.714	1.117	5.248	0.604	9.38	2009.78	0.299	64.55	0.015	353
35	15778	15778	59556	7000	1.675	98112	6080	2.595	2.595	9.796	1.151	5.190	0.607	9.31	2011.05	0.307	62.70	0.016	363
36	15578	15578	59956	7200	1.779	98312	6070	2.566	2.566	9.877	1.186	5.133	0.610	9.25	2012.30	0.316	60.94	0.016	374
37	15378	15378	60356	7400	1.889	98512	6061	2.537	2.537	9.959	1.221	5.075	0.613	9.20	2013.53	0.325	59.25	0.017	384
38	15178	15178	60756	7600	2.004	98712	6051	2.508	2.508	10.041	1.256	5.017	0.615	9.16	2014.75	0.334	57.63	0.017	395
39	14978	14978	61156	7800	2.126	98912	6041	2.479	2.479	10.123	1.291	4.959	0.618	9.12	2015.94	0.342	56.07	0.018	406
40	14778	14778	61556	8000	2.255	99112	6032	2.450	2.450	10.206	1.326	4.900	0.621	9.09	2017.12	0.351	54.56	0.018	418
41	14578	14578	61956	8200	2.391	99312	6022	2.421	2.421	10.288	1.362	4.842	0.624	9.06	2018.27	0.360	53.09	0.019	429
42	14378	14378	62356	8400	2.534	99512	6012	2.391	2.391	10.371	1.397	4.783	0.627	9.03	2019.41	0.369	51.67	0.019	441
43	14178	14178	62756	8600	2.685	99712	6003	2.362	2.362	10.455	1.433	4.724	0.629	9.01	2020.53	0.378	50.28	0.020	453
44	13978	13978	63156	8800	2.845	99912	5993	2.332	2.332	10.538	1.468	4.665	0.632	8.99	2021.64	0.386	48.93	0.020	466
45	13778	13778	63556	9000	3.013	100112	5983	2.303	2.303	10.622	1.504	4.605	0.635	8.98	2022.72	0.395	47.60	0.021	479
46	13578	13578	63956	9200	3.192	100312	5974	2.273	2.273	10.706	1.540	4.546	0.638	8.96	2023.79	0.404	46.31	0.022	492

Appendix C: Sample Calculations

The following tables show the formulas used in Excel to calculate the necessary values for costing and sizing. Many sizing and costing tables use the same formulas; therefore, representatives are shown here for each type of table. The far right column of each table is comments for various calculations.

	C	D	
3	M-01		Comments
4	Purchase Cost, Cp (2001)	=D5*D12*D16	
5	Base Purchase Cost, Cpo (2001)	=10^(D8+D9*LOG10(D7)+D10*(LOG10(D7))^2)	
6	Installed Cost, CBM (2001)	=D5*D17	
7	Volume (m^3)	3.324	based off 30 min holdup time
8	K1	3.5565	
9	K2	0.3776	
10	K3	0.0905	
11	Design Pressure, barg	3.44	
12	Pressure Factor, Fp	1	
13	D (m)	1.1215	based off L/D of 3
14	Operating Pressure (barg)	0	
15			
16	FM, from Figure A.18	3.1	
17	FBM	=D18+D19*D16*D12	
18	B1	1.49	
19	B2	1.52	
20	Purchase Cost, Cp (2016)	=D4*(D23/D24)	
21	Base Purchase Cost, Cpo (2016)	=D5*(D23/D24)	
22	Installed Cost, CBM (2016)	=D6*(D23/D24)	
23	2017 CEPCI (extrapolated)	542.4	
24	2001 CEPCI	394	

27	Total Costs for M-01		
28	Purchase Cost	=D20	
29	Installed Cost	=D22	
30	Total Module Cost	=1.18*D22	1.18 is the grass-roots factor

	C	D	
3	Pump Sizing- P-01		
4	Flow Rate (gpm)	29.3	flow rate from Aspen
5	Density (lbm/ft^3)	63.5	density from Aspen
6	Psuction		
7	Psu (psig)	0	
8	Pdischarge		
9	Pdischarge (psig)	220.5	
10	Pump calcs/spec		
11	Total Head (ft)	=(D9-D7)*144/D5	
12	Efficiency	0.75	
13	Hydraulic Hp	=D4*(D9-D7)/1714	
14	Shaft Hp (bhp)	=D13/D12	
15	Shaft Power (kW)	=D14*0.7457	
16	Motor Efficiency	0.8	
17	Purchased Power (hp)	=D14/D16	
18	Type of pump	Centrifugal single-stage se	
19	Type of motor	Electric	

22	C	D	
23	P-01 (Centrifugal Pump 1)		Feed Pump
24	Purchase Cost, Cp (2001)	=D25*D32*D36	
25	Base Purchase Cost, Cpo	=10^(D28+D29*LOG10(D27)+D30*(LOG10(D27))^2)	
26	Installed Cost, CBM (200	=D25*D37	
27	Shaft Power, kW	3.75	power found above
28	K1	3.3892	
29	K2	0.0536	
30	K3	0.1538	
31	Design Pressure, barg	18.65	
32	Pressure Factor, Fp	=10^(D33+D34*LOG10(D31)+D35*(LOG10(D31))^2)	
33	C1	-0.3935	
34	C2	0.3957	
35	C3	-0.00226	
36	FM, from Figure A.18	2.2	use stainless steel
37	FBM	=D38+D39*D36*D32	
38	B1	1.89	
39	B2	1.35	
40	Purchase Cost, Cp (2016)	=D24*(D43/D44)	
41	Base Purchase Cost, Cpo	=D25*(D43/D44)	
42	Installed Cost, CBM (201	=D26*(D43/D44)	
43	2017 CEPCI (extrapolate	542.4	

46	C	D	
47	Total Costs for P-01		
48	Purchase Cost	=D40	
49	Installed Cost	=D42	
50	Total Module Cost 2 pun	=1.18*D42*2	have 2 pumps in operation

52	C	D
53	P-01 Electricity	
54	Motor efficiency	0.8
55	Purchase hp (kW)	=D27/D54
56	Cost ($/yr)	=D55*24*365*0.07*0.9

	C	D
3	E-02 (Feed Heater)	
4	Purchase Cost, Cp (2001)	=D5*D12*D16
5	Base Purchase Cost, Cpo (2001)	=10^(D8+D9*LOG10(D7)+D10*(LOG10(D7))^2)
6	Installed Cost, CBM (2001)	=D5*D17
7	Area calc from below, (m^2)	=D41
8	K1	4.8306
9	K2	-0.8509
10	K3	0.3187
11	Design Pressure, barg	66.88
12	Pressure Factor, Fp	=10^(D13+D14*LOG10(D11)+D15*(LOG10(D11))^2)
13	C1	0.03881
14	C2	-0.11272
15	C3	0.08183
16	FM, from Figure A.18	2.75
17	FBM	=D18+D19*D16*D12
18	B1	1.63
19	B2	1.66
20	Purchase Cost, Cp (2016)	=D4*(D23/D24)
21	Base Purchase Cost, Cpo (2016)	=D5*(D23/D24)
22	Installed Cost, CBM (2016)	=D6*(D23/D24)
23	2017 CEPCI (extrapolated)	542.4
24	2001 CEPCI	394

26	C	D
27	Total Costs for E-02	
28	Purchase Cost	=D20
29	Installed Cost	=D22
30	Total Module Cost	=1.18*D22

	C	D	
3	E-02 Area		
4	DOW Therm G Tin (K)	573	
5	DOW Therm G Tout (K)	553	
6	Feed Tin (K)	327	from Aspen
7	Feed Tout (K)	548	from Aspen
8	ΔTlm (K)	=-((D7-D4)-(D6-D5))/(LN((D7-D4)/(D6-D5)))	
9	U (W/m^2*K)	280	from Turton
10	Q (W)	=D16*1000/3600	from Aspen
11	Area (m^2)	=D10/(D9*D8*0.9)	

	C	D	
3	E-02 HTF Flow		required mass flow Dowtherm S
4	Q (kJ/hr)	4166851.63768137	from Aspen
5	Cp (kJ/kg*K)	2.214	Dowtherm S Cp
6	m (kg/hr)	=D4/D5/(20)	
7	rho (kg/L)	0.89	Dowtherm S density
8	m (gpm)	=D6/D7*0.264172/60	

	C	D	
3	E-02 HTF Volume		required volume Dowtherm S
4	Area (ft^2)	=#REF!/(0.3048^2)	referenes heat transfer area of E-02
5	Pipe D (in)	1.52	
6	# of 16' segments	=D4/(D5/12*PI())/16	
7	Vtubes (ft^3)	=((D5/2/12)^2)*PI()*16*D6	volume taken up by tubes
8	Shell D (ft)	2.5	
9	Vtot (ft^3)	=((D8/2)^2)*PI()*16	total volume of HEX
10	Vfluid (gal)	=(D9-D7)*7.48052	void volume/Dowtherm S volume
11	Cost ($)	=50*D10	capital cost Dowtherm S for this unit

	C	D
2	R-01 (PFR)	
3	Purchase Cost, Cp (2001)	=D4*D11*D15
4	Base Purchase Cost, Cpo (2001)	=10^(D7+D8*LOG10(D6)+D9*(LOG10(D6))^2)
5	Installed Cost, CBM (2001)	=D4*D16
6	Area, m^2	=D35
7	K1	3.3444
8	K2	0.2745
9	K3	-0.0472
10	Design Pressure, barg	66.88
11	Pressure Factor, Fp	=10^(D12+D13*LOG10(D10)+D14*(LOG10(D10))^2)
12	C1	0.6072
13	C2	-0.912
14	C3	0.3327
15	FM, from Figure A.18	2.75
16	FBM	=D17+D18*D15*D11
17	B1	1.74
18	B2	1.55
19	Purchase Cost, Cp (2016)	=D3*(D22/D23)
20	Base Purchase Cost, Cpo (2016)	=D4*(D22/D23)
21	Installed Cost, CBM (2016)	=D5*(D22/D23)
22	2017 CEPCI (extrapolated)	542.9
23	2001 CEPCI	394

25	C	D
26	Total Costs for R-01 (PFR)	
27	Purchase Cost	=D19
28	Installed Cost	=D21
29	Grass Roots Cost	=1.18*D21+3.29*0.5*D20

31	C	D	
32	R-01 Area		req heat transfer area R-01
33	D (in)	1.5	D req for about 5 ft/s vel
34	L (ft)	3500	found from Excel R-01 model
35	A (m^2)	=(D33/12*PI())*D34*(0.3048^2)	

	C	D
2	R-02 (Evaporator)	
3	Base Purchase Cost, Cpo (2001)	=10^(D6+D7*LOG10(D5)+D8*(LOG10(D5))^2)
4	Installed Cost, CBM (2001)	=D3*D14*D10
5	Area calc from below, (m^2)	22.1
6	K1	5
7	K2	0.149
8	K3	-0.0134
9	Design Pressure, barg	5.778
10	Pressure Factor, Fp	=10^(D11+D12*LOG10(D9)+D13*(LOG10(D9))^2)
11	C1	0
12	C2	0
13	C3	0
14	FBM	2.2
15	Base Purchase Cost, Cpo (2016)	=D3*(D17/D18)
16	Installed Cost, CBM (2016)	=D4*(D17/D18)
17	2017 CEPCI (extrapolated)	542.4
18	2001 CEPCI	394

25	C	D
26	Total Costs for R-02	
27	Installed Cost	=D16
28	Grass Roots Cost	=1.18*D16+0.5*3.29*D15

31	C	D	
32	R-02 Area Calculation		req heat transfer area
33	Vapor Volumetric Flow (m3/s)	0.4706	taken from aspen
34	Diameter (m)	=SQRT(D33/(1*PI()/4))	assume flow vel of 1m/s
35	Film Thickness (m)	0.0127	taken from Seavey
36	Liquid Volume (m3)	0.295708	from Aspen
37	Height (m)	=D36/(PI()/4*D34^2-PI()/4*(D34-2*D35)^2)	
38	Area (m2)	=D37*(D34-2*D35)*PI()	

	C	D	
3	Transfer Line/T-02 Sizing		
4	Transfer Line Sizing		
5	Pipe size (in)	7	req D for flow velocity below 10ft/s (Rules of Thumb)
6	Total Mass flow (cfs)	=9345/3600	total mass flow of Duratherm in the HTF loop
7	Velocity (ft/s)	=D6/(((D5/2/12)^2)*PI())	
8	Length (ft)	500	estimated length of transfer piping
9	Transfer Piping (gal)	=D8*(((D5/2/12)^2)*PI())*7.48052	volume of Duratherm S in the transfer piping
10	Cost ($)	=D9*50	capital cost of Duratherm S for transfer piping
11	T-02 Sizing		Expansion tank for HTF Loop
12	Volume sys (no tank) (gal)	=#REF!+#REF!+#REF!+D9	total volume of Duratherm S required (except vol in T-02)
13	Volume sys (no tank) (m^3)	=D12/264.172	
14	Vtank (gal)	=D12*0.3/2	Tank should allow for expansion for 30% of system vol
15	Cost ($)	=50*D14	of Duratherm S, normal level should be 1/4 full

	C	D	
3	E-01 Flue Calc		Economizer Unit
4	Qprocess (kJ/hr)	=J4+M4+P4	total duty required of the 3 units using Duratherm
5	Heater eff	0.776	
6	Qreq (kJ/hr)	=D4/D5	
7	Gas HV (kJ/lb)	21100	value taken from engineeringtoolbox.com
8	NG (lg/hr)	=D6/D7	
9	NG (mol/hr)	=D8*453.6/16	
10	Combustion products		combustion products are calculated based off combustion of methane
11	CO2 (mol/hr)	=D9	with 20% excess air
12	CO2 (kg/hr)	=D11*44/1000	
13	H2O (mol/hr)	=D9*2	
14	H2O (kg/hr)	=D13*18/1000	
15	N2 (mol/hr)	=D9*7.2	
16	N2 (kg/hr)	=D15*28/1000	
17	Total flue mass (kg/hr)	=D16+D14+D12	
18	Cp (kJ/kg*K)	1.09	value taken from engineeringtoolbox.com
19	dT flue ©	70	assumed a flue gas temperature change of 70 K
20	Qflue (kJ/hr)	=D19*D18*D17	heat delivered by flue to process feed

Appendix D: Equation List

Heat exchanger design equations

5) $\Delta T_{lm,counterflow} = \frac{(T_{h,i}-T_{c,o})-(T_{h,o}-T_{c,i})}{\ln(\frac{T_{h,i}-T_{c,o}}{T_{h,o}-T_{c,i}})}$

$\Delta T_{lm,counterflow}$ = Log mean temperature difference for a counter-current heat exchanger
$T_{h,i}, T_{h,o}$ = Inlet and outlet temperatures of hot stream
$T_{c,i}$, $T_{c,o}$ = Inlet and outlet temperatures of cold stream

7) $q = U_o A \Delta T_{lm}$ (assuming subcooled liquid and saturated vapors)

q = Heat duty of heat exchanger
U_o = Overall heat transfer coefficient of heat exchanger
A = Area of heat exchanger
ΔT_{lm} = Log mean temperature difference of heat exchanger

Capital cost equations

8) $C_p = C_p^0 F_m F_p$

C_p = Actual purchased cost of specific equipment
C_p^0 = "Vanilla" (Carbon steel and 50 psig) purchased cost
F_m = Material Cost factor
F_p = Pressure Cost factor

9) $log_{10}C_p^0 = K_1 + K_2 log_{10}A + K_3[log_{10}A]^2$

C_p^0 = "Vanilla" (Carbon steel and 50 psig) purchased cost
K_1, K_2, K_3 = Equipment sizing factors from Turton Appendix A
A = "Capacity" of equipment being sized

10) $log_{10}F_p = C_1 + C_2 log_{10}P + C_3[log_{10}P]^2$

F_p = Pressure Cost factor
C_1, C_2, C_3 = Equipment pressure rating factors
P = Design pressure of equipment

11) $F_p = \frac{\frac{(P+1)D}{2[850-0.6(P+1)]}+0.00315}{0.0063}$

F_p = Pressure cost factor for a cylindrical process vessel
P = Design pressure of vessel

D = Diameter of vessel

12) $F_{BM} = C_p^0(B_1 + B_2F_MF_P)$

F_{BM} = Bare module cost factor – accounts for material of construction, design pressure, and installation costs
C_p^0 = "Vanilla" (Carbon steel and 50 psig) purchased cost
B_1, B_2 = Bare module factors – account for costs associated with installation
F_M = Material Cost factor
F_P = Pressure Cost factor

13) $C_{BM} = C_p^0F_{BM}$

C_{BM} = Bare module cost – Installed cost of specific equipment.
C_p^0 = "Vanilla" (Carbon steel and 50 psig) purchased cost
F_{BM} = Bare module cost factor – accounts for material of construction, design pressure, and installation costs

14) $C_{TM} = 1.18C_{BM}$

C_{TM} = Total Module cost
C_{BM} = Bare module cost

15) $C_{BM}^0 = 3.29C_p^o$

C_{BM}^0 = "Vanilla" Bare module cost
C_p^0 = "Vanilla" (Carbon steel and 50 psig) purchased cost

15) $C_{GR} = C_{TM} + .5C_{BM}^0$

C_{GR} = Grass roots cost
C_{TM} = Total Module cost
C_{BM}^0 = "Vanilla" Bare module cost

16) $Cost\ in\ Year\ A = Cost\ in\ Year\ B[\frac{CEPCI\ in\ Year\ A}{CEPCI\ in\ Year\ B}]$

$CEPCI$ = Chemical engineering plant cost index – compares plant costs through time

Operating cost equations

17) $N_{OL} = (6.29 + 31.7P^2 + 0.23N_{NP})^{0.5}$

N_{OL} = Number of operators required per shift
P = Number of processing steps involving particulate solids
N_{NP} = Number of non-particulate processing steps (heating, cooling, mixing, etc.)

Reaction Equations

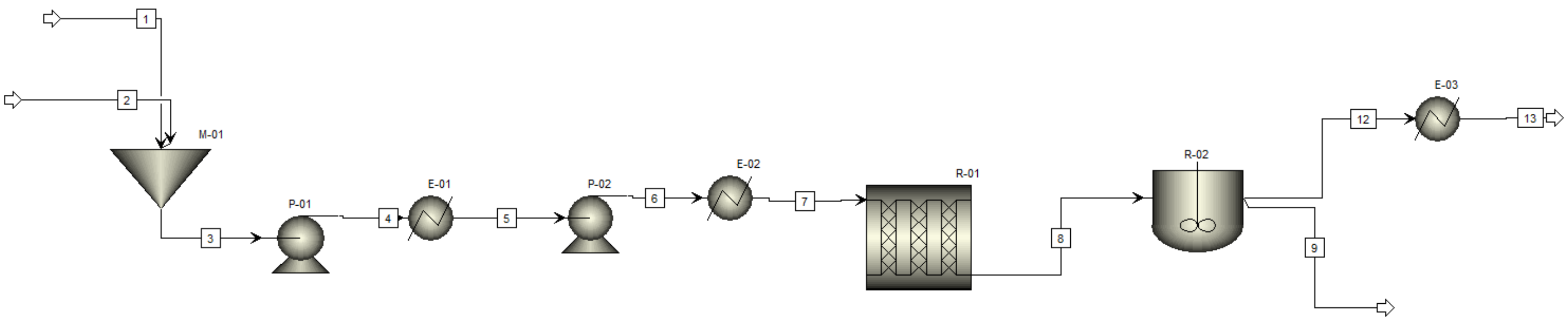
18) $k = Ae^{-E_a/RT}$

k = Reaction rate constant
A = Pre-exponential Factor
E_a = Activation Energy
R = Universal Gas constant
T = Absolute temperature

19) $r = kC_AC_B$

r = Reaction Rate
k = Reaction rate constant
C_A = Concentration of A
C_B = Concentration of B

Appendix E: Aspen Plus Printouts and Reports



Appendix E: Aspen Plus Printouts and Reports

Full Scale Block Report

```
BLOCK:  E-01     MODEL: HEATER
------------------------------
  INLET STREAM:          4
  OUTLET STREAM:         5
  PROPERTY OPTION SET:   POLYNRTL  POLYMER NRTL / REDLICH-KWONG

                     ***  MASS AND ENERGY BALANCE  ***
                                   IN               OUT        RELATIVE DIFF.
   TOTAL BALANCE
      MOLE(LBMOL/HR)            200.868         200.868         0.00000
      MASS(LB/HR   )            14983.7         14983.7         0.00000
      ENTHALPY(BTU/HR  )      -0.366107E+08   -0.362256E+08   -0.105206E-01

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

                         ***  INPUT DATA  ***
  TWO    PHASE  PQ  FLASH
  SPECIFIED PRESSURE                 PSIA                    223.196
  SPECIFIED HEAT DUTY                BTU/HR              385,168.
  MAXIMUM NO. ITERATIONS                                      30
  CONVERGENCE TOLERANCE                                         0.000100000



                          ***  RESULTS  ***
  OUTLET TEMPERATURE    F                                   127.19
  OUTLET PRESSURE       PSIA                                223.20
  OUTLET VAPOR FRACTION                                     0.0000



  V-L PHASE EQUILIBRIUM :

     COMP              F(I)          X(I)          Y(I)           K(I)
     ADIPI           0.25000       0.25000       0.43484E-06    0.12249E-07
     HMDA            0.25000       0.25000       0.13370E-01    0.37662E-03
     H2O             0.50000       0.50000       0.98663        0.13896E-01

BLOCK:  E-02     MODEL: HEATER
------------------------------
  INLET STREAM:          6
  OUTLET STREAM:         7
  PROPERTY OPTION SET:   POLYNRTL  POLYMER NRTL / REDLICH-KWONG

                     ***  MASS AND ENERGY BALANCE  ***
                                   IN               OUT        RELATIVE DIFF.
   TOTAL BALANCE
      MOLE(LBMOL/HR)            200.868         200.868         0.00000
```

```
    MASS(LB/HR   )            14983.7        14983.7        0.00000
    ENTHALPY(BTU/HR  )      -0.361834E+08   -0.322340E+08   -0.109150

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

                       ***  INPUT DATA  ***
  TWO    PHASE  TP  FLASH
  SPECIFIED TEMPERATURE              F                    527.000
  SPECIFIED PRESSURE                 PSIA                 908.696
  MAXIMUM NO. ITERATIONS                                   30
  CONVERGENCE TOLERANCE                                     0.000100000



                        ***  RESULTS  ***
  OUTLET TEMPERATURE    F                               527.00
  OUTLET PRESSURE       PSIA                            908.70
  HEAT DUTY             BTU/HR                         0.39494E+07
  OUTLET VAPOR FRACTION                                 0.0000



  V-L PHASE EQUILIBRIUM :

     COMP            F(I)          X(I)          Y(I)          K(I)
     ADIPI          0.25000       0.25000       0.56841E-02    0.14794E-01
     HMDA           0.25000       0.25000       0.76780E-01    0.19983
     H2O            0.50000       0.50000       0.91754         1.1940

BLOCK:  E-03     MODEL: HEATER
------------------------------
  INLET STREAM:          12
  OUTLET STREAM:         13
  PROPERTY OPTION SET:   POLYNRTL  POLYMER NRTL / REDLICH-KWONG

                   ***  MASS AND ENERGY BALANCE  ***
                                 IN              OUT        RELATIVE DIFF.
   TOTAL BALANCE
    MOLE(LBMOL/HR)            198.889        198.889        0.00000
    MASS(LB/HR   )            3608.49        3608.49        0.00000
    ENTHALPY(BTU/HR  )      -0.199903E+08   -0.239333E+08    0.164747

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

                       ***  INPUT DATA  ***
  TWO    PHASE  PV  FLASH
  SPECIFIED PRESSURE                 PSIA                  14.6959
  VAPOR FRACTION                                            0.0
  MAXIMUM NO. ITERATIONS                                   30
  CONVERGENCE TOLERANCE                                     0.000100000
```

```
                    ***  RESULTS  ***
  OUTLET TEMPERATURE    F                                   212.09
  OUTLET PRESSURE       PSIA                                14.696
  HEAT DUTY             BTU/HR                            -0.39429E+07
  OUTLET VAPOR FRACTION                                     0.0000



  V-L PHASE EQUILIBRIUM :

     COMP             F(I)           X(I)           Y(I)           K(I)
     ADIPI           0.66008E-04    0.66008E-04    0.47925E-08    0.72605E-04
     HMDA            0.12168E-02    0.12168E-02    0.78213E-04    0.64279E-01
     H2O             0.99872        0.99872        0.99992         1.0012

BLOCK:  M-01     MODEL: MIXER
-----------------------------
  INLET STREAMS:         1          2
  OUTLET STREAM:         3
  PROPERTY OPTION SET:   POLYNRTL  POLYMER NRTL / REDLICH-KWONG

                   ***  MASS AND ENERGY BALANCE  ***
                                 IN              OUT        RELATIVE DIFF.
   TOTAL BALANCE
      MOLE(LBMOL/HR)           200.868         200.868         0.00000
      MASS(LB/HR   )           14983.7         14983.7       0.121398E-15
      ENTHALPY(BTU/HR  )     -0.366235E+08   -0.366235E+08    0.241970E-10

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

                       ***  INPUT DATA  ***
  TWO    PHASE     FLASH
  MAXIMUM NO. ITERATIONS                                  30
  CONVERGENCE TOLERANCE                                    0.000100000
  OUTLET PRESSURE   PSIA                                14.6959

BLOCK:  P-01     MODEL: PUMP
----------------------------
  INLET STREAM:          3
  OUTLET STREAM:         4
  PROPERTY OPTION SET:   POLYNRTL  POLYMER NRTL / REDLICH-KWONG

                   ***  MASS AND ENERGY BALANCE  ***
                                 IN              OUT        RELATIVE DIFF.
   TOTAL BALANCE
      MOLE(LBMOL/HR)           200.868         200.868         0.00000
      MASS(LB/HR   )           14983.7         14983.7         0.00000
      ENTHALPY(BTU/HR  )     -0.366235E+08   -0.366107E+08   -0.348754E-03

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

                       ***  INPUT DATA  ***
   OUTLET PRESSURE  PSIA                               235.196
```

```
   PUMP EFFICIENCY                                           0.75000
   DRIVER EFFICIENCY                                         0.80000

   FLASH SPECIFICATIONS:
   LIQUID PHASE CALCULATION
   NO FLASH PERFORMED
   MAXIMUM NUMBER OF ITERATIONS                              30
   TOLERANCE                                                 0.000100000

                       ***  RESULTS  ***
   VOLUMETRIC FLOW RATE  CUFT/HR                           234.770
   PRESSURE CHANGE  PSI                                    220.500
   NPSH AVAILABLE   FT-LBF/LB                               32.4398
   FLUID POWER  HP                                           3.76486
   BRAKE POWER  HP                                           5.01981
   ELECTRICITY  KW                                           4.67909
   PUMP EFFICIENCY USED                                      0.75000
   NET WORK REQUIRED  HP                                     6.27477
   HEAD DEVELOPED FT-LBF/LB                                497.501

BLOCK:  P-02     MODEL: PUMP
----------------------------
  INLET STREAM:          5
  OUTLET STREAM:         6
  PROPERTY OPTION SET:   POLYNRTL  POLYMER NRTL / REDLICH-KWONG

                  ***  MASS AND ENERGY BALANCE  ***
                                IN              OUT        RELATIVE DIFF.
   TOTAL BALANCE
      MOLE(LBMOL/HR)           200.868         200.868         0.00000
      MASS(LB/HR   )           14983.7         14983.7         0.00000
      ENTHALPY(BTU/HR  )      -0.362256E+08   -0.361834E+08   -0.116358E-02

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

                      ***  INPUT DATA  ***
   OUTLET PRESSURE  PSIA                                   934.696
   PUMP EFFICIENCY                                           0.75000
   DRIVER EFFICIENCY                                         0.80000

   FLASH SPECIFICATIONS:
   LIQUID PHASE CALCULATION
   NO FLASH PERFORMED
   MAXIMUM NUMBER OF ITERATIONS                              30
   TOLERANCE                                                 0.000100000

                       ***  RESULTS  ***
   VOLUMETRIC FLOW RATE  CUFT/HR                           240.109
   PRESSURE CHANGE  PSI                                    711.500
   NPSH AVAILABLE   FT-LBF/LB                              512.015
   FLUID POWER  HP                                          12.4246
   BRAKE POWER  HP                                          16.5661
   ELECTRICITY  KW                                          15.4416
   PUMP EFFICIENCY USED                                      0.75000
   NET WORK REQUIRED  HP                                    20.7076
   HEAD DEVELOPED FT-LBF/LB                              1,641.82

BLOCK:  R-01     MODEL: RPLUG
```

```
 ----------------------------
   INLET STREAM:          7
   OUTLET STREAM:         8
   PROPERTY OPTION SET:   POLYNRTL  POLYMER NRTL / REDLICH-KWONG

                   ***  MASS AND ENERGY BALANCE  ***
                         IN          OUT       GENERATION   RELATIVE DIFF.
   TOTAL BALANCE
   MOLE(LBMOL/HR)         200.868       237.667       36.7991     -0.119586E-15
   MASS(LB/HR   )         14983.7       14983.7                   -0.727172E-12
   ENTHALPY(BTU/HR  )   -0.322340E+08 -0.285473E+08               -0.114372

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

                       ***  INPUT DATA  ***

   REACTOR TYPE:
     SPECIFIED TEMPERATURE
     LIQUID FLUID PHASE
   REACTOR TUBE LENGTH                FT                    3500.0
   REACTOR DIAMETER                   FT                   0.12500
   REACTOR RISE                       FT                    0.0000
   NUMBER OF REACTOR TUBES                                  1
   REACTOR VOLUME                     CUFT                  42.951
   PRESSURE DROP OPTION:                                    SPECIFIED
   HOLDUP OPTION:                                           NO-SLIP
   ERROR TOLERANCE                                          0.10000E-03
   INTEGRATION METHOD                                       GEAR
   CORRECTOR METHOD                                         NEWTON
   INITIAL STEP SIZE FACTOR                                 0.10000E-01
   CORRECTOR TOLERANCE FACTOR                               0.10000
   MAXIMUM NUMBER OF STEPS                                   1000

   CONSTANT REACTOR TEMPERATURE SET TO THE (MIXED)
   INLET PROCESS STREAM TEMPERATURE OF     527.00      F

    REACTION PARAGRAPH TYPE                                 SEGMENT-BAS
    GLOBAL BASES:
    PHASE                                                   L
    CBASIS                                                  MOLARITY
    SITE NO                                                    1

    STOICHIOMETRY:

    REACTION NUMBER:          1
      SUBSTREAM:  MIXED
        ADIPI      -1.0000      HMDA       -1.0000      H2O         1.0000      ADIPI-
E     1.0000
  HMDA-E      1.0000
      SUBSTREAM:  CIPSD
        ADIPI      -1.0000      METHA-01    1.0000      NYLON66     1.0000      ADIPI-
R     1.0000

    REACTION NUMBER:          2
      SUBSTREAM:  MIXED
        HMDA       -1.0000      H2O         1.0000      ADIPI-E    -1.0000      ADIPI-
R     1.0000
  HMDA-E      1.0000
```

```
      SUBSTREAM:  CIPSD
        ADIPI      -1.0000      METHA-01    1.0000      NYLON66    -1.0000      ADIPI-
E     1.0000
  ADIPI-R     1.0000      NITRO-01   -1.0000

    REACTION NUMBER:          3
      SUBSTREAM:  MIXED
        ADIPI      -1.0000      H2O         1.0000      ADIPI-E     1.0000      HMDA-E
-1.0000
  HMDA-R      1.0000
      SUBSTREAM:  CIPSD
        METHA-01    1.0000      NYLON66     1.0000      ADIPI-R    -1.0000      HMDA-E
1.0000

    REACTION NUMBER:          4
      SUBSTREAM:  MIXED
        H2O         1.0000      ADIPI-E    -1.0000      ADIPI-R     1.0000      HMDA-E
-1.0000
  HMDA-R      1.0000
      SUBSTREAM:  CIPSD
        METHA-01    1.0000      NYLON66    -1.0000      ADIPI-E     1.0000      ADIPI-
R    -1.0000
  HMDA-E      1.0000      NITRO-01   0.10000E+36

    POWERLAW EXPONENTS:

    REACTION NUMBER:          1
      SUBSTREAM:  MIXED
        ADIPI       1.0000      HMDA        1.0000
      SUBSTREAM:  CIPSD
        ADIPI       1.0000

    REACTION NUMBER:          2
      SUBSTREAM:  MIXED
        HMDA        1.0000      ADIPI-E     1.0000
      SUBSTREAM:  CIPSD
        ADIPI       1.0000      NYLON66     1.0000      NITRO-01    1.0000

    REACTION NUMBER:          3
      SUBSTREAM:  MIXED
        ADIPI       1.0000      HMDA-E      1.0000
      SUBSTREAM:  CIPSD
        ADIPI-R     1.0000

    REACTION NUMBER:          4
      SUBSTREAM:  MIXED
        ADIPI-E     1.0000      HMDA-E      1.0000
      SUBSTREAM:  CIPSD
        NYLON66     1.0000      ADIPI-R     1.0000      NITRO-01   0.10000E+36

      RATE CONSTANT ASSIGNMENTS
      REACTION    ACTIVITY    RATE CONSTANT SETS
          1      1.000          1
          2      1.000          1
          3      1.000          1
          4      1.000          1

    RATE PARAMETERS:

      RC NO   CATALYST   ORDER    K0         EACT         B         TREF
                                 1/HR       BTU/LBMOL              F

        1               1.00   11.11       1075.       0.0000    392.00
```

*** RESULTS ***

REACTOR DUTY	BTU/HR	0.36867E+07
RESIDENCE TIME	HR	0.14070
REACTOR MINIMUM TEMPERATURE	F	527.00
REACTOR MAXIMUM TEMPERATURE	F	527.00

*** RESULTS PROFILE (PROCESS SUBSTREAM MIXED) ***

LENGTH FT	PRESSURE PSIA	TEMPERATURE F	VAPOR FRAC	RES-TIME HR
0.0000	906.70	527.00	0.0000	0.0000
350.00	899.70	527.00	0.0000	0.13885E-01
700.00	892.70	527.00	0.0000	0.27866E-01
1050.0	885.70	527.00	0.0000	0.41881E-01
1400.0	878.70	527.00	0.0000	0.55913E-01
1750.0	871.70	527.00	0.0000	0.69966E-01
2100.0	864.70	527.00	0.0000	0.84046E-01
2450.0	857.70	527.00	0.0000	0.98158E-01
2800.0	850.70	527.00	0.0000	0.11230
3150.0	843.70	527.00	0.0000	0.12649
3500.0	836.70	527.00	0.0000	0.14070

LENGTH FT	DUTY BTU/HR	LIQUID HOLDUP
0.0000	0.0000	1.0000
350.00	0.12095E+07	1.0000
700.00	0.20150E+07	1.0000
1050.0	0.25387E+07	1.0000
1400.0	0.28887E+07	1.0000
1750.0	0.31322E+07	1.0000
2100.0	0.33083E+07	1.0000
2450.0	0.34402E+07	1.0000
2800.0	0.35419E+07	1.0000
3150.0	0.36221E+07	1.0000
3500.0	0.36867E+07	1.0000

*** TOTAL MOLE FRACTION PROFILE (PROCESS SUBSTREAM MIXED) ***

LENGTH FT	ADIPI	HMDA	H2O	NYLON66
0.0000	0.25000	0.25000	0.50000	0.0000
350.00	0.15955	0.15955	0.59060	0.90312E-01
700.00	0.10509	0.10509	0.65139	0.13843
1050.0	0.73369E-01	0.73369E-01	0.68984	0.16342
1400.0	0.54104E-01	0.54104E-01	0.71474	0.17705
1750.0	0.41717E-01	0.41717E-01	0.73160	0.18497
2100.0	0.33316E-01	0.33316E-01	0.74352	0.18985
2450.0	0.27351E-01	0.27351E-01	0.75229	0.19301
2800.0	0.22957E-01	0.22957E-01	0.75895	0.19514
3150.0	0.19620E-01	0.19620E-01	0.76414	0.19662
3500.0	0.17021E-01	0.17021E-01	0.76828	0.19768

*** TOTAL MASS FRACTION PROFILE (PROCESS SUBSTREAM MIXED) ***

LENGTH FT	ADIPI	HMDA	H2O	NYLON66

0.0000	0.48979	0.38946	0.12075	0.0000
350.00	0.31968	0.25420	0.14588	0.28024
700.00	0.21743	0.17289	0.16613	0.44355
1050.0	0.15616	0.12417	0.18100	0.53866
1400.0	0.11777	0.93644E-01	0.19178	0.59680
1750.0	0.92394E-01	0.73467E-01	0.19974	0.63440
2100.0	0.74790E-01	0.59469E-01	0.20575	0.65999
2450.0	0.62059E-01	0.49346E-01	0.21041	0.67818
2800.0	0.52538E-01	0.41776E-01	0.21411	0.69158
3150.0	0.45217E-01	0.35955E-01	0.21709	0.70174
3500.0	0.39455E-01	0.31373E-01	0.21954	0.70964

*** COMPONENT ATTRIBUTE PROFILE (PROCESS SUBSTREAM MIXED) ***

LENGTH FT	NYLON66 SFRAC ADIPI-E	NYLON66 SFRAC ADIPI-R	NYLON66 SFRAC HMDA-E	NYLON66 SFRAC HMDA-R
0.0000	0.0000	0.0000	0.0000	0.0000
350.00	0.40089	0.99107E-01	0.40089	0.99107E-01
700.00	0.32417	0.17583	0.32417	0.17583
1050.0	0.26754	0.23246	0.26754	0.23246
1400.0	0.22557	0.27443	0.22557	0.27443
1750.0	0.19382	0.30618	0.19382	0.30618
2100.0	0.16924	0.33076	0.16924	0.33076
2450.0	0.14977	0.35023	0.14977	0.35023
2800.0	0.13403	0.36597	0.13403	0.36597
3150.0	0.12109	0.37891	0.12109	0.37891
3500.0	0.11027	0.38973	0.11027	0.38973

LENGTH FT	NYLON66 SFLOW ADIPI-E	NYLON66 SFLOW ADIPI-R	NYLON66 SFLOW HMDA-E	NYLON66 SFLOW HMDA-R
0.0000	0.0000	0.0000	0.0000	0.0000
350.00	0.17619E-02	0.43556E-03	0.17619E-02	0.43556E-03
700.00	0.22812E-02	0.12373E-02	0.22812E-02	0.12373E-02
1050.0	0.23061E-02	0.20038E-02	0.23061E-02	0.20038E-02
1400.0	0.21681E-02	0.26377E-02	0.21681E-02	0.26377E-02
1750.0	0.19900E-02	0.31437E-02	0.19900E-02	0.31437E-02
2100.0	0.18146E-02	0.35465E-02	0.18146E-02	0.35465E-02
2450.0	0.16552E-02	0.38704E-02	0.16552E-02	0.38704E-02
2800.0	0.15142E-02	0.41343E-02	0.15142E-02	0.41343E-02
3150.0	0.13908E-02	0.43523E-02	0.13908E-02	0.43523E-02
3500.0	0.12830E-02	0.45345E-02	0.12830E-02	0.45345E-02

LENGTH FT	NYLON66 EFRAC ADIPI-E	NYLON66 EFRAC HMDA-E	NYLON66 ZMOM ZMOM	NYLON66 FMOM FMOM
0.0000	0.0000	0.0000	0.0000	0.0000
350.00	0.50000	0.50000	0.17619E-02	0.43949E-02
700.00	0.50000	0.50000	0.22812E-02	0.70369E-02
1050.0	0.50000	0.50000	0.23061E-02	0.86197E-02
1400.0	0.50000	0.50000	0.21681E-02	0.96117E-02
1750.0	0.50000	0.50000	0.19900E-02	0.10267E-01
2100.0	0.50000	0.50000	0.18146E-02	0.10722E-01
2450.0	0.50000	0.50000	0.16552E-02	0.11051E-01
2800.0	0.50000	0.50000	0.15142E-02	0.11297E-01
3150.0	0.50000	0.50000	0.13908E-02	0.11486E-01
3500.0	0.50000	0.50000	0.12830E-02	0.11635E-01

LENGTH	NYLON66	NYLON66
FT	DPN	MWN
	DPN	MWN
0.0000	0.0000	0.0000
350.00	2.4944	300.28
700.00	3.0848	367.09
1050.0	3.7378	440.98
1400.0	4.4332	519.67
1750.0	5.1595	601.86
2100.0	5.9088	686.65
2450.0	6.6768	773.55
2800.0	7.4608	862.27
3150.0	8.2585	952.54
3500.0	9.0683	1044.2

*** RESULTS PROFILE (PROCESS SUBSTREAM CIPSD) ***

LENGTH	PRESSURE	TEMPERATURE	RES-TIME
FT	PSIA	F	HR
0.0000	906.70	527.00	0.0000
350.00	899.70	527.00	0.13885E-01
700.00	892.70	527.00	0.27866E-01
1050.0	885.70	527.00	0.41881E-01
1400.0	878.70	527.00	0.55913E-01
1750.0	871.70	527.00	0.69966E-01
2100.0	864.70	527.00	0.84046E-01
2450.0	857.70	527.00	0.98158E-01
2800.0	850.70	527.00	0.11230
3150.0	843.70	527.00	0.12649
3500.0	836.70	527.00	0.14070

BLOCK: R-02 MODEL: RCSTR

INLET STREAM: 8
OUTLET STREAMS: 9 12
PROPERTY OPTION SET: POLYNRTL POLYMER NRTL / REDLICH-KWONG

*** MASS AND ENERGY BALANCE ***

	IN	OUT	GENERATION	RELATIVE DIFF.
TOTAL BALANCE				
MOLE(LBMOL/HR)	237.667	250.297	12.6299	0.113552E-15
MASS(LB/HR)	14983.7	14983.7		0.121398E-15
ENTHALPY(BTU/HR)	-0.285473E+08	-0.258321E+08		-0.951138E-01

*** CO2 EQUIVALENT SUMMARY ***

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

*** INPUT DATA ***

REACTOR TYPE: TEMP SPEC TWO PHASE REACTOR

RESIDENCE TIME	HR	0.50000E-01
REACTOR TEMPERATURE	F	491.00
REACTOR PRESSURE	PSIA	33.696

```
    REACTION PARAGRAPH TYPE                                  SEGMENT-BAS
    GLOBAL BASES:
    PHASE                                                    L
    CBASIS                                                   MOLARITY
    SITE NO                                                     1

    STOICHIOMETRY:

    REACTION NUMBER:          1
      SUBSTREAM:  MIXED
        ADIPI      -1.0000      HMDA       -1.0000      H2O         1.0000      ADIPI-
E     1.0000
  HMDA-E      1.0000
      SUBSTREAM:  CIPSD
        ADIPI      -1.0000      METHA-01    1.0000      NYLON66     1.0000      ADIPI-
R     1.0000

    REACTION NUMBER:          2
      SUBSTREAM:  MIXED
        HMDA       -1.0000      H2O         1.0000      ADIPI-E    -1.0000      ADIPI-
R     1.0000
  HMDA-E      1.0000
      SUBSTREAM:  CIPSD
        ADIPI      -1.0000      METHA-01    1.0000      NYLON66    -1.0000      ADIPI-
E     1.0000
  ADIPI-R     1.0000      NITRO-01   -1.0000

    REACTION NUMBER:          3
      SUBSTREAM:  MIXED
        ADIPI      -1.0000      H2O         1.0000      ADIPI-E     1.0000      HMDA-E
-1.0000
  HMDA-R      1.0000
      SUBSTREAM:  CIPSD
        METHA-01    1.0000      NYLON66     1.0000      ADIPI-R    -1.0000      HMDA-E
1.0000

    REACTION NUMBER:          4
      SUBSTREAM:  MIXED
        H2O         1.0000      ADIPI-E    -1.0000      ADIPI-R     1.0000      HMDA-E
-1.0000
  HMDA-R      1.0000
      SUBSTREAM:  CIPSD
        METHA-01    1.0000      NYLON66    -1.0000      ADIPI-E     1.0000      ADIPI-
R    -1.0000
  HMDA-E      1.0000      NITRO-01   0.10000E+36

    POWERLAW EXPONENTS:

    REACTION NUMBER:          1
      SUBSTREAM:  MIXED
        ADIPI       1.0000      HMDA        1.0000
      SUBSTREAM:  CIPSD
        ADIPI       1.0000

    REACTION NUMBER:          2
      SUBSTREAM:  MIXED
        HMDA        1.0000      ADIPI-E     1.0000
      SUBSTREAM:  CIPSD
        ADIPI       1.0000      NYLON66     1.0000      NITRO-01    1.0000

    REACTION NUMBER:          3
      SUBSTREAM:  MIXED
        ADIPI       1.0000      HMDA-E      1.0000
```

```
  SUBSTREAM:  CIPSD
    ADIPI-R     1.0000

REACTION NUMBER:          4
  SUBSTREAM:  MIXED
    ADIPI-E     1.0000      HMDA-E      1.0000
  SUBSTREAM:  CIPSD
    NYLON66     1.0000      ADIPI-R     1.0000      NITRO-01   0.10000E+36

  RATE CONSTANT ASSIGNMENTS
  REACTION    ACTIVITY    RATE CONSTANT SETS
        1      1.000         1
        2      1.000         1
        3      1.000         1
        4      1.000         1

RATE PARAMETERS:

  RC NO   CATALYST   ORDER    K0         EACT        B         TREF
                             1/HR        BTU/LBMOL              F

     1              1.00   11.11       1075.       0.0000    392.00

                       ***  RESULTS  ***

REACTOR HEAT DUTY                  BTU/HR                    0.27152E+07
REACTOR VOLUME                     CUFT                       3002.0
VAPOR PHASE VOLUME FRACTION                                  0.99652
VAPOR PHASE VOLUME                 CUFT                       2991.5
LIQUID PHASE VOLUME                CUFT                       10.443
```

Appendix E: Aspen Plus Printouts and Reports

Full Scale Stream Report

```
SUBSTREAM ATTR PSD TYPE: PSD
----------------------------

INTERVAL     LOWER LIMIT           UPPER LIMIT
    1          0.0     FT         6.5617-05  FT
    2       6.5617-05  FT         1.3123-04  FT
    3       1.3123-04  FT         1.9685-04  FT
    4       1.9685-04  FT         2.6247-04  FT
    5       2.6247-04  FT         3.2808-04  FT
    6       3.2808-04  FT         3.9370-04  FT
    7       3.9370-04  FT         4.5932-04  FT
    8       4.5932-04  FT         5.2493-04  FT
    9       5.2493-04  FT         5.9055-04  FT
   10       5.9055-04  FT         6.5617-04  FT


1 12 13 2 3
-----------

STREAM ID                1          12         13         2          3
FROM :                   ----       R-02       E-03       ----       M-01
TO   :                   M-01       E-03       ----       M-01       P-01
CLASS:                   MIXCIPSD   MIXCIPSD   MIXCIPSD   MIXCIPSD   MIXCIPSD
TOTAL STREAM:
  LB/HR                6740.2019  3608.4939  3608.4939  8243.5190  1.4984+04
  BTU/HR              -9.4647+06 -1.9990+07 -2.3933+07 -2.7159+07 -3.6624+07
SUBSTREAM: MIXED
PHASE:                   LIQUID     VAPOR      LIQUID     LIQUID     LIQUID
COMPONENTS: LBMOL/HR
  ADIPI                   0.0     1.3128-02  1.3128-02    50.2169    50.2169
  HMDA                   50.2169     0.2420     0.2420     0.0        50.2169
  METHA-01                0.0       0.0        0.0        0.0         0.0
  H2O                    50.2169   198.6343   198.6343    50.2169   100.4338
  NYLON66                 0.0       0.0        0.0        0.0         0.0
  NITRO-01                0.0       0.0        0.0        0.0         0.0
COMPONENTS: LB/HR
  ADIPI                   0.0        1.9186     1.9186  7338.8476  7338.8476
  HMDA                 5835.5305    28.1224    28.1224     0.0      5835.5305
  METHA-01                0.0       0.0        0.0        0.0         0.0
  H2O                   904.6714  3578.4528  3578.4528   904.6714  1809.3428
  NYLON66                 0.0       0.0        0.0        0.0         0.0
  NITRO-01                0.0       0.0        0.0        0.0         0.0
TOTAL FLOW:
  LBMOL/HR              100.4338   198.8894   198.8894   100.4338   200.8676
  LB/HR                6740.2019  3608.4939  3608.4939  8243.5190  1.4984+04
  CUFT/HR               120.2663  5.9831+04    63.0747   114.0296   234.7701
STATE VARIABLES:
  TEMP   F               77.0000   491.0000   212.0932    77.0000    80.2626
  PRES   PSIA            14.6959    33.6959    14.6959    14.6959    14.6959
  VFRAC                   0.0        1.0000     0.0        0.0         0.0
  LFRAC                   1.0000     0.0        1.0000     1.0000     1.0000
  SFRAC                   0.0        0.0        0.0        0.0         0.0
ENTHALPY:
  BTU/LBMOL           -9.4238+04 -1.0051+05 -1.2033+05 -2.7042+05 -1.8233+05
  BTU/LB              -1404.2136 -5539.8041 -6632.4880 -3294.5677 -2444.2202
  BTU/HR              -9.4647+06 -1.9990+07 -2.3933+07 -2.7159+07 -3.6624+07
ENTROPY:
```

BTU/LBMOL-R	-127.3887	-7.7660	-35.0797	-112.1008	-118.9907
BTU/LB-R	-1.8982	-0.4280	-1.9335	-1.3658	-1.5952
DENSITY:					
LBMOL/CUFT	0.8351	3.3242-03	3.1532	0.8808	0.8556
LB/CUFT	56.0440	6.0312-02	57.2099	72.2928	63.8229
AVG MW	67.1109	18.1432	18.1432	82.0791	74.5950
COMPONENT ATTRIBUTES:					
NYLON66 SFRAC					
ADIPI-E	MISSING	8.7083-03	8.7083-03	MISSING	MISSING
ADIPI-R	MISSING	0.4923	0.4923	MISSING	MISSING
HMDA-E	MISSING	4.7953-03	4.7953-03	MISSING	MISSING
HMDA-R	MISSING	0.4942	0.4942	MISSING	MISSING
SFLOW					
ADIPI-E	MISSING	0.0	0.0	MISSING	MISSING
ADIPI-R	MISSING	0.0	0.0	MISSING	MISSING
HMDA-E	MISSING	0.0	0.0	MISSING	MISSING
HMDA-R	MISSING	0.0	0.0	MISSING	MISSING
EFRAC					
ADIPI-E	MISSING	0.6449	0.6449	MISSING	MISSING
HMDA-E	MISSING	0.3551	0.3551	MISSING	MISSING
ZMOM					
ZMOM	MISSING	0.0	0.0	MISSING	MISSING
FMOM					
FMOM	MISSING	0.0	0.0	MISSING	MISSING
DPN					
DPN	MISSING	148.1092	148.1092	MISSING	MISSING
MWN					
MWN	MISSING	1.6782+04	1.6782+04	MISSING	MISSING

4 5 6 7 8

STREAM ID	4	5	6	7	8
FROM :	P-01	E-01	P-02	E-02	R-01
TO :	E-01	P-02	E-02	R-01	R-02
CLASS:	MIXCIPSD	MIXCIPSD	MIXCIPSD	MIXCIPSD	MIXCIPSD
TOTAL STREAM:					
LB/HR	1.4984+04	1.4984+04	1.4984+04	1.4984+04	1.4984+04
BTU/HR	-3.6611+07	-3.6226+07	-3.6183+07	-3.2234+07	-2.8547+07
SUBSTREAM: MIXED					
PHASE:	LIQUID	LIQUID	LIQUID	LIQUID	LIQUID
COMPONENTS: LBMOL/HR					
ADIPI	50.2169	50.2169	50.2169	50.2169	4.0452
HMDA	50.2169	50.2169	50.2169	50.2169	4.0452
METHA-01	0.0	0.0	0.0	0.0	0.0
H2O	100.4338	100.4338	100.4338	100.4338	182.5940
NYLON66	0.0	0.0	0.0	0.0	46.9822
NITRO-01	0.0	0.0	0.0	0.0	0.0
COMPONENTS: LB/HR					
ADIPI	7338.8476	7338.8476	7338.8476	7338.8476	591.1819
HMDA	5835.5305	5835.5305	5835.5305	5835.5305	470.0819
METHA-01	0.0	0.0	0.0	0.0	0.0
H2O	1809.3428	1809.3428	1809.3428	1809.3428	3289.4823
NYLON66	0.0	0.0	0.0	0.0	1.0633+04
NITRO-01	0.0	0.0	0.0	0.0	0.0
TOTAL FLOW:					
LBMOL/HR	200.8676	200.8676	200.8676	200.8676	237.6667
LB/HR	1.4984+04	1.4984+04	1.4984+04	1.4984+04	1.4984+04
CUFT/HR	234.8456	240.1091	240.3847	311.2127	301.8489
STATE VARIABLES:					
TEMP F	80.9492	127.1862	129.5219	527.0000	526.9995
PRES PSIA	235.1959	223.1959	934.6959	908.6959	836.6959
VFRAC	0.0	0.0	0.0	0.0	0.0

```
  LFRAC                  1.0000     1.0000     1.0000     1.0000     1.0000
  SFRAC                  0.0        0.0        0.0        0.0        0.0
ENTHALPY:
  BTU/LBMOL          -1.8226+05 -1.8035+05 -1.8014+05 -1.6047+05 -1.2011+05
  BTU/LB             -2443.3678 -2417.6620 -2414.8489 -2151.2686 -1905.2231
  BTU/HR             -3.6611+07 -3.6226+07 -3.6183+07 -3.2234+07 -2.8547+07
ENTROPY:
  BTU/LBMOL-R          -118.8721  -115.4451  -115.0888   -90.8162   -74.2682
  BTU/LB-R               -1.5936    -1.5476    -1.5428    -1.2175    -1.1780
DENSITY:
  LBMOL/CUFT             0.8553     0.8366     0.8356     0.6454     0.7874
  LB/CUFT               63.8024    62.4038    62.3323    48.1462    49.6398
AVG MW                  74.5950    74.5950    74.5950    74.5950    63.0451
COMPONENT ATTRIBUTES:
NYLON66  SFRAC
           ADIPI-E      MISSING    MISSING    MISSING    MISSING     0.1103
           ADIPI-R      MISSING    MISSING    MISSING    MISSING     0.3897
           HMDA-E       MISSING    MISSING    MISSING    MISSING     0.1103
           HMDA-R       MISSING    MISSING    MISSING    MISSING     0.3897
         SFLOW
           ADIPI-E      MISSING    MISSING    MISSING    MISSING    10.1831
           ADIPI-R      MISSING    MISSING    MISSING    MISSING    35.9886
           HMDA-E       MISSING    MISSING    MISSING    MISSING    10.1831
           HMDA-R       MISSING    MISSING    MISSING    MISSING    35.9886
         EFRAC
           ADIPI-E      MISSING    MISSING    MISSING    MISSING     0.5000
           HMDA-E       MISSING    MISSING    MISSING    MISSING     0.5000
         ZMOM
           ZMOM         MISSING    MISSING    MISSING    MISSING    10.1831
         FMOM
           FMOM         MISSING    MISSING    MISSING    MISSING    92.3433
         DPN
           DPN          MISSING    MISSING    MISSING    MISSING     9.0683
         MWN
           MWN          MISSING    MISSING    MISSING    MISSING  1044.1779

9
-

STREAM ID               9
FROM :                  R-02
TO   :                  ----
CLASS:                  MIXCIPSD
TOTAL STREAM:
  LB/HR               1.1375+04
  BTU/HR             -5.8417+06
SUBSTREAM: MIXED
PHASE:                  LIQUID
COMPONENTS: LBMOL/HR
  ADIPI               6.7845-02
  HMDA                3.4767-02
  METHA-01               0.0
  H2O                    1.1998
  NYLON66               50.1047
  NITRO-01               0.0
COMPONENTS: LB/HR
  ADIPI                  9.9150
  HMDA                   4.0402
  METHA-01               0.0
  H2O                   21.6152
  NYLON66             1.1340+04
  NITRO-01               0.0
TOTAL FLOW:
```

```
  LBMOL/HR              51.4072
  LB/HR               1.1375+04
  CUFT/HR              208.8572
STATE VARIABLES:
  TEMP   F             491.0000
  PRES   PSIA           33.6959
  VFRAC                  0.0
  LFRAC                  1.0000
  SFRAC                  0.0
ENTHALPY:
  BTU/LBMOL          -1.1364+05
  BTU/LB              -513.5490
  BTU/HR             -5.8417+06
ENTROPY:
  BTU/LBMOL-R         -248.6758
  BTU/LB-R              -1.1238
DENSITY:
  LBMOL/CUFT             0.2461
  LB/CUFT               54.4641
AVG MW                 221.2770
COMPONENT ATTRIBUTES:
NYLON66  SFRAC
           ADIPI-E    8.7083-03
           ADIPI-R       0.4923
           HMDA-E     4.7953-03
           HMDA-R        0.4942
         SFLOW
           ADIPI-E       0.8715
           ADIPI-R      49.2644
           HMDA-E        0.4799
           HMDA-R       49.4602
         EFRAC
           ADIPI-E       0.6449
           HMDA-E        0.3551
         ZMOM
           ZMOM          0.6757
         FMOM
           FMOM        100.0760
         DPN
           DPN         148.1092
         MWN
           MWN        1.6782+04

SUBSTREAM ATTR PSD TYPE: PSD
----------------------------

INTERVAL     LOWER LIMIT           UPPER LIMIT
    1          0.0     FT         6.5617-05  FT
    2       6.5617-05  FT         1.3123-04  FT
    3       1.3123-04  FT         1.9685-04  FT
    4       1.9685-04  FT         2.6247-04  FT
    5       2.6247-04  FT         3.2808-04  FT
    6       3.2808-04  FT         3.9370-04  FT
    7       3.9370-04  FT         4.5932-04  FT
    8       4.5932-04  FT         5.2493-04  FT
    9       5.2493-04  FT         5.9055-04  FT
   10       5.9055-04  FT         6.5617-04  FT


1
-

STREAM ID              1
```

```
FROM :                   ----
TO   :                   M-01
CLASS:                   MIXCIPSD
TOTAL STREAM:
  LB/HR               6740.2019
  BTU/HR             -9.4647+06
SUBSTREAM: MIXED
PHASE:                   LIQUID
COMPONENTS: LBMOL/HR
  ADIPI                    0.0
  HMDA                   50.2169
  METHA-01                 0.0
  H2O                    50.2169
  NYLON66                  0.0
  NITRO-01                 0.0
COMPONENTS: LB/HR
  ADIPI                    0.0
  HMDA                 5835.5305
  METHA-01                 0.0
  H2O                   904.6714
  NYLON66                  0.0
  NITRO-01                 0.0
TOTAL FLOW:
  LBMOL/HR              100.4338
  LB/HR                6740.2019
  CUFT/HR               120.2663
STATE VARIABLES:
  TEMP   F               77.0000
  PRES   PSIA            14.6959
  VFRAC                    0.0
  LFRAC                    1.0000
  SFRAC                    0.0
ENTHALPY:
  BTU/LBMOL          -9.4238+04
  BTU/LB             -1404.2136
  BTU/HR             -9.4647+06
ENTROPY:
  BTU/LBMOL-R          -127.3887
  BTU/LB-R               -1.8982
DENSITY:
  LBMOL/CUFT               0.8351
  LB/CUFT                56.0440
AVG MW                   67.1109
COMPONENT ATTRIBUTES:
NYLON66  SFRAC
         SFLOW
         EFRAC
         ZMOM
         FMOM
         DPN
         MWN

SUBSTREAM ATTR PSD TYPE: PSD
----------------------------
```

INTERVAL	LOWER LIMIT	UPPER LIMIT
1	0.0 FT	6.5617-05 FT
2	6.5617-05 FT	1.3123-04 FT
3	1.3123-04 FT	1.9685-04 FT
4	1.9685-04 FT	2.6247-04 FT
5	2.6247-04 FT	3.2808-04 FT
6	3.2808-04 FT	3.9370-04 FT
7	3.9370-04 FT	4.5932-04 FT

```
    8       4.5932-04  FT         5.2493-04  FT
    9       5.2493-04  FT         5.9055-04  FT
   10       5.9055-04  FT         6.5617-04  FT


2
-

STREAM ID                2
FROM :                   ----
TO   :                   M-01
CLASS:                   MIXCIPSD
TOTAL STREAM:
  LB/HR                8243.5190
  BTU/HR              -2.7159+07
SUBSTREAM: MIXED
PHASE:                   LIQUID
COMPONENTS: LBMOL/HR
  ADIPI                  50.2169
  HMDA                    0.0
  METHA-01                0.0
  H2O                    50.2169
  NYLON66                 0.0
  NITRO-01                0.0
COMPONENTS: LB/HR
  ADIPI                7338.8476
  HMDA                    0.0
  METHA-01                0.0
  H2O                   904.6714
  NYLON66                 0.0
  NITRO-01                0.0
TOTAL FLOW:
  LBMOL/HR              100.4338
  LB/HR                8243.5190
  CUFT/HR               114.0296
STATE VARIABLES:
  TEMP   F               77.0000
  PRES   PSIA            14.6959
  VFRAC                   0.0
  LFRAC                   1.0000
  SFRAC                   0.0
ENTHALPY:
  BTU/LBMOL           -2.7042+05
  BTU/LB              -3294.5677
  BTU/HR              -2.7159+07
ENTROPY:
  BTU/LBMOL-R          -112.1008
  BTU/LB-R               -1.3658
DENSITY:
  LBMOL/CUFT              0.8808
  LB/CUFT                72.2928
AVG MW                   82.0791
COMPONENT ATTRIBUTES:
NYLON66  SFRAC
         SFLOW
         EFRAC
         ZMOM
         FMOM
         DPN
         MWN

SUBSTREAM ATTR PSD TYPE: PSD
----------------------------
```

INTERVAL	LOWER LIMIT		UPPER LIMIT	
1	0.0	FT	6.5617-05	FT
2	6.5617-05	FT	1.3123-04	FT
3	1.3123-04	FT	1.9685-04	FT
4	1.9685-04	FT	2.6247-04	FT
5	2.6247-04	FT	3.2808-04	FT
6	3.2808-04	FT	3.9370-04	FT
7	3.9370-04	FT	4.5932-04	FT
8	4.5932-04	FT	5.2493-04	FT
9	5.2493-04	FT	5.9055-04	FT
10	5.9055-04	FT	6.5617-04	FT

3
-

```
STREAM ID                3
FROM :                   M-01
TO   :                   P-01
CLASS:                   MIXCIPSD
TOTAL STREAM:
  LB/HR                1.4984+04
  BTU/HR              -3.6624+07
SUBSTREAM: MIXED
PHASE:                   LIQUID
COMPONENTS: LBMOL/HR
  ADIPI                  50.2169
  HMDA                   50.2169
  METHA-01                0.0
  H2O                   100.4338
  NYLON66                 0.0
  NITRO-01                0.0
COMPONENTS: LB/HR
  ADIPI                7338.8476
  HMDA                 5835.5305
  METHA-01                0.0
  H2O                  1809.3428
  NYLON66                 0.0
  NITRO-01                0.0
TOTAL FLOW:
  LBMOL/HR              200.8676
  LB/HR                1.4984+04
  CUFT/HR               234.7701
STATE VARIABLES:
  TEMP   F               80.2626
  PRES   PSIA            14.6959
  VFRAC                   0.0
  LFRAC                   1.0000
  SFRAC                   0.0
ENTHALPY:
  BTU/LBMOL           -1.8233+05
  BTU/LB              -2444.2202
  BTU/HR              -3.6624+07
ENTROPY:
  BTU/LBMOL-R          -118.9907
  BTU/LB-R               -1.5952
DENSITY:
  LBMOL/CUFT              0.8556
  LB/CUFT                63.8229
AVG MW                   74.5950
COMPONENT ATTRIBUTES:
NYLON66  SFRAC
```

```
          SFLOW
          EFRAC
          ZMOM
          FMOM
          DPN
          MWN

SUBSTREAM ATTR PSD TYPE: PSD
----------------------------

INTERVAL     LOWER LIMIT           UPPER LIMIT
    1          0.0     FT         6.5617-05  FT
    2       6.5617-05  FT         1.3123-04  FT
    3       1.3123-04  FT         1.9685-04  FT
    4       1.9685-04  FT         2.6247-04  FT
    5       2.6247-04  FT         3.2808-04  FT
    6       3.2808-04  FT         3.9370-04  FT
    7       3.9370-04  FT         4.5932-04  FT
    8       4.5932-04  FT         5.2493-04  FT
    9       5.2493-04  FT         5.9055-04  FT
   10       5.9055-04  FT         6.5617-04  FT


4
-

STREAM ID                4
FROM :                   P-01
TO   :                   E-01
CLASS:                   MIXCIPSD
TOTAL STREAM:
  LB/HR                1.4984+04
  BTU/HR              -3.6611+07
SUBSTREAM: MIXED
PHASE:                   LIQUID
COMPONENTS: LBMOL/HR
  ADIPI                  50.2169
  HMDA                   50.2169
  METHA-01                0.0
  H2O                   100.4338
  NYLON66                 0.0
  NITRO-01                0.0
COMPONENTS: LB/HR
  ADIPI                7338.8476
  HMDA                 5835.5305
  METHA-01                0.0
  H2O                  1809.3428
  NYLON66                 0.0
  NITRO-01                0.0
TOTAL FLOW:
  LBMOL/HR              200.8676
  LB/HR                1.4984+04
  CUFT/HR               234.8456
STATE VARIABLES:
  TEMP   F               80.9492
  PRES   PSIA           235.1959
  VFRAC                   0.0
  LFRAC                   1.0000
  SFRAC                   0.0
ENTHALPY:
  BTU/LBMOL           -1.8226+05
  BTU/LB              -2443.3678
  BTU/HR              -3.6611+07
```

```
ENTROPY:
  BTU/LBMOL-R          -118.8721
  BTU/LB-R               -1.5936
DENSITY:
  LBMOL/CUFT              0.8553
  LB/CUFT                63.8024
AVG MW                   74.5950
COMPONENT ATTRIBUTES:
NYLON66  SFRAC
         SFLOW
         EFRAC
         ZMOM
         FMOM
         DPN
         MWN

SUBSTREAM ATTR PSD TYPE: PSD
----------------------------

INTERVAL     LOWER LIMIT           UPPER LIMIT
    1          0.0     FT          6.5617-05  FT
    2       6.5617-05  FT          1.3123-04  FT
    3       1.3123-04  FT          1.9685-04  FT
    4       1.9685-04  FT          2.6247-04  FT
    5       2.6247-04  FT          3.2808-04  FT
    6       3.2808-04  FT          3.9370-04  FT
    7       3.9370-04  FT          4.5932-04  FT
    8       4.5932-04  FT          5.2493-04  FT
    9       5.2493-04  FT          5.9055-04  FT
   10       5.9055-04  FT          6.5617-04  FT


5
-

STREAM ID                5
FROM :                   E-01
TO   :                   P-02
CLASS:                   MIXCIPSD
TOTAL STREAM:
  LB/HR                1.4984+04
  BTU/HR              -3.6226+07
SUBSTREAM: MIXED
PHASE:                   LIQUID
COMPONENTS: LBMOL/HR
  ADIPI                  50.2169
  HMDA                   50.2169
  METHA-01                0.0
  H2O                   100.4338
  NYLON66                 0.0
  NITRO-01                0.0
COMPONENTS: LB/HR
  ADIPI                7338.8476
  HMDA                 5835.5305
  METHA-01                0.0
  H2O                  1809.3428
  NYLON66                 0.0
  NITRO-01                0.0
TOTAL FLOW:
  LBMOL/HR              200.8676
  LB/HR                1.4984+04
  CUFT/HR               240.1091
STATE VARIABLES:
```

```
  TEMP   F              127.1862
  PRES   PSIA           223.1959
  VFRAC                   0.0
  LFRAC                   1.0000
  SFRAC                   0.0
ENTHALPY:
  BTU/LBMOL           -1.8035+05
  BTU/LB              -2417.6620
  BTU/HR              -3.6226+07
ENTROPY:
  BTU/LBMOL-R          -115.4451
  BTU/LB-R               -1.5476
DENSITY:
  LBMOL/CUFT              0.8366
  LB/CUFT                62.4038
AVG MW                   74.5950
COMPONENT ATTRIBUTES:
NYLON66  SFRAC
         SFLOW
         EFRAC
         ZMOM
         FMOM
         DPN
         MWN

SUBSTREAM ATTR PSD TYPE: PSD
----------------------------

INTERVAL     LOWER LIMIT           UPPER LIMIT
    1          0.0     FT         6.5617-05  FT
    2       6.5617-05  FT         1.3123-04  FT
    3       1.3123-04  FT         1.9685-04  FT
    4       1.9685-04  FT         2.6247-04  FT
    5       2.6247-04  FT         3.2808-04  FT
    6       3.2808-04  FT         3.9370-04  FT
    7       3.9370-04  FT         4.5932-04  FT
    8       4.5932-04  FT         5.2493-04  FT
    9       5.2493-04  FT         5.9055-04  FT
   10       5.9055-04  FT         6.5617-04  FT


6
-

STREAM ID                6
FROM :                   P-02
TO   :                   E-02
CLASS:                   MIXCIPSD
TOTAL STREAM:
  LB/HR                1.4984+04
  BTU/HR              -3.6183+07
SUBSTREAM: MIXED
PHASE:                   LIQUID
COMPONENTS: LBMOL/HR
  ADIPI                  50.2169
  HMDA                   50.2169
  METHA-01                0.0
  H2O                   100.4338
  NYLON66                 0.0
  NITRO-01                0.0
COMPONENTS: LB/HR
  ADIPI                7338.8476
  HMDA                 5835.5305
```

```
  METHA-01                0.0
  H2O                  1809.3428
  NYLON66                 0.0
  NITRO-01                0.0
TOTAL FLOW:
  LBMOL/HR              200.8676
  LB/HR                1.4984+04
  CUFT/HR               240.3847
STATE VARIABLES:
  TEMP   F              129.5219
  PRES   PSIA           934.6959
  VFRAC                   0.0
  LFRAC                   1.0000
  SFRAC                   0.0
ENTHALPY:
  BTU/LBMOL           -1.8014+05
  BTU/LB              -2414.8489
  BTU/HR              -3.6183+07
ENTROPY:
  BTU/LBMOL-R          -115.0888
  BTU/LB-R               -1.5428
DENSITY:
  LBMOL/CUFT              0.8356
  LB/CUFT                62.3323
AVG MW                   74.5950
COMPONENT ATTRIBUTES:
NYLON66  SFRAC
         SFLOW
         EFRAC
         ZMOM
         FMOM
         DPN
         MWN

SUBSTREAM ATTR PSD TYPE: PSD
----------------------------

INTERVAL     LOWER LIMIT           UPPER LIMIT
    1          0.0     FT         6.5617-05  FT
    2       6.5617-05  FT         1.3123-04  FT
    3       1.3123-04  FT         1.9685-04  FT
    4       1.9685-04  FT         2.6247-04  FT
    5       2.6247-04  FT         3.2808-04  FT
    6       3.2808-04  FT         3.9370-04  FT
    7       3.9370-04  FT         4.5932-04  FT
    8       4.5932-04  FT         5.2493-04  FT
    9       5.2493-04  FT         5.9055-04  FT
   10       5.9055-04  FT         6.5617-04  FT


7
-

STREAM ID                7
FROM :                   E-02
TO   :                   R-01
CLASS:                   MIXCIPSD
TOTAL STREAM:
  LB/HR                1.4984+04
  BTU/HR              -3.2234+07
SUBSTREAM: MIXED
PHASE:                   LIQUID
COMPONENTS: LBMOL/HR
```

```
  ADIPI                   50.2169
  HMDA                    50.2169
  METHA-01                 0.0
  H2O                    100.4338
  NYLON66                  0.0
  NITRO-01                 0.0
COMPONENTS: LB/HR
  ADIPI                 7338.8476
  HMDA                  5835.5305
  METHA-01                 0.0
  H2O                   1809.3428
  NYLON66                  0.0
  NITRO-01                 0.0
TOTAL FLOW:
  LBMOL/HR               200.8676
  LB/HR                 1.4984+04
  CUFT/HR                311.2127
STATE VARIABLES:
  TEMP   F               527.0000
  PRES   PSIA            908.6959
  VFRAC                    0.0
  LFRAC                    1.0000
  SFRAC                    0.0
ENTHALPY:
  BTU/LBMOL            -1.6047+05
  BTU/LB               -2151.2686
  BTU/HR               -3.2234+07
ENTROPY:
  BTU/LBMOL-R            -90.8162
  BTU/LB-R                -1.2175
DENSITY:
  LBMOL/CUFT               0.6454
  LB/CUFT                 48.1462
AVG MW                    74.5950
COMPONENT ATTRIBUTES:
NYLON66  SFRAC
         SFLOW
         EFRAC
         ZMOM
         FMOM
         DPN
         MWN

SUBSTREAM ATTR PSD TYPE: PSD
----------------------------

INTERVAL     LOWER LIMIT           UPPER LIMIT
    1          0.0     FT         6.5617-05  FT
    2       6.5617-05  FT         1.3123-04  FT
    3       1.3123-04  FT         1.9685-04  FT
    4       1.9685-04  FT         2.6247-04  FT
    5       2.6247-04  FT         3.2808-04  FT
    6       3.2808-04  FT         3.9370-04  FT
    7       3.9370-04  FT         4.5932-04  FT
    8       4.5932-04  FT         5.2493-04  FT
    9       5.2493-04  FT         5.9055-04  FT
   10       5.9055-04  FT         6.5617-04  FT


8
-

STREAM ID               8
```

```
FROM :                  R-01
TO   :                  R-02
CLASS:                  MIXCIPSD
TOTAL STREAM:
  LB/HR               1.4984+04
  BTU/HR             -2.8547+07
SUBSTREAM: MIXED
PHASE:                  LIQUID
COMPONENTS: LBMOL/HR
  ADIPI                  4.0452
  HMDA                   4.0452
  METHA-01               0.0
  H2O                  182.5940
  NYLON66               46.9822
  NITRO-01               0.0
COMPONENTS: LB/HR
  ADIPI                591.1819
  HMDA                 470.0819
  METHA-01               0.0
  H2O                 3289.4823
  NYLON66             1.0633+04
  NITRO-01               0.0
TOTAL FLOW:
  LBMOL/HR             237.6667
  LB/HR               1.4984+04
  CUFT/HR              301.8489
STATE VARIABLES:
  TEMP   F             526.9995
  PRES   PSIA          836.6959
  VFRAC                  0.0
  LFRAC                  1.0000
  SFRAC                  0.0
ENTHALPY:
  BTU/LBMOL          -1.2011+05
  BTU/LB             -1905.2231
  BTU/HR             -2.8547+07
ENTROPY:
  BTU/LBMOL-R          -74.2682
  BTU/LB-R              -1.1780
DENSITY:
  LBMOL/CUFT             0.7874
  LB/CUFT               49.6398
AVG MW                  63.0451
COMPONENT ATTRIBUTES:
NYLON66  SFRAC
           ADIPI-E       0.1103
           ADIPI-R       0.3897
           HMDA-E        0.1103
           HMDA-R        0.3897
         SFLOW
           ADIPI-E      10.1831
           ADIPI-R      35.9886
           HMDA-E       10.1831
           HMDA-R       35.9886
         EFRAC
           ADIPI-E       0.5000
           HMDA-E        0.5000
         ZMOM
           ZMOM         10.1831
         FMOM
           FMOM         92.3433
         DPN
           DPN           9.0683
```

```
         MWN
           MWN        1044.1779

SUBSTREAM ATTR PSD TYPE: PSD
----------------------------

INTERVAL     LOWER LIMIT           UPPER LIMIT
    1          0.0     FT         6.5617-05  FT
    2       6.5617-05  FT         1.3123-04  FT
    3       1.3123-04  FT         1.9685-04  FT
    4       1.9685-04  FT         2.6247-04  FT
    5       2.6247-04  FT         3.2808-04  FT
    6       3.2808-04  FT         3.9370-04  FT
    7       3.9370-04  FT         4.5932-04  FT
    8       4.5932-04  FT         5.2493-04  FT
    9       5.2493-04  FT         5.9055-04  FT
   10       5.9055-04  FT         6.5617-04  FT


9
-

STREAM ID                9
FROM :                   R-02
TO   :                   ----
CLASS:                   MIXCIPSD
TOTAL STREAM:
  LB/HR                1.1375+04
  BTU/HR              -5.8417+06
SUBSTREAM: MIXED
PHASE:                   LIQUID
COMPONENTS: LBMOL/HR
  ADIPI                6.7845-02
  HMDA                 3.4767-02
  METHA-01                0.0
  H2O                     1.1998
  NYLON66                50.1047
  NITRO-01                0.0
COMPONENTS: LB/HR
  ADIPI                   9.9150
  HMDA                    4.0402
  METHA-01                0.0
  H2O                    21.6152
  NYLON66              1.1340+04
  NITRO-01                0.0
TOTAL FLOW:
  LBMOL/HR               51.4072
  LB/HR                1.1375+04
  CUFT/HR               208.8572
STATE VARIABLES:
  TEMP   F              491.0000
  PRES   PSIA            33.6959
  VFRAC                   0.0
  LFRAC                   1.0000
  SFRAC                   0.0
ENTHALPY:
  BTU/LBMOL           -1.1364+05
  BTU/LB               -513.5490
  BTU/HR              -5.8417+06
ENTROPY:
  BTU/LBMOL-R          -248.6758
  BTU/LB-R               -1.1238
DENSITY:
```

```
  LBMOL/CUFT             0.2461
  LB/CUFT               54.4641
AVG MW                 221.2770
COMPONENT ATTRIBUTES:
NYLON66  SFRAC
           ADIPI-E    8.7083-03
           ADIPI-R       0.4923
           HMDA-E     4.7953-03
           HMDA-R        0.4942
         SFLOW
           ADIPI-E       0.8715
           ADIPI-R      49.2644
           HMDA-E        0.4799
           HMDA-R       49.4602
         EFRAC
           ADIPI-E       0.6449
           HMDA-E        0.3551
         ZMOM
           ZMOM          0.6757
         FMOM
           FMOM        100.0760
         DPN
           DPN         148.1092
         MWN
           MWN        1.6782+04

SUBSTREAM ATTR PSD TYPE: PSD
----------------------------

INTERVAL     LOWER LIMIT           UPPER LIMIT
    1          0.0     FT         6.5617-05  FT
    2       6.5617-05  FT         1.3123-04  FT
    3       1.3123-04  FT         1.9685-04  FT
    4       1.9685-04  FT         2.6247-04  FT
    5       2.6247-04  FT         3.2808-04  FT
    6       3.2808-04  FT         3.9370-04  FT
    7       3.9370-04  FT         4.5932-04  FT
    8       4.5932-04  FT         5.2493-04  FT
    9       5.2493-04  FT         5.9055-04  FT
   10       5.9055-04  FT         6.5617-04  FT


12
--

STREAM ID               12
FROM :                  R-02
TO   :                  E-03
CLASS:                  MIXCIPSD
TOTAL STREAM:
  LB/HR               3608.4939
  BTU/HR             -1.9990+07
SUBSTREAM: MIXED
PHASE:                  VAPOR
COMPONENTS: LBMOL/HR
  ADIPI               1.3128-02
  HMDA                   0.2420
  METHA-01               0.0
  H2O                  198.6343
  NYLON66                0.0
  NITRO-01               0.0
COMPONENTS: LB/HR
  ADIPI                  1.9186
```

```
  HMDA                    28.1224
  METHA-01                 0.0
  H2O                   3578.4528
  NYLON66                  0.0
  NITRO-01                 0.0
TOTAL FLOW:
  LBMOL/HR               198.8894
  LB/HR                 3608.4939
  CUFT/HR               5.9831+04
STATE VARIABLES:
  TEMP   F               491.0000
  PRES   PSIA             33.6959
  VFRAC                    1.0000
  LFRAC                    0.0
  SFRAC                    0.0
ENTHALPY:
  BTU/LBMOL            -1.0051+05
  BTU/LB               -5539.8041
  BTU/HR               -1.9990+07
ENTROPY:
  BTU/LBMOL-R             -7.7660
  BTU/LB-R                -0.4280
DENSITY:
  LBMOL/CUFT            3.3242-03
  LB/CUFT               6.0312-02
AVG MW                    18.1432
COMPONENT ATTRIBUTES:
NYLON66  SFRAC
           ADIPI-E    8.7083-03
           ADIPI-R       0.4923
           HMDA-E     4.7953-03
           HMDA-R        0.4942
         SFLOW
           ADIPI-E       0.0
           ADIPI-R       0.0
           HMDA-E        0.0
           HMDA-R        0.0
         EFRAC
           ADIPI-E       0.6449
           HMDA-E        0.3551
         ZMOM
           ZMOM          0.0
         FMOM
           FMOM          0.0
         DPN
           DPN         148.1092
         MWN
           MWN        1.6782+04

SUBSTREAM ATTR PSD TYPE: PSD
----------------------------

INTERVAL     LOWER LIMIT          UPPER LIMIT
    1          0.0     FT         6.5617-05  FT
    2       6.5617-05  FT         1.3123-04  FT
    3       1.3123-04  FT         1.9685-04  FT
    4       1.9685-04  FT         2.6247-04  FT
    5       2.6247-04  FT         3.2808-04  FT
    6       3.2808-04  FT         3.9370-04  FT
    7       3.9370-04  FT         4.5932-04  FT
    8       4.5932-04  FT         5.2493-04  FT
    9       5.2493-04  FT         5.9055-04  FT
   10       5.9055-04  FT         6.5617-04  FT
```

```
13
--

STREAM ID                 13
FROM :                    E-03
TO   :                    ----
CLASS:                    MIXCIPSD
TOTAL STREAM:
  LB/HR                 3608.4939
  BTU/HR               -2.3933+07
SUBSTREAM: MIXED
PHASE:                    LIQUID
COMPONENTS: LBMOL/HR
  ADIPI                 1.3128-02
  HMDA                     0.2420
  METHA-01                 0.0
  H2O                    198.6343
  NYLON66                  0.0
  NITRO-01                 0.0
COMPONENTS: LB/HR
  ADIPI                    1.9186
  HMDA                    28.1224
  METHA-01                 0.0
  H2O                   3578.4528
  NYLON66                  0.0
  NITRO-01                 0.0
TOTAL FLOW:
  LBMOL/HR               198.8894
  LB/HR                 3608.4939
  CUFT/HR                 63.0747
STATE VARIABLES:
  TEMP   F               212.0932
  PRES   PSIA             14.6959
  VFRAC                    0.0
  LFRAC                    1.0000
  SFRAC                    0.0
ENTHALPY:
  BTU/LBMOL            -1.2033+05
  BTU/LB               -6632.4880
  BTU/HR               -2.3933+07
ENTROPY:
  BTU/LBMOL-R            -35.0797
  BTU/LB-R                -1.9335
DENSITY:
  LBMOL/CUFT               3.1532
  LB/CUFT                 57.2099
AVG MW                    18.1432
COMPONENT ATTRIBUTES:
NYLON66  SFRAC
           ADIPI-E    8.7083-03
           ADIPI-R       0.4923
           HMDA-E     4.7953-03
           HMDA-R        0.4942
         SFLOW
           ADIPI-E       0.0
           ADIPI-R       0.0
           HMDA-E        0.0
           HMDA-R        0.0
         EFRAC
           ADIPI-E       0.6449
           HMDA-E        0.3551
```

```
ZMOM
  ZMOM           0.0
FMOM
  FMOM           0.0
DPN
  DPN          148.1092
MWN
  MWN        1.6782+04
```

Appendix E: Aspen Plus Printouts and Reports

Turndown Block Report

```
BLOCK:  B-02     MODEL: PUMP
----------------------------
  INLET STREAM:          5
  OUTLET STREAM:         6
  PROPERTY OPTION SET:   POLYNRTL  POLYMER NRTL / REDLICH-KWONG

                     ***  MASS AND ENERGY BALANCE  ***
                                  IN              OUT        RELATIVE DIFF.
   TOTAL BALANCE
      MOLE(LBMOL/HR)           132.400         132.400         0.00000
      MASS(LB/HR   )           9876.38         9876.38         0.00000
      ENTHALPY(BTU/HR  )      -0.238774E+08   -0.238496E+08   -0.116363E-02

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

                         ***  INPUT DATA  ***
   OUTLET PRESSURE  PSIA                                    934.696
   PUMP EFFICIENCY                                            0.75000
   DRIVER EFFICIENCY                                          0.80000

   FLASH SPECIFICATIONS:
   LIQUID PHASE CALCULATION
   NO FLASH PERFORMED
   MAXIMUM NUMBER OF ITERATIONS                               30
   TOLERANCE                                                  0.000100000

                          ***  RESULTS  ***
   VOLUMETRIC FLOW RATE  CUFT/HR                            158.270
   PRESSURE CHANGE  PSI                                     711.500
   NPSH AVAILABLE   FT-LBF/LB                               512.025
   FLUID POWER  HP                                            8.18977
   BRAKE POWER  HP                                           10.9197
   ELECTRICITY  KW                                           10.1785
   PUMP EFFICIENCY USED                                       0.75000
   NET WORK REQUIRED  HP                                     13.6496
   HEAD DEVELOPED FT-LBF/LB                               1,641.87

BLOCK:  E-01     MODEL: HEATER
------------------------------
  INLET STREAM:          4
  OUTLET STREAM:         5
  PROPERTY OPTION SET:   POLYNRTL  POLYMER NRTL / REDLICH-KWONG

                     ***  MASS AND ENERGY BALANCE  ***
                                  IN              OUT        RELATIVE DIFF.
   TOTAL BALANCE
      MOLE(LBMOL/HR)           132.400         132.400         0.00000
      MASS(LB/HR   )           9876.38         9876.38         0.00000
      ENTHALPY(BTU/HR  )      -0.241316E+08   -0.238774E+08   -0.105343E-01

                     ***  CO2 EQUIVALENT SUMMARY ***
```

```
 FEED STREAMS CO2E              0.00000      LB/HR
 PRODUCT STREAMS CO2E           0.00000      LB/HR
 NET STREAMS CO2E PRODUCTION    0.00000      LB/HR
 UTILITIES CO2E PRODUCTION      0.00000      LB/HR
 TOTAL CO2E PRODUCTION          0.00000      LB/HR

                      ***  INPUT DATA  ***
TWO    PHASE  PQ  FLASH
SPECIFIED PRESSURE                    PSIA                    223.196
SPECIFIED HEAT DUTY                   BTU/HR              254,211.
MAXIMUM NO. ITERATIONS                                         30
CONVERGENCE TOLERANCE                                            0.000100000



                       ***  RESULTS  ***
OUTLET TEMPERATURE    F                                     127.25
OUTLET PRESSURE       PSIA                                  223.20
OUTLET VAPOR FRACTION                                       0.0000



V-L PHASE EQUILIBRIUM :

   COMP              F(I)          X(I)          Y(I)          K(I)
   ADIPI           0.25000       0.25000       0.43575E-06   0.12294E-07
   HMDA            0.25000       0.25000       0.13372E-01   0.37727E-03
   H2O             0.50000       0.50000       0.98663       0.13918E-01

BLOCK:  E-02     MODEL: HEATER
------------------------------
INLET STREAM:           6
OUTLET STREAM:          7
PROPERTY OPTION SET:   POLYNRTL  POLYMER NRTL / REDLICH-KWONG

                  ***  MASS AND ENERGY BALANCE  ***
                                IN              OUT        RELATIVE DIFF.
 TOTAL BALANCE
    MOLE(LBMOL/HR)           132.400         132.400         0.00000
    MASS(LB/HR   )           9876.38         9876.38         0.00000
    ENTHALPY(BTU/HR  )      -0.238496E+08   -0.212467E+08   -0.109137

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

                      ***  INPUT DATA  ***
TWO    PHASE  TP  FLASH
SPECIFIED TEMPERATURE                 F                       527.000
SPECIFIED PRESSURE                    PSIA                    908.696
MAXIMUM NO. ITERATIONS                                         30
CONVERGENCE TOLERANCE                                            0.000100000



                       ***  RESULTS  ***
OUTLET TEMPERATURE    F                                     527.00
OUTLET PRESSURE       PSIA                                  908.70
HEAT DUTY             BTU/HR                               0.26029E+07
OUTLET VAPOR FRACTION                                       0.0000
```

V-L PHASE EQUILIBRIUM :

COMP	F(I)	X(I)	Y(I)	K(I)
ADIPI	0.25000	0.25000	0.56841E-02	0.14794E-01
HMDA	0.25000	0.25000	0.76780E-01	0.19983
H2O	0.50000	0.50000	0.91754	1.1940

BLOCK: E-03   MODEL: HEATER

INLET STREAM: 12
OUTLET STREAM: 13
PROPERTY OPTION SET: POLYNRTL POLYMER NRTL / REDLICH-KWONG

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(LBMOL/HR)	131.200	131.200	0.00000
MASS(LB/HR)	2372.39	2372.39	-0.191683E-15
ENTHALPY(BTU/HR)	-0.131917E+08	-0.157912E+08	0.164618

*** CO2 EQUIVALENT SUMMARY ***

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

*** INPUT DATA ***

TWO   PHASE PV FLASH

SPECIFIED PRESSURE	PSIA	14.6959
VAPOR FRACTION		0.0
MAXIMUM NO. ITERATIONS		30
CONVERGENCE TOLERANCE		0.000100000

*** RESULTS ***

OUTLET TEMPERATURE	F	212.06
OUTLET PRESSURE	PSIA	14.696
HEAT DUTY	BTU/HR	-0.25995E+07
OUTLET VAPOR FRACTION		0.0000

V-L PHASE EQUILIBRIUM :

COMP	F(I)	X(I)	Y(I)	K(I)
ADIPI	0.28605E-04	0.28605E-04	0.20864E-08	0.72940E-04
HMDA	0.64499E-03	0.64499E-03	0.41559E-04	0.64434E-01
H2O	0.99933	0.99933	0.99996	1.0006

BLOCK: M-01   MODEL: MIXER

INLET STREAMS: 1   2
OUTLET STREAM: 3
PROPERTY OPTION SET: POLYNRTL POLYMER NRTL / REDLICH-KWONG

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			

```
      MOLE(LBMOL/HR)            132.400         132.400         0.00000
      MASS(LB/HR   )            9876.38         9876.38        0.184176E-15
      ENTHALPY(BTU/HR  )      -0.241400E+08   -0.241400E+08    0.241969E-10

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

                       ***  INPUT DATA  ***
  TWO    PHASE      FLASH
  MAXIMUM NO. ITERATIONS                                   30
  CONVERGENCE TOLERANCE                                     0.000100000
  OUTLET PRESSURE   PSIA                                  14.6959

BLOCK:  P-01     MODEL: PUMP
----------------------------
  INLET STREAM:          3
  OUTLET STREAM:         4
  PROPERTY OPTION SET:   POLYNRTL  POLYMER NRTL / REDLICH-KWONG

                   ***  MASS AND ENERGY BALANCE  ***
                                IN              OUT        RELATIVE DIFF.
   TOTAL BALANCE
      MOLE(LBMOL/HR)            132.400         132.400         0.00000
      MASS(LB/HR   )            9876.38         9876.38         0.00000
      ENTHALPY(BTU/HR  )      -0.241400E+08   -0.241316E+08   -0.348754E-03

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

                       ***  INPUT DATA  ***
   OUTLET PRESSURE  PSIA                                 235.196
   PUMP EFFICIENCY                                         0.75000
   DRIVER EFFICIENCY                                       0.80000

   FLASH SPECIFICATIONS:
   LIQUID PHASE CALCULATION
   NO FLASH PERFORMED
   MAXIMUM NUMBER OF ITERATIONS                            30
   TOLERANCE                                               0.000100000

                        ***  RESULTS  ***
   VOLUMETRIC FLOW RATE  CUFT/HR                         154.747
   PRESSURE CHANGE  PSI                                  220.500
   NPSH AVAILABLE   FT-LBF/LB                             32.4398
   FLUID POWER  HP                                         2.48157
   BRAKE POWER  HP                                         3.30876
   ELECTRICITY  KW                                         3.08418
   PUMP EFFICIENCY USED                                    0.75000
   NET WORK REQUIRED  HP                                   4.13595
   HEAD DEVELOPED FT-LBF/LB                              497.501

BLOCK:  R-01     MODEL: RPLUG
-----------------------------
  INLET STREAM:          7
  OUTLET STREAM:         8
```

```
   PROPERTY OPTION SET:   POLYNRTL  POLYMER NRTL / REDLICH-KWONG

                      ***  MASS AND ENERGY BALANCE  ***
                              IN          OUT       GENERATION   RELATIVE DIFF.
   TOTAL BALANCE
   MOLE(LBMOL/HR)         132.400      159.626      27.2265       0.00000
   MASS(LB/HR   )         9876.38      9876.38                   0.495248E-12
   ENTHALPY(BTU/HR  )   -0.212467E+08 -0.186870E+08              -0.120479

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

                          ***  INPUT DATA  ***

   REACTOR TYPE:
     SPECIFIED TEMPERATURE
     LIQUID FLUID PHASE
   REACTOR TUBE LENGTH                FT                  3500.0
   REACTOR DIAMETER                   FT                 0.12500
   REACTOR RISE                       FT                  0.0000
   NUMBER OF REACTOR TUBES                                1
   REACTOR VOLUME                     CUFT                42.951
   PRESSURE DROP OPTION:                                  SPECIFIED
   HOLDUP OPTION:                                         NO-SLIP
   ERROR TOLERANCE                                        0.10000E-03
   INTEGRATION METHOD                                     GEAR
   CORRECTOR METHOD                                       NEWTON
   INITIAL STEP SIZE FACTOR                               0.10000E-01
   CORRECTOR TOLERANCE FACTOR                             0.10000
   MAXIMUM NUMBER OF STEPS                                 1000

   CONSTANT REACTOR TEMPERATURE SET TO THE (MIXED)
   INLET PROCESS STREAM TEMPERATURE OF     527.00      F

    REACTION PARAGRAPH TYPE                               SEGMENT-BAS
    GLOBAL BASES:
    PHASE                                                 L
    CBASIS                                                MOLARITY
    SITE NO                                                  1

    STOICHIOMETRY:

    REACTION NUMBER:          1
      SUBSTREAM:  MIXED
        ADIPI      -1.0000      HMDA       -1.0000      H2O         1.0000      ADIPI-
E     1.0000
  HMDA-E      1.0000
      SUBSTREAM:  CIPSD
        ADIPI      -1.0000      METHA-01    1.0000      NYLON66     1.0000      ADIPI-
R     1.0000

    REACTION NUMBER:          2
      SUBSTREAM:  MIXED
        HMDA       -1.0000      H2O         1.0000      ADIPI-E    -1.0000      ADIPI-
R     1.0000
  HMDA-E      1.0000
      SUBSTREAM:  CIPSD
        ADIPI      -1.0000      METHA-01    1.0000      NYLON66    -1.0000      ADIPI-
E     1.0000
```

```
  ADIPI-R     1.0000      NITRO-01   -1.0000

    REACTION NUMBER:          3
      SUBSTREAM:  MIXED
        ADIPI      -1.0000      H2O         1.0000      ADIPI-E     1.0000      HMDA-E
-1.0000
  HMDA-R      1.0000
      SUBSTREAM:  CIPSD
        METHA-01    1.0000      NYLON66     1.0000      ADIPI-R    -1.0000      HMDA-E
1.0000

    REACTION NUMBER:          4
      SUBSTREAM:  MIXED
        H2O         1.0000      ADIPI-E    -1.0000      ADIPI-R     1.0000      HMDA-E
-1.0000
  HMDA-R      1.0000
      SUBSTREAM:  CIPSD
        METHA-01    1.0000      NYLON66    -1.0000      ADIPI-E     1.0000      ADIPI-
R    -1.0000
  HMDA-E      1.0000      NITRO-01   0.10000E+36

    POWERLAW EXPONENTS:

    REACTION NUMBER:          1
      SUBSTREAM:  MIXED
        ADIPI       1.0000      HMDA        1.0000
      SUBSTREAM:  CIPSD
        ADIPI       1.0000

    REACTION NUMBER:          2
      SUBSTREAM:  MIXED
        HMDA        1.0000      ADIPI-E     1.0000
      SUBSTREAM:  CIPSD
        ADIPI       1.0000      NYLON66     1.0000      NITRO-01    1.0000

    REACTION NUMBER:          3
      SUBSTREAM:  MIXED
        ADIPI       1.0000      HMDA-E      1.0000
      SUBSTREAM:  CIPSD
        ADIPI-R     1.0000

    REACTION NUMBER:          4
      SUBSTREAM:  MIXED
        ADIPI-E     1.0000      HMDA-E      1.0000
      SUBSTREAM:  CIPSD
        NYLON66     1.0000      ADIPI-R     1.0000      NITRO-01   0.10000E+36

      RATE CONSTANT ASSIGNMENTS
      REACTION    ACTIVITY    RATE CONSTANT SETS
            1      1.000         1
            2      1.000         1
            3      1.000         1
            4      1.000         1

    RATE PARAMETERS:

      RC NO   CATALYST   ORDER    K0         EACT        B         TREF
                                 1/HR       BTU/LBMOL             F

          1              1.00   11.11       1075.       0.0000    392.00

                          ***  RESULTS  ***
```

REACTOR DUTY	BTU/HR	0.25598E+07
RESIDENCE TIME	HR	0.21463
REACTOR MINIMUM TEMPERATURE	F	527.00
REACTOR MAXIMUM TEMPERATURE	F	527.00

*** RESULTS PROFILE (PROCESS SUBSTREAM MIXED) ***

LENGTH FT	PRESSURE PSIA	TEMPERATURE F	VAPOR FRAC	RES-TIME HR
0.0000	906.70	527.00	0.0000	0.0000
350.00	899.70	527.00	0.0000	0.21109E-01
700.00	892.70	527.00	0.0000	0.42361E-01
1050.0	885.70	527.00	0.0000	0.63658E-01
1400.0	878.70	527.00	0.0000	0.85011E-01
1750.0	871.70	527.00	0.0000	0.10644
2100.0	864.70	527.00	0.0000	0.12795
2450.0	857.70	527.00	0.0000	0.14953
2800.0	850.70	527.00	0.0000	0.17117
3150.0	843.70	527.00	0.0000	0.19288
3500.0	836.70	527.00	0.0000	0.21463

LENGTH FT	DUTY BTU/HR	LIQUID HOLDUP
0.0000	0.0000	1.0000
350.00	0.11004E+07	1.0000
700.00	0.16828E+07	1.0000
1050.0	0.19992E+07	1.0000
1400.0	0.21874E+07	1.0000
1750.0	0.23088E+07	1.0000
2100.0	0.23922E+07	1.0000
2450.0	0.24524E+07	1.0000
2800.0	0.24974E+07	1.0000
3150.0	0.25322E+07	1.0000
3500.0	0.25598E+07	1.0000

*** TOTAL MOLE FRACTION PROFILE (PROCESS SUBSTREAM MIXED) ***

LENGTH FT	ADIPI	HMDA	H2O	NYLON66
0.0000	0.25000	0.25000	0.50000	0.0000
350.00	0.12770	0.12770	0.62546	0.11915
700.00	0.72546E-01	0.72546E-01	0.69088	0.16403
1050.0	0.46651E-01	0.46651E-01	0.72479	0.18191
1400.0	0.32842E-01	0.32842E-01	0.74421	0.19011
1750.0	0.24627E-01	0.24627E-01	0.75640	0.19435
2100.0	0.19324E-01	0.19324E-01	0.76461	0.19675
2450.0	0.15687E-01	0.15687E-01	0.77044	0.19819
2800.0	0.13074E-01	0.13074E-01	0.77476	0.19909
3150.0	0.11124E-01	0.11124E-01	0.77807	0.19969
3500.0	0.96242E-02	0.96242E-02	0.78067	0.20008

*** TOTAL MASS FRACTION PROFILE (PROCESS SUBSTREAM MIXED) ***

LENGTH FT	ADIPI	HMDA	H2O	NYLON66
0.0000	0.48979	0.38946	0.12075	0.0000
350.00	0.26016	0.20686	0.15708	0.37590

700.00	0.15455	0.12289	0.18143	0.54114
1050.0	0.10258	0.81564E-01	0.19646	0.61941
1400.0	0.73787E-01	0.58672E-01	0.20611	0.66143
1750.0	0.56170E-01	0.44664E-01	0.21267	0.68649
2100.0	0.44563E-01	0.35435E-01	0.21736	0.70264
2450.0	0.36476E-01	0.29004E-01	0.22084	0.71368
2800.0	0.30596E-01	0.24329E-01	0.22351	0.72156
3150.0	0.26167E-01	0.20807E-01	0.22562	0.72741
3500.0	0.22733E-01	0.18076E-01	0.22731	0.73188

*** COMPONENT ATTRIBUTE PROFILE (PROCESS SUBSTREAM MIXED) ***

LENGTH FT	NYLON66 SFRAC ADIPI-E	NYLON66 SFRAC ADIPI-R	NYLON66 SFRAC HMDA-E	NYLON66 SFRAC HMDA-R
0.0000	0.0000	0.0000	0.0000	0.0000
350.00	0.35840	0.14160	0.35840	0.14160
700.00	0.26589	0.23411	0.26589	0.23411
1050.0	0.20702	0.29298	0.20702	0.29298
1400.0	0.16776	0.33224	0.16776	0.33224
1750.0	0.14017	0.35983	0.14017	0.35983
2100.0	0.11989	0.38011	0.11989	0.38011
2450.0	0.10443	0.39557	0.10443	0.39557
2800.0	0.92316E-01	0.40768	0.92316E-01	0.40768
3150.0	0.82598E-01	0.41740	0.82598E-01	0.41740
3500.0	0.74649E-01	0.42535	0.74649E-01	0.42535

LENGTH FT	NYLON66 SFLOW ADIPI-E	NYLON66 SFLOW ADIPI-R	NYLON66 SFLOW HMDA-E	NYLON66 SFLOW HMDA-R
0.0000	0.0000	0.0000	0.0000	0.0000
350.00	0.14016E-02	0.55374E-03	0.14016E-02	0.55374E-03
700.00	0.15180E-02	0.13366E-02	0.15180E-02	0.13366E-02
1050.0	0.13652E-02	0.19320E-02	0.13652E-02	0.19320E-02
1400.0	0.11885E-02	0.23537E-02	0.11885E-02	0.23537E-02
1750.0	0.10351E-02	0.26572E-02	0.10351E-02	0.26572E-02
2100.0	0.90899E-03	0.28821E-02	0.90899E-03	0.28821E-02
2450.0	0.80619E-03	0.30537E-02	0.80619E-03	0.30537E-02
2800.0	0.72191E-03	0.31881E-02	0.72191E-03	0.31881E-02
3150.0	0.65215E-03	0.32956E-02	0.65215E-03	0.32956E-02
3500.0	0.59375E-03	0.33832E-02	0.59375E-03	0.33832E-02

LENGTH FT	NYLON66 EFRAC ADIPI-E	NYLON66 EFRAC HMDA-E	NYLON66 ZMOM ZMOM	NYLON66 FMOM FMOM
0.0000	0.0000	0.0000	0.0000	0.0000
350.00	0.50000	0.50000	0.14016E-02	0.39106E-02
700.00	0.50000	0.50000	0.15180E-02	0.57092E-02
1050.0	0.50000	0.50000	0.13652E-02	0.65942E-02
1400.0	0.50000	0.50000	0.11885E-02	0.70845E-02
1750.0	0.50000	0.50000	0.10351E-02	0.73845E-02
2100.0	0.50000	0.50000	0.90899E-03	0.75822E-02
2450.0	0.50000	0.50000	0.80619E-03	0.77199E-02
2800.0	0.50000	0.50000	0.72191E-03	0.78200E-02
3150.0	0.50000	0.50000	0.65215E-03	0.78954E-02
3500.0	0.50000	0.50000	0.59375E-03	0.79539E-02

LENGTH FT	NYLON66 DPN	NYLON66 MWN

	DPN	MWN
0.0000	0.0000	0.0000
350.00	2.7902	333.75
700.00	3.7610	443.61
1050.0	4.8304	564.62
1400.0	5.9609	692.55
1750.0	7.1342	825.32
2100.0	8.3413	961.91
2450.0	9.5757	1101.6
2800.0	10.832	1243.8
3150.0	12.107	1388.0
3500.0	13.396	1533.9

*** RESULTS PROFILE (PROCESS SUBSTREAM CIPSD) ***

LENGTH FT	PRESSURE PSIA	TEMPERATURE F	RES-TIME HR
0.0000	906.70	527.00	0.0000
350.00	899.70	527.00	0.21109E-01
700.00	892.70	527.00	0.42361E-01
1050.0	885.70	527.00	0.63658E-01
1400.0	878.70	527.00	0.85011E-01
1750.0	871.70	527.00	0.10644
2100.0	864.70	527.00	0.12795
2450.0	857.70	527.00	0.14953
2800.0	850.70	527.00	0.17117
3150.0	843.70	527.00	0.19288
3500.0	836.70	527.00	0.21463

BLOCK: R-02   MODEL: RCSTR

INLET STREAM: 8
OUTLET STREAMS: 9   12
PROPERTY OPTION SET: POLYNRTL POLYMER NRTL / REDLICH-KWONG

*** MASS AND ENERGY BALANCE ***

	IN	OUT	GENERATION	RELATIVE DIFF.
TOTAL BALANCE				
MOLE(LBMOL/HR)	159.626	165.096	5.46994	0.00000
MASS(LB/HR)	9876.38	9876.38		0.368351E-15
ENTHALPY(BTU/HR)	-0.186870E+08	-0.170210E+08		-0.891489E-01

*** CO2 EQUIVALENT SUMMARY ***

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

*** INPUT DATA ***

REACTOR TYPE: TEMP SPEC TWO   PHASE REACTOR

REACTOR VOLUME	CUFT	3002.0
REACTOR TEMPERATURE	F	491.00
REACTOR PRESSURE	PSIA	33.696

REACTION PARAGRAPH TYPE	SEGMENT-BAS
GLOBAL BASES:	
PHASE	L

```
    CBASIS                                                    MOLARITY
    SITE NO                                                      1

    STOICHIOMETRY:

    REACTION NUMBER:          1
      SUBSTREAM:  MIXED
        ADIPI      -1.0000      HMDA       -1.0000      H2O         1.0000      ADIPI-
E     1.0000
  HMDA-E      1.0000
      SUBSTREAM:  CIPSD
        ADIPI      -1.0000      METHA-01    1.0000      NYLON66     1.0000      ADIPI-
R     1.0000

    REACTION NUMBER:          2
      SUBSTREAM:  MIXED
        HMDA       -1.0000      H2O         1.0000      ADIPI-E    -1.0000      ADIPI-
R     1.0000
  HMDA-E      1.0000
      SUBSTREAM:  CIPSD
        ADIPI      -1.0000      METHA-01    1.0000      NYLON66    -1.0000      ADIPI-
E     1.0000
  ADIPI-R     1.0000      NITRO-01   -1.0000

    REACTION NUMBER:          3
      SUBSTREAM:  MIXED
        ADIPI      -1.0000      H2O         1.0000      ADIPI-E     1.0000      HMDA-E
-1.0000
  HMDA-R      1.0000
      SUBSTREAM:  CIPSD
        METHA-01    1.0000      NYLON66     1.0000      ADIPI-R    -1.0000      HMDA-E
1.0000

    REACTION NUMBER:          4
      SUBSTREAM:  MIXED
        H2O         1.0000      ADIPI-E    -1.0000      ADIPI-R     1.0000      HMDA-E
-1.0000
  HMDA-R      1.0000
      SUBSTREAM:  CIPSD
        METHA-01    1.0000      NYLON66    -1.0000      ADIPI-E     1.0000      ADIPI-
R    -1.0000
  HMDA-E      1.0000      NITRO-01   0.10000E+36

    POWERLAW EXPONENTS:

    REACTION NUMBER:          1
      SUBSTREAM:  MIXED
        ADIPI       1.0000      HMDA        1.0000
      SUBSTREAM:  CIPSD
        ADIPI       1.0000

    REACTION NUMBER:          2
      SUBSTREAM:  MIXED
        HMDA        1.0000      ADIPI-E     1.0000
      SUBSTREAM:  CIPSD
        ADIPI       1.0000      NYLON66     1.0000      NITRO-01    1.0000

    REACTION NUMBER:          3
      SUBSTREAM:  MIXED
        ADIPI       1.0000      HMDA-E      1.0000
      SUBSTREAM:  CIPSD
        ADIPI-R     1.0000
```

```
REACTION NUMBER:          4
  SUBSTREAM:  MIXED
    ADIPI-E     1.0000      HMDA-E      1.0000
  SUBSTREAM:  CIPSD
    NYLON66     1.0000      ADIPI-R     1.0000      NITRO-01   0.10000E+36

  RATE CONSTANT ASSIGNMENTS
  REACTION    ACTIVITY    RATE CONSTANT SETS
        1      1.000         1
        2      1.000         1
        3      1.000         1
        4      1.000         1

RATE PARAMETERS:

  RC NO   CATALYST   ORDER    K0         EACT        B         TREF
                             1/HR        BTU/LBMOL              F

      1              1.00   11.11       1075.       0.0000    392.00

                       ***  RESULTS  ***

REACTOR HEAT DUTY                  BTU/HR                     0.16659E+07
RESIDENCE TIME                     HR                         0.75796E-01
VAPOR PHASE VOLUME FRACTION                                   0.99652
VAPOR PHASE VOLUME                 CUFT                        2991.6
LIQUID PHASE VOLUME                CUFT                        10.444
```

Appendix E: Aspen Plus Printouts and Reports

Turndown Stream Report

```
SUBSTREAM ATTR PSD TYPE: PSD
----------------------------

INTERVAL     LOWER LIMIT           UPPER LIMIT
    1          0.0     FT         6.5617-05  FT
    2       6.5617-05  FT         1.3123-04  FT
    3       1.3123-04  FT         1.9685-04  FT
    4       1.9685-04  FT         2.6247-04  FT
    5       2.6247-04  FT         3.2808-04  FT
    6       3.2808-04  FT         3.9370-04  FT
    7       3.9370-04  FT         4.5932-04  FT
    8       4.5932-04  FT         5.2493-04  FT
    9       5.2493-04  FT         5.9055-04  FT
   10       5.9055-04  FT         6.5617-04  FT


1 12 13 2 3
-----------

STREAM ID               1          12         13         2          3
FROM :                  ----       R-02       E-03       ----       M-01
TO   :                  M-01       E-03       ----       M-01       P-01
CLASS:                  MIXCIPSD   MIXCIPSD   MIXCIPSD   MIXCIPSD   MIXCIPSD
TOTAL STREAM:
  LB/HR               4442.7416  2372.3870  2372.3870  5433.6391  9876.3806
  BTU/HR             -6.2386+06 -1.3192+07 -1.5791+07 -1.7901+07 -2.4140+07
SUBSTREAM: MIXED
PHASE:                  LIQUID     VAPOR      LIQUID     LIQUID     LIQUID
COMPONENTS: LBMOL/HR
  ADIPI                  0.0      3.7529-03  3.7529-03    33.1000    33.1000
  HMDA                  33.1000   8.4623-02  8.4623-02     0.0       33.1000
  METHA-01               0.0        0.0        0.0         0.0        0.0
  H2O                   33.1000   131.1112   131.1112    33.1000    66.2000
  NYLON66                0.0        0.0        0.0         0.0        0.0
  NITRO-01               0.0        0.0        0.0         0.0        0.0
COMPONENTS: LB/HR
  ADIPI                  0.0        0.5485     0.5485  4837.3333  4837.3333
  HMDA                3846.4358     9.8337     9.8337     0.0     3846.4358
  METHA-01               0.0        0.0        0.0         0.0        0.0
  H2O                  596.3058  2362.0048  2362.0048   596.3058  1192.6115
  NYLON66                0.0        0.0        0.0         0.0        0.0
  NITRO-01               0.0        0.0        0.0         0.0        0.0
TOTAL FLOW:
  LBMOL/HR              66.2000   131.1996   131.1996    66.2000   132.4000
  LB/HR               4442.7416  2372.3870  2372.3870  5433.6391  9876.3806
  CUFT/HR               79.2724  3.9468+04    41.4290    75.1615   154.7466
STATE VARIABLES:
  TEMP   F              77.0000   491.0000   212.0642    77.0000    80.2626
  PRES   PSIA           14.6959    33.6959    14.6959    14.6959    14.6959
  VFRAC                  0.0        1.0000     0.0         0.0        0.0
  LFRAC                  1.0000     0.0        1.0000      1.0000     1.0000
  SFRAC                  0.0        0.0        0.0         0.0        0.0
ENTHALPY:
  BTU/LBMOL          -9.4238+04 -1.0055+05 -1.2036+05 -2.7042+05 -1.8233+05
  BTU/LB             -1404.2136 -5560.5260 -6656.2670 -3294.5677 -2444.2202
  BTU/HR             -6.2386+06 -1.3192+07 -1.5791+07 -1.7901+07 -2.4140+07
ENTROPY:
  BTU/LBMOL-R          -127.3887    -7.6832   -34.9861  -112.1008  -118.9907
```

BTU/LB-R	-1.8982	-0.4249	-1.9348	-1.3658	-1.5952
DENSITY:					
LBMOL/CUFT	0.8351	3.3242-03	3.1669	0.8808	0.8556
LB/CUFT	56.0440	6.0108-02	57.2639	72.2928	63.8229
AVG MW	67.1109	18.0823	18.0823	82.0791	74.5950
COMPONENT ATTRIBUTES:					
NYLON66 SFRAC					
ADIPI-E	MISSING	6.8450-03	6.8450-03	MISSING	MISSING
ADIPI-R	MISSING	0.4937	0.4937	MISSING	MISSING
HMDA-E	MISSING	4.6156-03	4.6156-03	MISSING	MISSING
HMDA-R	MISSING	0.4948	0.4948	MISSING	MISSING
SFLOW					
ADIPI-E	MISSING	0.0	0.0	MISSING	MISSING
ADIPI-R	MISSING	0.0	0.0	MISSING	MISSING
HMDA-E	MISSING	0.0	0.0	MISSING	MISSING
HMDA-R	MISSING	0.0	0.0	MISSING	MISSING
EFRAC					
ADIPI-E	MISSING	0.5973	0.5973	MISSING	MISSING
HMDA-E	MISSING	0.4027	0.4027	MISSING	MISSING
ZMOM					
ZMOM	MISSING	0.0	0.0	MISSING	MISSING
FMOM					
FMOM	MISSING	0.0	0.0	MISSING	MISSING
DPN					
DPN	MISSING	174.5096	174.5096	MISSING	MISSING
MWN					
MWN	MISSING	1.9768+04	1.9768+04	MISSING	MISSING

4 5 6 7 8

STREAM ID	4	5	6	7	8
FROM :	P-01	E-01	B-02	E-02	R-01
TO :	E-01	B-02	E-02	R-01	R-02
CLASS:	MIXCIPSD	MIXCIPSD	MIXCIPSD	MIXCIPSD	MIXCIPSD
TOTAL STREAM:					
LB/HR	9876.3806	9876.3806	9876.3806	9876.3806	9876.3806
BTU/HR	-2.4132+07	-2.3877+07	-2.3850+07	-2.1247+07	-1.8687+07
SUBSTREAM: MIXED					
PHASE:	LIQUID	LIQUID	LIQUID	LIQUID	LIQUID
COMPONENTS: LBMOL/HR					
ADIPI	33.1000	33.1000	33.1000	33.1000	1.5363
HMDA	33.1000	33.1000	33.1000	33.1000	1.5363
METHA-01	0.0	0.0	0.0	0.0	0.0
H2O	66.2000	66.2000	66.2000	66.2000	124.6151
NYLON66	0.0	0.0	0.0	0.0	31.9388
NITRO-01	0.0	0.0	0.0	0.0	0.0
COMPONENTS: LB/HR					
ADIPI	4837.3333	4837.3333	4837.3333	4837.3333	224.5150
HMDA	3846.4358	3846.4358	3846.4358	3846.4358	178.5245
METHA-01	0.0	0.0	0.0	0.0	0.0
H2O	1192.6115	1192.6115	1192.6115	1192.6115	2244.9757
NYLON66	0.0	0.0	0.0	0.0	7228.3654
NITRO-01	0.0	0.0	0.0	0.0	0.0
TOTAL FLOW:					
LBMOL/HR	132.4000	132.4000	132.4000	132.4000	159.6265
LB/HR	9876.3806	9876.3806	9876.3806	9876.3806	9876.3806
CUFT/HR	154.7963	158.2703	158.4520	205.1329	197.2766
STATE VARIABLES:					
TEMP F	80.9492	127.2454	129.5813	527.0000	526.9995
PRES PSIA	235.1959	223.1959	934.6959	908.6959	836.6959
VFRAC	0.0	0.0	0.0	0.0	0.0
LFRAC	1.0000	1.0000	1.0000	1.0000	1.0000

SFRAC	0.0	0.0	0.0	0.0	0.0
ENTHALPY:					
BTU/LBMOL	-1.8226+05	-1.8034+05	-1.8013+05	-1.6047+05	-1.1707+05
BTU/LB	-2443.3678	-2417.6285	-2414.8153	-2151.2686	-1892.0863
BTU/HR	-2.4132+07	-2.3877+07	-2.3850+07	-2.1247+07	-1.8687+07
ENTROPY:					
BTU/LBMOL-R	-118.8721	-115.4408	-115.0846	-90.8162	-73.1105
BTU/LB-R	-1.5936	-1.5476	-1.5428	-1.2175	-1.1816
DENSITY:					
LBMOL/CUFT	0.8553	0.8365	0.8356	0.6454	0.8092
LB/CUFT	63.8024	62.4020	62.3304	48.1462	50.0636
AVG MW	74.5950	74.5950	74.5950	74.5950	61.8718
COMPONENT ATTRIBUTES:					
NYLON66 SFRAC					
ADIPI-E	MISSING	MISSING	MISSING	MISSING	7.4649-02
ADIPI-R	MISSING	MISSING	MISSING	MISSING	0.4254
HMDA-E	MISSING	MISSING	MISSING	MISSING	7.4649-02
HMDA-R	MISSING	MISSING	MISSING	MISSING	0.4254
SFLOW					
ADIPI-E	MISSING	MISSING	MISSING	MISSING	4.7124
ADIPI-R	MISSING	MISSING	MISSING	MISSING	26.8514
HMDA-E	MISSING	MISSING	MISSING	MISSING	4.7124
HMDA-R	MISSING	MISSING	MISSING	MISSING	26.8514
EFRAC					
ADIPI-E	MISSING	MISSING	MISSING	MISSING	0.5000
HMDA-E	MISSING	MISSING	MISSING	MISSING	0.5000
ZMOM					
ZMOM	MISSING	MISSING	MISSING	MISSING	4.7124
FMOM					
FMOM	MISSING	MISSING	MISSING	MISSING	63.1275
DPN					
DPN	MISSING	MISSING	MISSING	MISSING	13.3961
MWN					
MWN	MISSING	MISSING	MISSING	MISSING	1533.9125

9
-

STREAM ID	9
FROM :	R-02
TO :	----
CLASS:	MIXCIPSD
TOTAL STREAM:	
LB/HR	7503.9937
BTU/HR	-3.8293+06
SUBSTREAM: MIXED	
PHASE:	LIQUID
COMPONENTS: LBMOL/HR	
ADIPI	1.9361-02
HMDA	1.2150-02
METHA-01	0.0
H2O	0.7903
NYLON66	33.0751
NITRO-01	0.0
COMPONENTS: LB/HR	
ADIPI	2.8295
HMDA	1.4119
METHA-01	0.0
H2O	14.2368
NYLON66	7485.5155
NITRO-01	0.0
TOTAL FLOW:	
LBMOL/HR	33.8968

```
  LB/HR                 7503.9937
  CUFT/HR                137.7878
STATE VARIABLES:
  TEMP   F               491.0000
  PRES   PSIA             33.6959
  VFRAC                    0.0
  LFRAC                    1.0000
  SFRAC                    0.0
ENTHALPY:
  BTU/LBMOL            -1.1297+05
  BTU/LB               -510.3045
  BTU/HR               -3.8293+06
ENTROPY:
  BTU/LBMOL-R          -248.8977
  BTU/LB-R               -1.1243
DENSITY:
  LBMOL/CUFT               0.2460
  LB/CUFT                 54.4605
AVG MW                   221.3774
COMPONENT ATTRIBUTES:
NYLON66  SFRAC
           ADIPI-E    6.8450-03
           ADIPI-R       0.4937
           HMDA-E     4.6156-03
           HMDA-R        0.4948
         SFLOW
           ADIPI-E       0.4523
           ADIPI-R      32.6246
           HMDA-E        0.3050
           HMDA-R       32.6982
         EFRAC
           ADIPI-E       0.5973
           HMDA-E        0.4027
         ZMOM
           ZMOM          0.3787
         FMOM
           FMOM         66.0801
         DPN
           DPN         174.5096
         MWN
           MWN        1.9768+04

SUBSTREAM ATTR PSD TYPE: PSD
----------------------------

INTERVAL     LOWER LIMIT           UPPER LIMIT
    1          0.0     FT         6.5617-05  FT
    2       6.5617-05  FT         1.3123-04  FT
    3       1.3123-04  FT         1.9685-04  FT
    4       1.9685-04  FT         2.6247-04  FT
    5       2.6247-04  FT         3.2808-04  FT
    6       3.2808-04  FT         3.9370-04  FT
    7       3.9370-04  FT         4.5932-04  FT
    8       4.5932-04  FT         5.2493-04  FT
    9       5.2493-04  FT         5.9055-04  FT
   10       5.9055-04  FT         6.5617-04  FT


1
-

STREAM ID                1
FROM :                   ----
```

```
TO   :                  M-01
CLASS:                  MIXCIPSD
TOTAL STREAM:
  LB/HR               4442.7416
  BTU/HR             -6.2386+06
SUBSTREAM: MIXED
PHASE:                  LIQUID
COMPONENTS: LBMOL/HR
  ADIPI                  0.0
  HMDA                  33.1000
  METHA-01               0.0
  H2O                   33.1000
  NYLON66                0.0
  NITRO-01               0.0
COMPONENTS: LB/HR
  ADIPI                  0.0
  HMDA                3846.4358
  METHA-01               0.0
  H2O                  596.3058
  NYLON66                0.0
  NITRO-01               0.0
TOTAL FLOW:
  LBMOL/HR              66.2000
  LB/HR               4442.7416
  CUFT/HR               79.2724
STATE VARIABLES:
  TEMP   F              77.0000
  PRES   PSIA           14.6959
  VFRAC                  0.0
  LFRAC                  1.0000
  SFRAC                  0.0
ENTHALPY:
  BTU/LBMOL          -9.4238+04
  BTU/LB             -1404.2136
  BTU/HR             -6.2386+06
ENTROPY:
  BTU/LBMOL-R          -127.3887
  BTU/LB-R               -1.8982
DENSITY:
  LBMOL/CUFT             0.8351
  LB/CUFT               56.0440
AVG MW                  67.1109
COMPONENT ATTRIBUTES:
NYLON66  SFRAC
         SFLOW
         EFRAC
         ZMOM
         FMOM
         DPN
         MWN

SUBSTREAM ATTR PSD TYPE: PSD
----------------------------

INTERVAL     LOWER LIMIT          UPPER LIMIT
    1          0.0     FT         6.5617-05  FT
    2       6.5617-05  FT         1.3123-04  FT
    3       1.3123-04  FT         1.9685-04  FT
    4       1.9685-04  FT         2.6247-04  FT
    5       2.6247-04  FT         3.2808-04  FT
    6       3.2808-04  FT         3.9370-04  FT
    7       3.9370-04  FT         4.5932-04  FT
    8       4.5932-04  FT         5.2493-04  FT
```

```
    9       5.2493-04  FT         5.9055-04  FT
   10       5.9055-04  FT         6.5617-04  FT


2
-

STREAM ID                2
FROM :                   ----
TO   :                   M-01
CLASS:                   MIXCIPSD
TOTAL STREAM:
  LB/HR                5433.6391
  BTU/HR              -1.7901+07
SUBSTREAM: MIXED
PHASE:                   LIQUID
COMPONENTS: LBMOL/HR
  ADIPI                  33.1000
  HMDA                    0.0
  METHA-01                0.0
  H2O                    33.1000
  NYLON66                 0.0
  NITRO-01                0.0
COMPONENTS: LB/HR
  ADIPI                4837.3333
  HMDA                    0.0
  METHA-01                0.0
  H2O                   596.3058
  NYLON66                 0.0
  NITRO-01                0.0
TOTAL FLOW:
  LBMOL/HR               66.2000
  LB/HR                5433.6391
  CUFT/HR                75.1615
STATE VARIABLES:
  TEMP   F               77.0000
  PRES   PSIA            14.6959
  VFRAC                   0.0
  LFRAC                   1.0000
  SFRAC                   0.0
ENTHALPY:
  BTU/LBMOL           -2.7042+05
  BTU/LB              -3294.5677
  BTU/HR              -1.7901+07
ENTROPY:
  BTU/LBMOL-R          -112.1008
  BTU/LB-R               -1.3658
DENSITY:
  LBMOL/CUFT              0.8808
  LB/CUFT                72.2928
AVG MW                   82.0791
COMPONENT ATTRIBUTES:
NYLON66  SFRAC
         SFLOW
         EFRAC
         ZMOM
         FMOM
         DPN
         MWN

SUBSTREAM ATTR PSD TYPE: PSD
----------------------------
```

INTERVAL	LOWER LIMIT		UPPER LIMIT	
1	0.0	FT	6.5617-05	FT
2	6.5617-05	FT	1.3123-04	FT
3	1.3123-04	FT	1.9685-04	FT
4	1.9685-04	FT	2.6247-04	FT
5	2.6247-04	FT	3.2808-04	FT
6	3.2808-04	FT	3.9370-04	FT
7	3.9370-04	FT	4.5932-04	FT
8	4.5932-04	FT	5.2493-04	FT
9	5.2493-04	FT	5.9055-04	FT
10	5.9055-04	FT	6.5617-04	FT

3
-

STREAM ID	3
FROM :	M-01
TO :	P-01
CLASS:	MIXCIPSD
TOTAL STREAM:	
LB/HR	9876.3806
BTU/HR	-2.4140+07
SUBSTREAM: MIXED	
PHASE:	LIQUID
COMPONENTS: LBMOL/HR	
ADIPI	33.1000
HMDA	33.1000
METHA-01	0.0
H2O	66.2000
NYLON66	0.0
NITRO-01	0.0
COMPONENTS: LB/HR	
ADIPI	4837.3333
HMDA	3846.4358
METHA-01	0.0
H2O	1192.6115
NYLON66	0.0
NITRO-01	0.0
TOTAL FLOW:	
LBMOL/HR	132.4000
LB/HR	9876.3806
CUFT/HR	154.7466
STATE VARIABLES:	
TEMP F	80.2626
PRES PSIA	14.6959
VFRAC	0.0
LFRAC	1.0000
SFRAC	0.0
ENTHALPY:	
BTU/LBMOL	-1.8233+05
BTU/LB	-2444.2202
BTU/HR	-2.4140+07
ENTROPY:	
BTU/LBMOL-R	-118.9907
BTU/LB-R	-1.5952
DENSITY:	
LBMOL/CUFT	0.8556
LB/CUFT	63.8229
AVG MW	74.5950
COMPONENT ATTRIBUTES:	
NYLON66 SFRAC	
SFLOW	

```
         EFRAC
         ZMOM
         FMOM
         DPN
         MWN

SUBSTREAM ATTR PSD TYPE: PSD
----------------------------

INTERVAL     LOWER LIMIT           UPPER LIMIT
    1          0.0     FT          6.5617-05  FT
    2       6.5617-05  FT          1.3123-04  FT
    3       1.3123-04  FT          1.9685-04  FT
    4       1.9685-04  FT          2.6247-04  FT
    5       2.6247-04  FT          3.2808-04  FT
    6       3.2808-04  FT          3.9370-04  FT
    7       3.9370-04  FT          4.5932-04  FT
    8       4.5932-04  FT          5.2493-04  FT
    9       5.2493-04  FT          5.9055-04  FT
   10       5.9055-04  FT          6.5617-04  FT


4
-

STREAM ID                4
FROM :                   P-01
TO   :                   E-01
CLASS:                   MIXCIPSD
TOTAL STREAM:
  LB/HR                9876.3806
  BTU/HR              -2.4132+07
SUBSTREAM: MIXED
PHASE:                   LIQUID
COMPONENTS: LBMOL/HR
  ADIPI                  33.1000
  HMDA                   33.1000
  METHA-01                0.0
  H2O                    66.2000
  NYLON66                 0.0
  NITRO-01                0.0
COMPONENTS: LB/HR
  ADIPI                4837.3333
  HMDA                 3846.4358
  METHA-01                0.0
  H2O                  1192.6115
  NYLON66                 0.0
  NITRO-01                0.0
TOTAL FLOW:
  LBMOL/HR              132.4000
  LB/HR                9876.3806
  CUFT/HR               154.7963
STATE VARIABLES:
  TEMP   F               80.9492
  PRES   PSIA           235.1959
  VFRAC                   0.0
  LFRAC                   1.0000
  SFRAC                   0.0
ENTHALPY:
  BTU/LBMOL           -1.8226+05
  BTU/LB              -2443.3678
  BTU/HR              -2.4132+07
ENTROPY:
```

```
  BTU/LBMOL-R          -118.8721
  BTU/LB-R               -1.5936
DENSITY:
  LBMOL/CUFT              0.8553
  LB/CUFT                63.8024
AVG MW                   74.5950
COMPONENT ATTRIBUTES:
NYLON66  SFRAC
         SFLOW
         EFRAC
         ZMOM
         FMOM
         DPN
         MWN

SUBSTREAM ATTR PSD TYPE: PSD
----------------------------

INTERVAL     LOWER LIMIT           UPPER LIMIT
    1          0.0     FT         6.5617-05  FT
    2       6.5617-05  FT         1.3123-04  FT
    3       1.3123-04  FT         1.9685-04  FT
    4       1.9685-04  FT         2.6247-04  FT
    5       2.6247-04  FT         3.2808-04  FT
    6       3.2808-04  FT         3.9370-04  FT
    7       3.9370-04  FT         4.5932-04  FT
    8       4.5932-04  FT         5.2493-04  FT
    9       5.2493-04  FT         5.9055-04  FT
   10       5.9055-04  FT         6.5617-04  FT


5
-

STREAM ID                5
FROM :                   E-01
TO   :                   B-02
CLASS:                   MIXCIPSD
TOTAL STREAM:
  LB/HR                9876.3806
  BTU/HR              -2.3877+07
SUBSTREAM: MIXED
PHASE:                   LIQUID
COMPONENTS: LBMOL/HR
  ADIPI                  33.1000
  HMDA                   33.1000
  METHA-01                0.0
  H2O                    66.2000
  NYLON66                 0.0
  NITRO-01                0.0
COMPONENTS: LB/HR
  ADIPI                4837.3333
  HMDA                 3846.4358
  METHA-01                0.0
  H2O                  1192.6115
  NYLON66                 0.0
  NITRO-01                0.0
TOTAL FLOW:
  LBMOL/HR              132.4000
  LB/HR                9876.3806
  CUFT/HR               158.2703
STATE VARIABLES:
  TEMP   F              127.2454
```

```
  PRES   PSIA           223.1959
  VFRAC                   0.0
  LFRAC                   1.0000
  SFRAC                   0.0
ENTHALPY:
  BTU/LBMOL          -1.8034+05
  BTU/LB             -2417.6285
  BTU/HR             -2.3877+07
ENTROPY:
  BTU/LBMOL-R          -115.4408
  BTU/LB-R               -1.5476
DENSITY:
  LBMOL/CUFT              0.8365
  LB/CUFT                62.4020
AVG MW                   74.5950
COMPONENT ATTRIBUTES:
NYLON66  SFRAC
         SFLOW
         EFRAC
         ZMOM
         FMOM
         DPN
         MWN

SUBSTREAM ATTR PSD TYPE: PSD
----------------------------

INTERVAL     LOWER LIMIT           UPPER LIMIT
    1          0.0     FT          6.5617-05  FT
    2       6.5617-05  FT          1.3123-04  FT
    3       1.3123-04  FT          1.9685-04  FT
    4       1.9685-04  FT          2.6247-04  FT
    5       2.6247-04  FT          3.2808-04  FT
    6       3.2808-04  FT          3.9370-04  FT
    7       3.9370-04  FT          4.5932-04  FT
    8       4.5932-04  FT          5.2493-04  FT
    9       5.2493-04  FT          5.9055-04  FT
   10       5.9055-04  FT          6.5617-04  FT


6
-

STREAM ID                6
FROM :                   B-02
TO   :                   E-02
CLASS:                   MIXCIPSD
TOTAL STREAM:
  LB/HR                9876.3806
  BTU/HR             -2.3850+07
SUBSTREAM: MIXED
PHASE:                   LIQUID
COMPONENTS: LBMOL/HR
  ADIPI                  33.1000
  HMDA                   33.1000
  METHA-01                0.0
  H2O                    66.2000
  NYLON66                 0.0
  NITRO-01                0.0
COMPONENTS: LB/HR
  ADIPI                4837.3333
  HMDA                 3846.4358
  METHA-01                0.0
```

```
  H2O                  1192.6115
  NYLON66                 0.0
  NITRO-01                0.0
TOTAL FLOW:
  LBMOL/HR              132.4000
  LB/HR                9876.3806
  CUFT/HR               158.4520
STATE VARIABLES:
  TEMP   F              129.5813
  PRES   PSIA           934.6959
  VFRAC                   0.0
  LFRAC                   1.0000
  SFRAC                   0.0
ENTHALPY:
  BTU/LBMOL           -1.8013+05
  BTU/LB              -2414.8153
  BTU/HR              -2.3850+07
ENTROPY:
  BTU/LBMOL-R          -115.0846
  BTU/LB-R               -1.5428
DENSITY:
  LBMOL/CUFT              0.8356
  LB/CUFT                62.3304
AVG MW                   74.5950
COMPONENT ATTRIBUTES:
NYLON66  SFRAC
         SFLOW
         EFRAC
         ZMOM
         FMOM
         DPN
         MWN

SUBSTREAM ATTR PSD TYPE: PSD
----------------------------

INTERVAL     LOWER LIMIT           UPPER LIMIT
    1          0.0     FT         6.5617-05  FT
    2       6.5617-05  FT         1.3123-04  FT
    3       1.3123-04  FT         1.9685-04  FT
    4       1.9685-04  FT         2.6247-04  FT
    5       2.6247-04  FT         3.2808-04  FT
    6       3.2808-04  FT         3.9370-04  FT
    7       3.9370-04  FT         4.5932-04  FT
    8       4.5932-04  FT         5.2493-04  FT
    9       5.2493-04  FT         5.9055-04  FT
   10       5.9055-04  FT         6.5617-04  FT


7
-

STREAM ID                7
FROM :                   E-02
TO   :                   R-01
CLASS:                   MIXCIPSD
TOTAL STREAM:
  LB/HR                9876.3806
  BTU/HR              -2.1247+07
SUBSTREAM: MIXED
PHASE:                   LIQUID
COMPONENTS: LBMOL/HR
  ADIPI                  33.1000
```

```
  HMDA                    33.1000
  METHA-01                 0.0
  H2O                     66.2000
  NYLON66                  0.0
  NITRO-01                 0.0
COMPONENTS: LB/HR
  ADIPI                 4837.3333
  HMDA                  3846.4358
  METHA-01                 0.0
  H2O                   1192.6115
  NYLON66                  0.0
  NITRO-01                 0.0
TOTAL FLOW:
  LBMOL/HR               132.4000
  LB/HR                 9876.3806
  CUFT/HR                205.1329
STATE VARIABLES:
  TEMP   F               527.0000
  PRES   PSIA            908.6959
  VFRAC                    0.0
  LFRAC                    1.0000
  SFRAC                    0.0
ENTHALPY:
  BTU/LBMOL            -1.6047+05
  BTU/LB               -2151.2686
  BTU/HR               -2.1247+07
ENTROPY:
  BTU/LBMOL-R            -90.8162
  BTU/LB-R                -1.2175
DENSITY:
  LBMOL/CUFT               0.6454
  LB/CUFT                 48.1462
AVG MW                    74.5950
COMPONENT ATTRIBUTES:
NYLON66  SFRAC
         SFLOW
         EFRAC
         ZMOM
         FMOM
         DPN
         MWN

SUBSTREAM ATTR PSD TYPE: PSD
----------------------------

INTERVAL     LOWER LIMIT           UPPER LIMIT
    1          0.0     FT         6.5617-05  FT
    2       6.5617-05  FT         1.3123-04  FT
    3       1.3123-04  FT         1.9685-04  FT
    4       1.9685-04  FT         2.6247-04  FT
    5       2.6247-04  FT         3.2808-04  FT
    6       3.2808-04  FT         3.9370-04  FT
    7       3.9370-04  FT         4.5932-04  FT
    8       4.5932-04  FT         5.2493-04  FT
    9       5.2493-04  FT         5.9055-04  FT
   10       5.9055-04  FT         6.5617-04  FT


8
-

STREAM ID                 8
FROM :                    R-01
```

```
TO   :                   R-02
CLASS:                   MIXCIPSD
TOTAL STREAM:
  LB/HR                9876.3806
  BTU/HR              -1.8687+07
SUBSTREAM: MIXED
PHASE:                   LIQUID
COMPONENTS: LBMOL/HR
  ADIPI                   1.5363
  HMDA                    1.5363
  METHA-01                0.0
  H2O                   124.6151
  NYLON66                31.9388
  NITRO-01                0.0
COMPONENTS: LB/HR
  ADIPI                 224.5150
  HMDA                  178.5245
  METHA-01                0.0
  H2O                  2244.9757
  NYLON66              7228.3654
  NITRO-01                0.0
TOTAL FLOW:
  LBMOL/HR              159.6265
  LB/HR                9876.3806
  CUFT/HR               197.2766
STATE VARIABLES:
  TEMP   F              526.9995
  PRES   PSIA           836.6959
  VFRAC                   0.0
  LFRAC                   1.0000
  SFRAC                   0.0
ENTHALPY:
  BTU/LBMOL           -1.1707+05
  BTU/LB              -1892.0863
  BTU/HR              -1.8687+07
ENTROPY:
  BTU/LBMOL-R           -73.1105
  BTU/LB-R               -1.1816
DENSITY:
  LBMOL/CUFT              0.8092
  LB/CUFT                50.0636
AVG MW                   61.8718
COMPONENT ATTRIBUTES:
NYLON66  SFRAC
           ADIPI-E    7.4649-02
           ADIPI-R       0.4254
           HMDA-E     7.4649-02
           HMDA-R        0.4254
         SFLOW
           ADIPI-E       4.7124
           ADIPI-R      26.8514
           HMDA-E        4.7124
           HMDA-R       26.8514
         EFRAC
           ADIPI-E       0.5000
           HMDA-E        0.5000
         ZMOM
           ZMOM          4.7124
         FMOM
           FMOM         63.1275
         DPN
           DPN          13.3961
         MWN
```

```
           MWN        1533.9125

SUBSTREAM ATTR PSD TYPE: PSD
----------------------------

INTERVAL     LOWER LIMIT           UPPER LIMIT
    1          0.0     FT         6.5617-05  FT
    2       6.5617-05  FT         1.3123-04  FT
    3       1.3123-04  FT         1.9685-04  FT
    4       1.9685-04  FT         2.6247-04  FT
    5       2.6247-04  FT         3.2808-04  FT
    6       3.2808-04  FT         3.9370-04  FT
    7       3.9370-04  FT         4.5932-04  FT
    8       4.5932-04  FT         5.2493-04  FT
    9       5.2493-04  FT         5.9055-04  FT
   10       5.9055-04  FT         6.5617-04  FT


9
-

STREAM ID                 9
FROM :                    R-02
TO   :                    ----
CLASS:                    MIXCIPSD
TOTAL STREAM:
  LB/HR                 7503.9937
  BTU/HR               -3.8293+06
SUBSTREAM: MIXED
PHASE:                    LIQUID
COMPONENTS: LBMOL/HR
  ADIPI                 1.9361-02
  HMDA                  1.2150-02
  METHA-01                 0.0
  H2O                      0.7903
  NYLON66                 33.0751
  NITRO-01                 0.0
COMPONENTS: LB/HR
  ADIPI                    2.8295
  HMDA                     1.4119
  METHA-01                 0.0
  H2O                     14.2368
  NYLON66               7485.5155
  NITRO-01                 0.0
TOTAL FLOW:
  LBMOL/HR                33.8968
  LB/HR                 7503.9937
  CUFT/HR                137.7878
STATE VARIABLES:
  TEMP   F               491.0000
  PRES   PSIA             33.6959
  VFRAC                    0.0
  LFRAC                    1.0000
  SFRAC                    0.0
ENTHALPY:
  BTU/LBMOL            -1.1297+05
  BTU/LB               -510.3045
  BTU/HR               -3.8293+06
ENTROPY:
  BTU/LBMOL-R          -248.8977
  BTU/LB-R                -1.1243
DENSITY:
  LBMOL/CUFT               0.2460
```

```
  LB/CUFT                54.4605
AVG MW                  221.3774
COMPONENT ATTRIBUTES:
NYLON66  SFRAC
           ADIPI-E    6.8450-03
           ADIPI-R       0.4937
           HMDA-E     4.6156-03
           HMDA-R        0.4948
         SFLOW
           ADIPI-E       0.4523
           ADIPI-R      32.6246
           HMDA-E        0.3050
           HMDA-R       32.6982
         EFRAC
           ADIPI-E       0.5973
           HMDA-E        0.4027
         ZMOM
           ZMOM          0.3787
         FMOM
           FMOM         66.0801
         DPN
           DPN         174.5096
         MWN
           MWN        1.9768+04

SUBSTREAM ATTR PSD TYPE: PSD
----------------------------

INTERVAL     LOWER LIMIT           UPPER LIMIT
    1          0.0     FT         6.5617-05  FT
    2       6.5617-05  FT         1.3123-04  FT
    3       1.3123-04  FT         1.9685-04  FT
    4       1.9685-04  FT         2.6247-04  FT
    5       2.6247-04  FT         3.2808-04  FT
    6       3.2808-04  FT         3.9370-04  FT
    7       3.9370-04  FT         4.5932-04  FT
    8       4.5932-04  FT         5.2493-04  FT
    9       5.2493-04  FT         5.9055-04  FT
   10       5.9055-04  FT         6.5617-04  FT


12
--

STREAM ID                12
FROM :                   R-02
TO   :                   E-03
CLASS:                   MIXCIPSD
TOTAL STREAM:
  LB/HR                2372.3870
  BTU/HR              -1.3192+07
SUBSTREAM: MIXED
PHASE:                   VAPOR
COMPONENTS: LBMOL/HR
  ADIPI                3.7529-03
  HMDA                 8.4623-02
  METHA-01               0.0
  H2O                   131.1112
  NYLON66                0.0
  NITRO-01               0.0
COMPONENTS: LB/HR
  ADIPI                  0.5485
  HMDA                   9.8337
```

```
  METHA-01               0.0
  H2O                 2362.0048
  NYLON66                0.0
  NITRO-01               0.0
TOTAL FLOW:
  LBMOL/HR             131.1996
  LB/HR               2372.3870
  CUFT/HR             3.9468+04
STATE VARIABLES:
  TEMP   F             491.0000
  PRES   PSIA           33.6959
  VFRAC                  1.0000
  LFRAC                  0.0
  SFRAC                  0.0
ENTHALPY:
  BTU/LBMOL          -1.0055+05
  BTU/LB             -5560.5260
  BTU/HR             -1.3192+07
ENTROPY:
  BTU/LBMOL-R           -7.6832
  BTU/LB-R              -0.4249
DENSITY:
  LBMOL/CUFT          3.3242-03
  LB/CUFT             6.0108-02
AVG MW                  18.0823
COMPONENT ATTRIBUTES:
NYLON66  SFRAC
           ADIPI-E    6.8450-03
           ADIPI-R       0.4937
           HMDA-E     4.6156-03
           HMDA-R        0.4948
         SFLOW
           ADIPI-E       0.0
           ADIPI-R       0.0
           HMDA-E        0.0
           HMDA-R        0.0
         EFRAC
           ADIPI-E       0.5973
           HMDA-E        0.4027
         ZMOM
           ZMOM          0.0
         FMOM
           FMOM          0.0
         DPN
           DPN         174.5096
         MWN
           MWN        1.9768+04

SUBSTREAM ATTR PSD TYPE: PSD
----------------------------
```

INTERVAL	LOWER LIMIT		UPPER LIMIT	
1	0.0	FT	6.5617-05	FT
2	6.5617-05	FT	1.3123-04	FT
3	1.3123-04	FT	1.9685-04	FT
4	1.9685-04	FT	2.6247-04	FT
5	2.6247-04	FT	3.2808-04	FT
6	3.2808-04	FT	3.9370-04	FT
7	3.9370-04	FT	4.5932-04	FT
8	4.5932-04	FT	5.2493-04	FT
9	5.2493-04	FT	5.9055-04	FT
10	5.9055-04	FT	6.5617-04	FT

13
--

```
STREAM ID                13
FROM :                   E-03
TO   :                   ----
CLASS:                   MIXCIPSD
TOTAL STREAM:
  LB/HR               2372.3870
  BTU/HR             -1.5791+07
SUBSTREAM: MIXED
PHASE:                   LIQUID
COMPONENTS: LBMOL/HR
  ADIPI               3.7529-03
  HMDA                8.4623-02
  METHA-01               0.0
  H2O                  131.1112
  NYLON66                0.0
  NITRO-01               0.0
COMPONENTS: LB/HR
  ADIPI                  0.5485
  HMDA                   9.8337
  METHA-01               0.0
  H2O                 2362.0048
  NYLON66                0.0
  NITRO-01               0.0
TOTAL FLOW:
  LBMOL/HR             131.1996
  LB/HR               2372.3870
  CUFT/HR               41.4290
STATE VARIABLES:
  TEMP   F             212.0642
  PRES   PSIA           14.6959
  VFRAC                  0.0
  LFRAC                  1.0000
  SFRAC                  0.0
ENTHALPY:
  BTU/LBMOL          -1.2036+05
  BTU/LB             -6656.2670
  BTU/HR             -1.5791+07
ENTROPY:
  BTU/LBMOL-R          -34.9861
  BTU/LB-R              -1.9348
DENSITY:
  LBMOL/CUFT             3.1669
  LB/CUFT               57.2639
AVG MW                  18.0823
COMPONENT ATTRIBUTES:
NYLON66  SFRAC
           ADIPI-E    6.8450-03
           ADIPI-R       0.4937
           HMDA-E     4.6156-03
           HMDA-R        0.4948
         SFLOW
           ADIPI-E       0.0
           ADIPI-R       0.0
           HMDA-E        0.0
           HMDA-R        0.0
         EFRAC
           ADIPI-E       0.5973
           HMDA-E        0.4027
         ZMOM
```

```
  ZMOM           0.0
FMOM
  FMOM           0.0
DPN
  DPN          174.5096
MWN
  MWN        1.9768+04
```