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A Proposed Process and Economic Analysis for a Manufacturing Facility for Nylon 6,6

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Abstract

The global nylon market is a multi-billion-dollar industry that has been thriving in recent years due to advances in the process technology and its flexibility as a material. Nylon 6,6 is a versatile material with uses in many industries because of its ability manipulated into many forms. It is commonly used in applications that require heat resistance, chemical resistance, and high mechanical strength. It is commonly used in luggage, car parts, carpets, and many other plastic products that require the properties that nylon 6,6 exhibits. The versatility and demand for nylon 6,6 make it an attractive process for many potential chemical companies. This report contains a proposal for a nylon 6,6 manufacturing plant that includes a proposed location of Calvert City, KY, a proposed process, a grass roots economic analysis of the plant, and a HAZOP analysis of the process to help mitigate possible risks. The process starts by having the feed chemicals mixed, then pressurized and heated. The heated and pressurized feed is then split in half and sent through two identical varying diameter plug flow reactors. Once the nylon salt is formed, the mixture is then flashed twice at different temperatures to remove the excess water and unreacted chemicals. After the water is removed and the nylon salt has been polymerized, the molten nylon is sent through a granulator and formed into pellets for packaging and transport. The process was found to be profitable at current market prices of reactants and products with an IRR of ~21% which exceeds the assumed IRR of 20% to make the process profitable.

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Introduction

The reaction that creates nylon 6,6 is a step growth polymerization that utilizes adipic acid (ADA) and hexamethylene diamine (HMDA). The polycondensation of adipic acid and HMDA forms nylon 6,6 with water as the byproduct. Initially the ADA, HMDA, and water need to be mixed and put into a reaction vessel, where the nylon salt is formed. After the nylon salt is formed, the water needs to be removed in order to drive the reaction towards polymerization. Removing the water causes amide bonds to form, polymerizing the nylon salts and forming molten nylon. Once molten nylon is formed, it can be processed in whatever method is desired. The two most popular choices are to pelletize it or to spin it into fibers with a spinneret. The proposal outlines the process with a desired output of 85 MM lbs/yr of nylon 6,6 from ADA and HMDA and states that it is to be assumed that the plant will be build in Calvert City, KY.

There are many concerns to be addressed in designing a process, but the most important of those concerns are safety and sustainability. The reactants in this process are hazardous and flammable, so extra care needs to be taken to mitigate the risks that come along with utilizing those reactants. Part of this risk mitigation entails the development of an accurate HAZOP evaluation and the gathering of up to date MSDS's for the chemicals involved. This process also is required to take place under high pressure and temperature, which adds another level of danger. High pressures and temperatures require constant monitoring and an effective process control scheme. Sustainability must be taken into account as well considering that there will be waste and side streams present, which need to be dealt with through recycling and wastewater treatment. It is also important to take into account changing economic conditions when determining the economic feasibility of a industrial plant, so a turndown case of 67% in order to ensure that the process would remain profitable even at a lower production rate. In this case, the turndown rate of production gives an IRR of ~14.6%, which, while still being profitable, is lower than the economically attractive IRR of 20%.

Process Flow Diagram and Material Balances

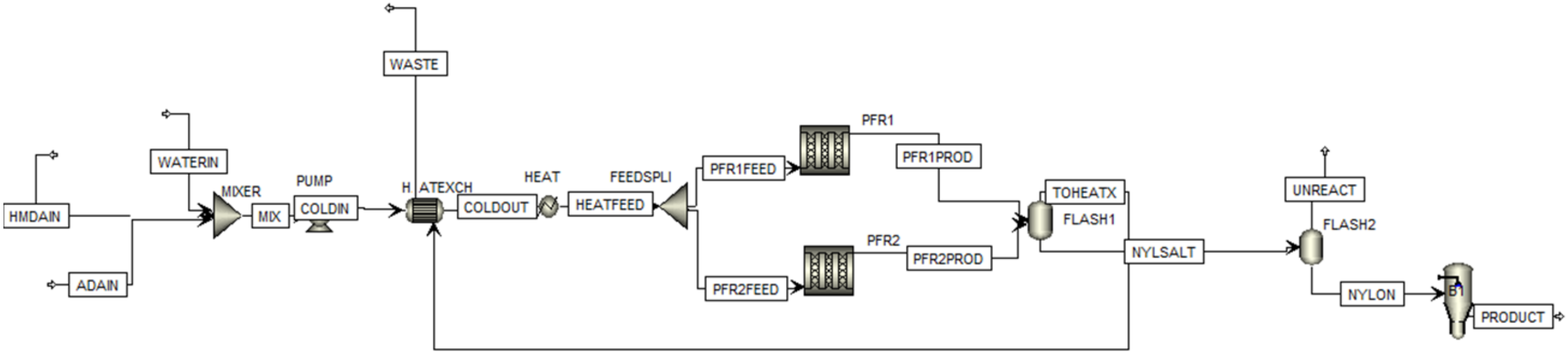

Figure 1: Process PFD

Table 1: Material Balance

Material Balances

	In(kg/hr)	Out(kg/hr)
Water	648.5501	1309.53877
HMDA	2266.027	7.9468623
ADA	2849.789	9.99E+00
Nylon6,6	0	4.44E+03
Total Mass	5764.3661	5764.365721
∆Mass		0.00037886

The calculated ∆Mass of 0.00037886 kg/hr is consistent with the assumption that there is no accumulation of mass in the system. The ∆Mass that was recorded is likely caused by the process simulator rounding off during its calculations and is small enough that it can be ignored

Process Description

As illustrated in Figure 1, the nylon 6,6 process starts by mixing water, ADA, and HMDA together in a mixing tank, which utilizes a top mounted mixer. The literature recommendations for feed composition is 60% water, 20% HMDA, and 20% ADA, but during the ASPEN optimization, it was found that since the process creates its own water and recycle streams will be utilized, the product concentrations were not affected noticeably by the amount of water in the mixture, so a value of ~10% water was chosen for the feed. After the mixer, a pump was used to pressurize the feed according to literature recommendations. The literature recommends pressurizing the feed to 10 atm, but the product concentration was not affected noticeably by a reduction in pressure and the process would be a lot safer at lower pressures, so 5 atm was chosen as the operating pressure of the pump. Once the feed is pressurized, it goes through a heat exchanger that utilizes the water vapor let off at the first flash drum after the plug flow reactors further into the process. This steam, once steady state is reached, is enough to eliminate the use of the heater present after the heat exchanger. The heater will only be used during startup to help the reaction reach steady state, and then it will be shut off, saving energy.

Once the feed is pressurized and heated, it is split into two equal flows and put through two identical plug flow reactors. The literature recommended a length of 1000m for the plug flow reactors, but during the ASPEN optimization, it was found that a much shorter plug flow reactor could be used and the product output changed minimally, so to save money, two 0.5m plug flow reactors were used. In order to overcome the viscous effects of the nylon salt formation, the plug flow reactors were designed to have a varying diameter from 0.1m to 0.5m. After the feed leaves the plug flow reactors, in order to push the reaction to polymerize, it is important to remove as much water as possible.

In order to remove the water, the heated, pressurized product stream from the plug flow reactors is then put through a flash drum at atmospheric pressure and 378k. This removes most of the water and very little unreacted chemicals. This vapor stream is then put through the heat exchanger after the feed pump in order to save energy by heating the feed so that the heater does not need to be used. Once this first flash is complete, there is still a significant amount of unreacted reactants left in the stream, so a second flash is used to remove the unreacted chemicals and what is left of the water. This second flash takes place at 650 K and atmospheric pressure in order to vaporize the unreacted chemicals so that they can be recycled. It is recommended that this recycle stream of unreacted chemicals be used to create steam or electricity for the plant in order to condense it to a liquid so that it can be added back into the feed. This will drastically reduce waste and reduce the required amount of city water needing to be constantly added to the process. Once the final flash is complete, molten nylon makes up 99.99% of the product stream and can be directed to either a pelletizer to make nylon pellets, or a spinneret to make nylon fibers. The proposed process assumes a pelletizer because most of the online sources for bulk nylon sell in pellet form.

Energy Balance and Utility Requirements

Table 3: Process Energy Balance

Energy Balance						
	ADAIN	HMDAIN	WATERIN	UNREACT	NYLON	WASTE
Total Flow kg/hr	2849.789	2266.027	648.5501	897.3008	4440.558	426.5073
Temperature K	300	300	300	650	650	373.17
Enthalpy J/kg	-6.64E+06	-1.29E+06	-1.59E+07	-1.26E+07	-9.47E+05	-1.48E+07
Power (Kwh)	-1.89E+10	-2.92E+09	-1.03E+10	-1.13E+10	-4.21E+09	-6.31E+09
Power In (Kwh)	-3.21E+10					
Power Out (Kwh)	-2.18E+10					
ΔPower (Out-In)Kwh	10,345,514,534					

Table 4: Utilities Costs

Utilities Energy				
Utilities	kwh/hr	kwh/yr	$/hr	$/yr
Pump	0.013454016	117.8571794	$0.17	$1,520.74
HeatX (Startup Only)	0.435108765	3811.552777	$5.61	$134.74
Mixer	0.013454016	117.8571794	$0.17	$1,520.74
pelletizer	2.654170293	23250.53176	$34.25	$300,006.51
Total Utilities	3.116187089	27297.7989	$ 965.01	$303,182.72

Equipment List and Unit Descriptions

Mixer:

The mixer is used to combine the feed components into an aqueous solution before they get pressurized and heated in preparation for the plug flow reactors.

Feed Pump:

The feed pump is used to pressurize the feed solution in order to increase the product yield.

Heat Exchanger:

The heat exchanger utilizes waste heat from the first flash's vapor stream to heat the feed stream before it goes into the plug flow reactors to increase the rate of reaction. Since the heat exchanger utilizes waste heat from the first flash's vapor stream, it only works when the process is at steady state. This means the heater needs to be used during startup

Heater:

The heater is used during startup to heat the feed stream before it goes into the plug flow reactors in order to increase the rate of reaction. Once the process is at steady state, the heater can be turned off and the heat exchanger can take over, saving energy.

Plug Flow Reactors:

The plug flow reactors are used to facilitate the reaction of ADA and HMDA into nylon salt. These reactions are carried out at high temperature and pressure in order to increase product yield. Two plug flow reactors in parallel were chosen to increase overall product yield by lowering the flow rate through both reactors. The plug flow reactors are designed with varying diameter in order to overcome the increasing viscosity from the increasing nylon salt concentration down the length of the reactor.

Splitter:

The flow splitter is used here to divide the heated, pressurized feed stream flow rate so that it is evenly divided between the two plug flow reactors.

Flash Drum:

The flash drums are used to purify the nylon product from the water and unreacted chemicals present in the solution. The first flash drum takes most of the water out of the nylon salt stream flowing out of the plug flow reactors, which drives the nylon salts to polymerize. The second flash takes the remaining water and unreacted chemicals out of the molten nylon, purifying the product and enabling the recycle of the water and unreacted chemicals. It is suggested that the vapor stream from the second flash be used to create steam or electricity in order for it to be condensed before it is added to the feed stream as a recycle.

Pelletizer:

The pelletizer is used as a way to package nylon in a usable form. Nylon pelletizers can make different sized pellets of nylon and those pellets can be transported and then melted down again for various uses.

Equipment Specification Sheets

Table 5: Pump Attributes

Pump	
Name	DCP CENTRIF PUMP
User tag number	PUMP
Remarks 1	Equipment mapped from 'PUMP'.
Quoted cost per item [USD]	$ 4,800.00
Quoted cost per installed item [USD]	$ 32,600.00
Currency unit for matl cost	
Number of identical items	
Installation option	
Casing material	
Liquid flow rate [l/min]	103.2502886
Fluid head [meter]	40.44102798
Speed [rpm]	
Fluid specific gravity	1.023379
Driver power [kW]	
Driver type	
Seal type	
Design gauge pressure [barg]	5.776588665
Design temperature [K]	394.2611111
Fluid viscosity [cP]	0.5
Pump efficiency [fraction]	0.331314
Allow resize	

Table 6: Flash Drum Attributes

Vertical vessel		
Name	DVT CYLINDER FLASH2-flash vessel	DVT CYLINDER FLASH1-flash vessel
User tag number	FLASH2-flash vessel	FLASH1-flash vessel
Remarks 1	Equipment mapped from 'FLASH2'.	Equipment mapped from 'FLASH1'.
Quoted cost per item [USD]	$ 17,600.00	$ 17,500.00
Quoted cost per installed item [USD]	$ 107,500.00	$ 206,900.00
Currency unit for matl cost		
Number of identical items		
Installation option		
Application		
Shell material		
Liquid volume [l]	3269.297609	3269.297609
Vessel diameter [meter]	1.0668	1.0668
Vessel tangent to tangent height [meter]	3.6576	3.6576
Design gauge pressure [barg]	1.03425	5.776588665
Vacuum design gauge pressure [barg]		
Design temperature [K]	677.7777778	405.7777778
Operating temperature [K]	650	378
Skirt height [meter]		
Vessel leg height [meter]		
Wind or seismic design		
Fluid volume [fraction]		
Base material thickness [meter]		
Corrosion allowance [meter]		
Cladding material		
Cladding thickness [meter]		
Head type		
ASME design basis		
Allow resize		

Table 7: PFR Attributes

PFR's		
Name	DTW PACKED PFR2	DTW PACKED PFR1
User tag number	PFR2	PFR1
Remarks 1	Equipment mapped from 'PFR2'.	Equipment mapped from 'PFR1'.
Quoted cost per item [USD]	$ 9,600.00	$ 9,600.00
Quoted cost per installed item [USD]	$ 70,600.00	$ 70,600.00
Currency unit for matl cost		
Number of identical items		
Installation option		
Application		
Shell material		
Vessel diameter [meter]	0.3048	0.3048
Vessel tangent to tangent height [meter]	1.0668	1.0668
Design gauge pressure [barg]	5.776588665	5.776588665
Vacuum design gauge pressure [barg]		
Design temperature [K]	394.2611111	394.2611111
Operating temperature [K]	350	350
Packing type		
Number of packed sections		
Total packing height [meter]	0.762	0.762
Cladding material		
Skirt height [meter]		
Wind or seismic design		
Fluid volume		
Base material thickness [meter]		
Corrosion allowance [meter]		
Cladding thickness [meter]		
Jacket design gauge pressure [barg]		
Jacket type		
Jacket material		
Head type		
Molecular weight Overhead prod	0	0
ASME design basis		
Allow resize		

Table 8: Heater and Heat Exchanger Attributes

Heat Exchanger and Heater		
Name	DHE TEMA EXCH HEATEXCH	DHE TEMA EXCH HEATER
User tag number	HEATEXCH	HEAT
Remarks 1	Equipment mapped from 'HEATEXCH'.	Equipment mapped from 'HEAT'.
Quoted cost per item [USD]	$ 9,700.00	$ 8,400.00
Quoted cost per installed item [USD]	$ 62,600.00	$ 62,100.00
Currency unit for matl cost		
Number of identical items	1	1
Installation option		
Heat transfer area [sqm]	4.86557607	2.030486305
Number of shells		
Front end TEMA symbol	B	B
Shell TEMA symbol	E	E
Rear end TEMA symbol	M	M
Heat exchanger design option		
Tube material		
Tube design gauge pressure [barg]	5.776588665	7.6054608
Tube design temperature [K]	405.7777778	465.2611111
Tube operating temperature [K]	350	437.4833333
Tube outside diameter [meter]	0.0254	0.0254
Shell material		
Shell design gauge pressure [barg]	3.51329602	5.776588665
Shell design temperature [K]	405.7777778	394.2611111
Shell operating temperature [K]	378	350
Tube side pipe material		
Shell side pipe material		
Number of tubes per shell		
Tube length extended [meter]	6.096	6.096
Tube gauge		
Tube pitch [meter]	0.03175	0.03175

Shell diameter [meter]		
Shell wall thickness [meter]		
Shell corrosion allowance [meter]		
Expansion joint		
Tube sheet material		
Number of tube passes	1	1
Number of shell passes	1	1
Allow resize		

Table 9: Other Equipment Attributes

Mixer Tank, Mixer Motor, Feed Splitter, Pelletizer				
Name	MIXERTANK	C MIXER	C FEEDSPLI	Pelletizer
User tag number		MIXER	FEEDSPLI	Pelletizer
Remarks 1		Equipment mapped from 'MIXER'.	Equipment mapped from 'FEEDSPLI'.	
Code of account		100	100	
Quoted cost per item [USD]	$ 4,000.00	$ 12,864.00	Negligible	$80,000
Quoted cost per installed item [USD]	$ 10,000.00	$ 95,101.71	Negligible	$480,000
Icarus/User COA option				
Material cost per unit		0	0	
Currency unit for matl cost				
Labor hours per unit [hr]				
Number of identical items				
Installation option				
Unit of measure				
Quantity		1	1	1

Quantity adjustment option				
Item classification				
Item type				
Material		SS		
Component weight [kg]				20 tons
ID in bulk report				

Equipment Cost Summary

Table 10: Equipment Cost Summary

Unit operation					
Name	Equipment Cost [USD]	Installed Cost [USD]	Equipment Weight [LBS]	Installed Weight [LBS]	Utility Cost [USD/HR]
PUMP	$4,800.00	$32,600.00	250	3199	$ 0.17
FLASH2	$17,600.00	$206,900.00	3000	19078	$
PFR2	$ 9,600.00	$70,600.00	830	5943	$
PFR1	$ 9,600.00	$ 70,600.00	830	5943	$
FLASH1	$ 17,500.00	$107,500.00	3100	13919	$
HEATEXCH	$9,700.00	$ 62,600.00	1000	7772	$
HEAT	$8,400.00	$62,100.00	540	7856	$5.61
MIXER	$12,864.00	$95,101.71	200	1000	$ 0.17
MIXERTANK	$ 4,000.00	$10,000.00			$
Pelletizer	$80,000	$480,000			$34.25
	Total Installed	$1,198,001.71			

Fixed Capital Investment Summary

Table 11: Fixed Capital Investment Values

CTM ($)	$ 1,980,041.18
CGR ($)	$ 2,819,041.68
ΣCBM ($)	$ 1,678,001.00
FCI ($)	$ 2,819,041.68

Equation 1 calculates the total module cost based on the bare module cost.

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

C_{TM}= Total Module Cost

$C_{BM,i}$ = Bare Module Cost

Equation 2 calculates the total grassroots cost as a function of total module cost.

$$FCI = C_{GR} = C_{TM} + 0.5 \sum_{i=1}^{n} C_{BM,i} \tag{2}$$

FCI = Fixed Capital Investment

C_{GR} = Grassroots Cost

C_{TM} = Total Module Cost

$C_{BM,i}$ = Bare Module Cost

Safety, Health, and Environmental Considerations

As this process requires high temperatures and pressures, it is extremely important to have a rigorous process control system in place to avoid equipment failure. Constant monitoring of the temperature, pressure, and flow data are important in order to ensure that a runaway reaction is not present and to allow proper, timely response. The fixed set points in the process control scheme will be the temperature and pressure, but the flow rates are easily manipulated at any point in the process via control valves. Increases in heat and pressure will lead to increased heat and pressure down the line and could easily build to the point of equipment failure.

The system's startup procedure will need to take into account that the first flash drum is not putting out vapor to heat the heat exchanger. This will require that the heater be used to heat the feed to the required temperature before it reaches the plug flow reactors.

The chemicals used in this process are toxic to humans and are flammable, so care should be taken to follow instructions in the HAZOP analysis (Appendix A2) in order to avoid personal injury and process failure. Proper PPE should always be worn when in vicinity to the process. Another safety concern is the high pressure and temperature at which this process will operate. It is crucial to utilize the proper PPE in an environment that requires these high temperatures and pressures in order to avoid injury to plant personell.

The environmental effects of this process are mostly contained in the wastewater treatment and the possibility of a large leak of reactant or product. The wastewater treatment plant will be best implemented if a third party is hired to implement and build a wastewater treatment plant onsite. The treatment is required to remove unreacted chemicals and nylon from the waste streams. Once proper levels of contaminants have been reached in accordance with EPA guidelines, the property proposed has frontage on the Tennessee River, so the treated waste stream can be piped into the river. A rigorous preventative maintenance program and an adequate spill containment system for the plant will mitigate the risks of a large scale spill.

Other Important Considerations

None.

Manufacturing Costs (Exclusive of Capital Requirements)

Equation 4 calculates the manufacturing costs based on the costs of raw materials, salaries, etc.

$$COM_D = 0.18FCI + 2.73C_{OL} + 1.23(C_{UT} + C_{WT} + C_{RM}) \tag{4}$$

COM_D = cost of manufacturing without depreciation
C_{OL} = cost of operating labor
C_{UT} = cost of utilities
C_{WT} = cost of water treatment
C_{RM} = cost of raw materials

Table 12: Operating Labor Costs

Salaries					
	Number Needed		Approx Salary per year		
Secretary	1		$23,000		$23,000
Manager	3		$58,000		$174,000
Engineer	1		$72,000		$72,000
Operators	12		$32,000		$384,000
Janitor	1		$23,000		$23,000
Maintenance	3		$30,000		$90,000
Accountant	1		$38,000		$38,000
Total On Salaries					$804,000

Table 13: Raw Material Costs*

Raw Materials					
	$/metric ton		Stream In kg/hr	$/hr	$/yr
Adipic Acid	$1,500		2849.789	$4,274.68	$37,446,227.46
HMDA	$2,500		2266.027	$5,665.07	$49,625,991.30

*Appendix A.3) Invista Raw Material Quote

Table 14: Utility Costs

Utilities			
	$/hr	$/yr	kwh
Pump	$0.17	$1,520.74	0.013454016
HeatX (Startup Only)	$5.61	$134.74	0.435108765
Mixer	$0.17	$1,520.74	0.013454016
pelletizer	$34.25	$300,006.51	2.654170293
Total Utilities		$303,182.72	

Table 15: Wastewater Treatment Costs*

Wastewater Treat			
Wastewater system install		$75,000	total
Operating Costs		$5,500	/yr

*These are approximate values gathered from SamcoTech’s website. This company specializes in industrial wastewater treatment.

Economic Analysis

Table 16: Full Production Economic Analysis

FIXED	VARIABLES									
All $ in Millions										
Land	Revenue	FCI	FCI yr 1	FCI yr 2		COM$_d$	Tax	IRR	Working Capital	
$4.20	$117	$2.819	$1.6914	$1.13		$110.190	6%	20.00%	$0.5638	
EOY	Investment	d$_x$	FCI-d$_x$	COM$_d$	R	(R-COM$_d$-d$_x$)(1-t)+d$_x$	Cash Flow	SUM Cash Flow	Discounted Cash Flow	SUM DCF
0	$ (4.20)	$ -	$ 2.82	$ -	$ -	$ -	$ (4.20)	$ (4.20)	$ (4.20)	$ (4.20)
1	($2)	$ -	$ 2.82	$ -	$ -	$ -	$ (1.69)	$ (5.89)	$ (1.41)	$ (5.61)
2	($1.13)	$ -	$ 2.82	$ -	$ -	$ -	$ (1.13)	$ (7.02)	$ (0.78)	$ (6.39)
4	$ -	$ 0.56	$ 2.26	$110	$ 117.41	$ 6.82	$ 6.82	$ (0.20)	$ 3.29	$ (3.10)
5	$ -	$ 0.90	$ 1.35	$ 110.19	$ 117.41	$ 6.84	$ 6.84	$ 6.65	$ 2.75	$ (0.35)
6	$ -	$ 0.54	$ 0.81	$ 110.19	$ 117.41	$ 6.82	$ 6.82	$ 13.47	$ 2.28	$ 1.93
7	$ -	$ 0.32	$ 0.49	$ 110.19	$ 117.41	$ 6.81	$ 6.81	$ 20.27	$ 1.90	$ 3.83
8	$ -	$ 0.32	$ 0.16	$ 110.19	$ 117.41	$ 6.81	$ 6.81	$ 27.08	$ 1.58	$ 5.41
9	$ -	$ -	$ 0.16	$ 110.19	$ 117.41	$ 6.79	$ 6.79	$ 33.87	$ 1.32	$ 6.73
10	$ -	$ -	$ 0.16	$ 110.19	$ 117.41	$ 6.79	$ 6.79	$ 40.66	$ 1.10	$ 7.83
11	$ -	$ -	$ 0.16	$ 110.19	$ 117.41	$ 6.79	$ 6.79	$ 47.45	$ 0.91	$ 8.74
12	$ -	$ -	$ 0.16	$ 110.19	$ 117.41	$ 6.79	$ 6.79	$ 54.23	$ 0.76	$ 9.50
13	$ 5.05	$ -	$ 0.16	$ 110.19	$ 117.41	$ 6.79	$ 11.83	$ 66.07	$ 1.11	$ 10.61

Table 16: Turndown Case Economic Analysis

FIXED	VARIABLES	Turndown Case								
All $ in Millions										
Land	Revenue	FCI	FCI yr 1	FCI yr 2		COMd	Tax	IRR	Working Capital	
$4.20	$79	$2.819	$1.6914	$1.13		$74.472	6%	14.63%	$0.5638	
EOY	Investment	dx	FCI-dx	COMd	R	(R-COMd-dx)(1-t)+dx	Cash Flow	SUM Cash Flow	Discounted Cash Flow	SUM DCF
0	$ (4.20)	$ -	$ 2.82	$ -	$ -	$ -	$ (4.20)	$ (4.20)	$ (4.20)	$ (4.20)
1	($2)	$ -	$ 2.82	$ -	$ -	$ -	$ (1.69)	$ (5.89)	$ (1.48)	$ (5.68)
2	($1.13)	$ -	$ 2.82	$ -	$ -	$ -	$ (1.13)	$ (7.02)	$ (0.86)	$ (6.53)
4	$ -	$ 0.56	$ 2.26	$74	$ 78.67	$ 3.98	$ 3.98	$ (3.04)	$ 2.30	$ (4.23)
5	$ -	$ 0.90	$ 1.35	$ 74.47	$ 78.67	$ 4.00	$ 4.00	$ 0.95	$ 2.02	$ (2.21)
6	$ -	$ 0.54	$ 0.81	$ 74.47	$ 78.67	$ 3.98	$ 3.98	$ 4.93	$ 1.75	$ (0.46)
7	$ -	$ 0.32	$ 0.49	$ 74.47	$ 78.67	$ 3.96	$ 3.96	$ 8.89	$ 1.52	$ 1.07
8	$ -	$ 0.32	$ 0.16	$ 74.47	$ 78.67	$ 3.96	$ 3.96	$ 12.85	$ 1.33	$ 2.39
9	$ -	$ -	$ 0.16	$ 74.47	$ 78.67	$ 3.94	$ 3.94	$ 16.80	$ 1.15	$ 3.55
10	$ -	$ -	$ 0.16	$ 74.47	$ 78.67	$ 3.94	$ 3.94	$ 20.74	$ 1.01	$ 4.55
11	$ -	$ -	$ 0.16	$ 74.47	$ 78.67	$ 3.94	$ 3.94	$ 24.68	$ 0.88	$ 5.43
12	$ -	$ -	$ 0.16	$ 74.47	$ 78.67	$ 3.94	$ 3.94	$ 28.62	$ 0.77	$ 6.20
13	$ 5.05	$ -	$ 0.16	$ 74.47	$ 78.67	$ 3.94	$ 8.99	$ 37.61	$ 1.52	$ 7.72

The grass roots economic analysis of this plant was carried out using a 5 year MACRS depreciation scale, Kentucky's 6% corporate tax rate (TaxFoundation.org), and the estimated costs of utilities, operating labor costs, etc. The parcel of land chosen is west of Calvert City, KY and has 139 acres of industrial zoned land with 5 miles of frontage on the Tennessee River (Zillow.com). The manufacturing costs and FCI were calculated using the methods detailed in Turton et al. The IRR was found to be ~21%, which meets the assumed IRR of 20% which would make this process economically attractive to investors. The turndown case, however, leads to an IRR of ~14.6%, which, while still being profitable, is not as attractive for possible investors, so care should be taken to only go to the turndown case if no other options are available.

Conclusions and Recommendations

In conclusion, this plant will be profitable based on current prices of products and reactants. A plant making 85 MMlb/year nylon 6,6 will net $6.8 million dollars per year once costs of manufacturing, labor, and utilities are taken out to give an IRR of ~21%, which exceeds the 20% IRR associated with an economically attractive process. The turndown case is still profitable, but only has an IRR of ~14.6%, which is not as economically feasible, so if it was decided to go ahead with the plant, care should be taken to avoid the turndown rate of production if at all possible.

It is suggested that the proposed process be taken to third party vendors for another point of view. Also, third parties should be contacted who specialize in the optimization of processes, wastewater treatment, and process control. These factors were hard to take into account as the methods of optimization, wastewater treatment, and process control vary widely from process to process. Quotes from vendors regarding actual equipment, utility, raw material, and product prices would drastically improve the accuracy of the economic analysis of the proposed plant.

Acknowledgements

Aspen Process Simulator access was provided by the University of Arkansas College of Chemical Engineering.

Library and literature access was provided by the University of Arkansas Library System.

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*Due to the variety of the sources utilized, conventional citation format was not utilized. Contact the author if there are any questions as to the sources.

Appendix

A 1) HAZOP Report

CAMEO Chemicals

Substances In This Report

1. HEXAMETHYLENEDIAMINE, SOLID

2. WATER

3. ADIPIC ACID

Contents

This report contains:

- ⚠ Reaction hazard predictions associated with mixing these substances.

- ⚠ Detailed information from the datasheet for each substance.

Chemical Reactivity

Substances In The Mix

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

⚠ Summary of Hazard Predictions (for all pairs of sunstances)

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

⚠ Summary of Gas Predictions (for all pairs of sunstances)

May produce the following gases:

- ⚠ Acid Fumes
- ⚠ Base Fumes

Hazard Predictions (for each pair of substances)

WATER *mixed with*
HEXAMETHYLENEDIAMINE, SOLID

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

ADIPIC ACID *mixed with*
HEXAMETHYLENEDIAMINE, SOLID

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

ADIPIC ACID *mixed with*
WATER

- ⚠ No known hazardous reaction

Chemical Datasheet

HEXAMETHYLENEDIAMINE, SOLID

Chemical Identifiers

CAS Number	UN/NA Number	DOT Hazard Label	USCG CHRIS Code
⚠ 124-09-4	⚠ 2280	⚠ Corrosive	⚠ HMD

NFPA 704

data unavailable

NIOSH Pocket Guide	International Chem Safety Card
none	⚠ HEXAMETHYLENEDIAMINE

General Description

Hexamethylenediamine, solid is a colorless crystalline solid. It is soluble in water. It is corrosive to metals and tissue. Produces toxic oxides of nitrogen during combustion.

Hazards

Reactivity Alerts

none

Air & Water Reactions

May be sensitive to air. Water soluble.

Fire Hazard

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

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

Health Hazard

Vapors cause irritation of eyes and respiratory tract. Liquid irritates eyes and skin, may cause dermatitis. (USCG, 1999)

Reactivity Profile

HEXAMETHYLENEDIAMINE is hygroscopic. This compound can react with strong oxidizing materials. It is incompatible with acids, acid chlorides and acid anhydrides. It is also incompatible with ketones, aldehydes, nitrates, phenols, isocyanates, monomers and chlorinated compounds. (NTP, 1992).

Belongs to the Following Reactive Group(s)

- ⚠ Amines, Phosphines, and Pyridines

Potentially Incompatible Absorbents

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

- ⚠ Mineral-Based & Clay-Based Absorbents

Response Recommendations

Isolation and Evacuation

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

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

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

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

Firefighting

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

SMALL FIRE: Dry chemical, CO2 or water spray.

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

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

Non-Fire Response

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

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

Protective Clothing

Protective clothing; eye protection. (USCG, 1999)

DuPont Tychem® Suit Fabrics

Normalized Breakthrough Times (in Minutes)

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

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

Special Warnings from DuPont

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

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

(DuPont, 2016)

First Aid

EYES: First check the victim for contact lenses and remove if present. Flush victim's eyes with water or normal saline solution for 20 to 30 minutes while simultaneously calling a hospital or poison control center. Do not put any ointments, oils, or medication in the victim's eyes without specific instructions from a physician. IMMEDIATELY transport the victim after flushing eyes to a hospital even if no symptoms (such as redness or irritation) develop.

SKIN: IMMEDIATELY flood affected skin with water while removing and isolating all contaminated clothing. Gently wash all affected skin areas thoroughly with soap and water. IMMEDIATELY call a hospital or poison control center even if no symptoms (such as redness or irritation) develop. IMMEDIATELY transport the victim to a hospital for treatment after washing the affected areas.

INHALATION: IMMEDIATELY leave the contaminated area; take deep breaths of fresh air. If symptoms (such as wheezing, coughing, shortness of breath, or burning in the mouth, throat, or chest) develop, call a physician and be prepared to transport the victim to a hospital. Provide proper respiratory protection to rescuers entering an unknown atmosphere. Whenever possible, Self-Contained Breathing Apparatus (SCBA) should be used; if not available, use a level of protection greater than or equal to that advised under Protective Clothing.

INGESTION: DO NOT INDUCE VOMITING. Corrosive chemicals will destroy the membranes of the mouth, throat, and esophagus and, in addition, have a high risk of being aspirated into the victim's lungs during vomiting which increases the medical problems. If the victim is conscious and not convulsing, give 1 or 2 glasses of water to dilute the chemical and IMMEDIATELY call a hospital or poison control center. IMMEDIATELY transport the victim to a hospital. If the victim is convulsing or unconscious, do not give anything by mouth, ensure that the victim's airway is open and lay the victim on his/her side with the head lower than the body. DO NOT INDUCE VOMITING. Transport the victim IMMEDIATELY to a hospital. (NTP, 1992)

Physical Properties

Chemical Formula: ⚠ C6H16N2

Flash Point: 178 ° F (NTP, 1992)

Lower Explosive Limit (LEL): 0.7 % (NTP, 1992)

Upper Explosive Limit (UEL): 6.3 % (NTP, 1992)

Autoignition Temperature: 734 to 788 ° F (NTP, 1992)

Melting Point: 108 ° F (NTP, 1992)

Vapor Pressure: 1.1 mm Hg at 122 ° F ; 3 mm Hg at 140° F (NTP, 1992)

Vapor Density (Relative to Air): 4.01 (NTP, 1992)

Specific Gravity: (anhyd.) 0.799 at 140.0° F (70% soln.) 0.933 at 20°C (USCG, 1999)

Boiling Point: 401 ° F at 760 mm Hg (NTP, 1992)

Molecular Weight: 116.24 (NTP, 1992)

Water Solubility: greater than or equal to 100 mg/mL at 73° F (NTP, 1992)

Ionization Potential: data unavailable

IDLH: data unavailable

AEGLs (Acute Exposure Guideline Levels)

No AEGL information available.

ERPGs (Emergency Response Planning Guidelines)

No ERPG information available.

PACs (Protective Action Criteria)

No PAC information available.

Regulatory Information

EPA Consolidated List of Lists

No regulatory information available.

DHS Chemical Facility Anti-Terrorism Standards (CFATS)

No regulatory information available.

Alternate Chemical Names

- ⚠ ALPHA,OMEGA-HEXANEDIAMINE
- ⚠ 1,6-DIAMINO-N-HEXANE
- ⚠ 1,6-DIAMINOHEXANE
- ⚠ HEXAMETHYLENE DIAMINE, SOLID
- ⚠ HEXAMETHYLENEDIAMINE
- ⚠ HEXAMETHYLENEDIAMINE, SOLID
- ⚠ HEXAMETHYLENEDIAMINE, [SOLID]
- ⚠ 1,6-HEXAMETHYLENEDIAMINE
- ⚠ 1,6-HEXANEDIAMINE
- ⚠ HEXYLENEDIAMINE
- ⚠ 1,6-HEXYLENEDIAMINE
- ⚠ HMDA
- ⚠ NCI-C61405
- ⚠ V 1

Chemical Datasheet

WATER

Chemical Identifiers

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

NFPA 704

data unavailable

NIOSH Pocket Guide	International Chem Safety Card
none	none

General Description

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

Hazards

Reactivity Alerts

none

Air & Water Reactions

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

Fire Hazard

No information available.

Health Hazard

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

Reactivity Profile

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

Belongs to the Following Reactive Group(s)

- ⚠ Water and Aqueous Solutions

Potentially Incompatible Absorbents

No information available.

Response Recommendations

Isolation and Evacuation

No information available.

Firefighting

No information available.

Non-Fire Response

No information available.

Protective Clothing

No information available.

DuPont Tychem® Suit Fabrics

No information available.

First Aid

No information available.

Physical Properties

Chemical Formula: ⚠ H2O

Flash Point: data unavailable

Lower Explosive Limit (LEL): data unavailable

Upper Explosive Limit (UEL): data unavailable

Autoignition Temperature: data unavailable

Melting Point: 32 ° F

Vapor Pressure: data unavailable

Vapor Density (Relative to Air): data unavailable

Specific Gravity: 1

Boiling Point: 212 ° F at 760 mm Hg

Molecular Weight: data unavailable

Water Solubility: data unavailable

Ionization Potential: data unavailable

IDLH: data unavailable

AEGLs (Acute Exposure Guideline Levels)

No AEGL information available.

ERPGs (Emergency Response Planning Guidelines)

No ERPG information available.

PACs (Protective Action Criteria)

No PAC information available.

Regulatory Information

EPA Consolidated List of Lists

No regulatory information available.

DHS Chemical Facility Anti-Terrorism Standards (CFATS)

No regulatory information available.

Alternate Chemical Names

- ⚠ DIHYDROGEN OXIDE
- ⚠ WATER

Chemical Datasheet

ADIPIC ACID

Chemical Identifiers

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

NFPA 704

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

(NFPA, 2010)

NIOSH Pocket Guide	International Chem Safety Card
none	ADIPIC ACID

General Description

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

Hazards

Reactivity Alerts

none

Air & Water Reactions

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

Fire Hazard

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

Health Hazard

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

Reactivity Profile

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

Belongs to the Following Reactive Group(s)

Acids, Carboxylic

Potentially Incompatible Absorbents

No information available.

Response Recommendations

Isolation and Evacuation

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

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

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

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

Firefighting

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

SMALL FIRE: Dry chemical, CO2, water spray or regular foam.

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

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

Non-Fire Response

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

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

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

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

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

Protective Clothing

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

DuPont Tychem® Suit Fabrics

No information available.

First Aid

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

EYES: flush with water for at least 15 min.

SKIN: flush with water. (USCG, 1999)

Physical Properties

Chemical Formula: $C_6H_{10}O_4$

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

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

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

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

Melting Point: 304 ° F (USCG, 1999)

Vapor Pressure: data unavailable

Vapor Density (Relative to Air): data unavailable

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

Boiling Point: data unavailable

Molecular Weight: 146.1 (USCG, 1999)

Water Solubility: data unavailable

Ionization Potential: data unavailable

IDLH: data unavailable

AEGLs (Acute Exposure Guideline Levels)

No AEGL information available.

ERPGs (Emergency Response Planning Guidelines)

No ERPG information available.

PACs (Protective Action Criteria)

No PAC information available.

Regulatory Information

EPA Consolidated List of Lists

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

(EPA List of Lists, 2015)

DHS Chemical Facility Anti-Terrorism Standards (CFATS)

No regulatory information available.

Alternate Chemical Names

ACIFLOCTIN
ACINETTEN
ADILACTETTEN
ADIPIC ACID
ADIPINIC ACID
ASAPIC
1,4-BUTANEDICARBOXYLIC ACID
HEXANEDIOIC ACID
1,6-HEXANEDIOIC ACID
INIPOL DS

A.2) Process Stream Tables

	ADAIN	HMDAIN	WATERIN	MIX	COLDIN	COLDOUT	HEATFEED	PFR1FEED	PFR1PROD	PFR2FEED	PFR2PROD	TOHEATX	NYLSALT	UNREACT	NYLON	WASTE
	MIXER	MIXER	MIXER	PUMP	HEATEXCH	HEAT	FEEDSPLI	PFR1	FLASH1	PFR2	FLASH1	HEATEXCH	FLASH2			
				MIXER	PUMP	HEATEXCH	HEAT	FEEDSPLI	PFR1	FEEDSPLI	PFR2	FLASH1	FLASH1	FLASH2	FLASH2	HEATEXCH
	LIQUID	LIQUID	LIQUID	LIQUID	LIQUID	LIQUID	LIQUID	LIQUID	LIQUID	LIQUID	LIQUID	VAPOR	LIQUID	VAPOR	LIQUID	MIXED
Substream: MIXED																
Mass Flow kg/hr																
WATER	0	0	648.5501	648.5501	648.5501	648.5501	648.5501	324.275	654.7692	324.275	654.7692	426.3614	883.1774	880.843	2.33437	426.3614
ADA	2849.789	0	0	2849.789	2849.789	2849.789	2849.789	1424.894	4.997044	1424.894	4.997044	4.98E-05	9.99E+00	8.797958	1.20E+00	4.98E-05
HMDA	0	2266.027	0	2266.027	2266.027	2266.027	2266.027	1133.014	3.973431	1133.014	3.973431	0.1458399	7.801022	7.659813	0.141209	0.14584
NYLON66	0	0	0	0	0	0	0	0	2218.443	0	2218.443	3.13E-80	4.44E+03	1.57E-75	4.44E+03	3.13E-80
Total Flow kg/hr	2849.789	2266.027	648.5501	5764.366	5764.366	5764.366	5764.366	2882.183	2882.183	2882.183	2882.183	426.5073	5337.859	897.3008	4440.558	426.5073
Vapor Frac	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0.332599
Liquid Frac	1	1	1	1	1	1	1	1	1	1	1	0	1	0	1	0.667401
Solid Frac	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Temperature K	300	300	300	299.9955	300.4096	350	350	350	350	350	350	378	378	650	650	373.17
Pressure atm	1	1	0.0349119	1	5	5	5	5	5	5	5	1	1	1	1	1
Enthalpy J/kg	-6.64E+06	-1.29E+06	-1.59E+07	-5.57E+06	-5.57E+06	-5.46E+06	-5.46E+06	-5.46E+06	-4.89E+06	-5.46E+06	-4.89E+06	-1.33E+07	-3.95E+06	-1.26E+07	-9.47E+05	-1.48E+07
Entropy J/kg-K	-5320.333	-7806.725	-9030.742	-6601.33	-6597.29	-6251.471	-6251.471	-6251.471	-6251.193	-6251.471	-6251.193	-2027.536	-5886.836	-1005.501	-4113.33	-6092.82
Average MW	146.143	116.2065	18.01528	76.85821	76.85821	76.85821	76.85821	76.85821	62.36347	76.85821	62.36347	18.02049	77.62591	18.30466	224.9119	18.02049
NYLON66 SFRAC																
ADA-R									0.4440912		0.4440912	0.4440912	0.4440912	0.4440912	0.444091	0.444091
ADA-E									0.0559087		0.0559087	0.0559087	0.0559087	0.0559087	0.055909	0.055909
HMDA-R									0.4440912		0.4440912	0.4440912	0.4440912	0.4440912	0.444091	0.444091
HMDA-E									0.0559087		0.0559087	0.0559087	0.0559087	0.0559087	0.055909	0.055909
NYLON66 SFLOW kmol/hr																
ADA-R									8.629409		8.629409	1.22E-82	1.73E+01	6.10E-78	1.73E+01	1.22E-82
ADA-E									1.086398		1.086398	1.53E-83	2.17E+00	7.68E-79	2.17E+00	1.53E-83
HMDA-R									8.629409		8.629409	1.22E-82	1.73E+01	6.10E-78	1.73E+01	1.22E-82
HMDA-E									1.086398		1.086398	1.53E-83	2.17E+00	7.68E-79	2.17E+00	1.53E-83
NYLON66 EFRAC																
ADA-E									0.5		0.5	0.5	0.5	0.5	0.5	0.5
HMDA-E									0.5		0.5	0.5	0.5	0.5	0.5	0.5
NYLON66 ZMOM kmol/hr																
ZMOM									1.086398		1.086398	1.53E-83	2.17E+00	7.68E-79	2.17E+00	1.53E-83
NYLON66 FMOM kmol/hr																
FMOM									19.43161		19.43161	2.74E-82	3.89E+01	1.37E-77	3.89E+01	2.74E-82
NYLON66 DPN																
DPN									17.88628		17.88628	17.88628	17.88628	17.88628	17.88628	17.88628
NYLON66 MWN																
MWN									2042.017		2042.017	2042.017	2042.017	2042.017	2042.017	2042.017

A.3) Invista Raw Material Quote

Dear Students:
Your request for adipic acid and hexamethylene diamine (HMD) pricing was passed on to me due to my involvement in AIChE. Please use this indicative delivered pricing for your economics.
Adipic acid $1,500/metric tonne
HMD $2,500/metric tonne
Good luck on your senior design project.
Best regards,
INVISTA