Department of Chemical and Biomolecular Engineering
School of Engineering and Applied Science
University of Pennsylvania
220 S. 33rd Street Philadelphia, PA 19104
April 23, 2019

Dear Dr. Robert Riggleman and Professor Bruce Vrana,

Enclosed is a proposal for a process design that converts waste trash plastic bags into recycled low density polyethylene product. The proposed design employs a dissolution and precipitation method using a solvent and nonsolvent. The main process is fed 50 tons per day of waste trash plastic bags to produce a low density polyethylene (LDPE) product at a polymer grade purity greater than 99.99%. The plant is to be located in an industrial complex in the Northeast United States where waste trash plastic bags are in great abundance (most likely near New York City or Philadelphia).

Waste trash bags are transported to the facility where they are stored to satisfy the large feedstock capacity required. The trash bags are sent to a cleaning line where they are shredded and the majority of contaminants are removed before being sent to the dissolution vessel. The shredded plastic combines with heated toluene solvent to dissolve all the polymer. A series of filters in parallel remove any remaining undissolved impurities before the solution is sent to the precipitation vessel. It is combined with heated isopropanol nonsolvent where the polymer precipitates out. The solid polymer granules are separated from the solvent/nonsolvent mixture and dried to attain a purity of 99.99%. The solvent/nonsolvent mixture is separated to be recycled. Energy and heat integration is optimized to reduce operating expenses.

The plant is designed to operate continuously with an industrial standard operating factor of 0.9. Waste trash grocery bags are acquired at no cost and the final LDPE product is valued at $0.48 per pound (a 20% discount due to predicted discoloration). The proposed design requires an investment of $14.9 MM to meet the processing goal and yields an investor's rate of return (IRR) of 21.97%. We recommend investing in the process and directing research towards enhancing the filtration technology while also being wary of waste trash bag and LDPE product market prices.

Kind Regards,

Pensiri Naviroj	James Treacy	Conrad Urffer

Chemical Recycling of Plastics by Dissolution

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1 Abstract

There is significant upside potential for the recycling of plastic wastes, especially for waste polyethylene plastic bags. Plastic containers and packaging have the most tonnage of waste plastics sent to landfills, and there are limited number of communities collecting single-use polyethylene plastics bags for recycling. This project explores the dissolution-precipitation technique as a viable plastics recycling method. Beginning with a feed assumed to be primarily low density polyethylene (LDPE), plastic bag waste is cleaned and 50 tons per day of this cleaned LDPE waste enters the main process. The proposed design includes a dissolution and precipitation vessel. The design is modeled to induce polymer dissolution with a toluene solvent and polymer precipitation in granule form with an isopropanol nonsolvent. The slurry from the precipitation is filtered and dried, and the recycled LDPE is recovered with a 99.99% purity. The solvent and nonsolvent are separated using distillation, and the toluene and isopropanol are recycled to minimize raw material operating costs. Pumps, heat exchangers, purge streams and surge tanks are additionally included in the design. Heat and energy are optimized to minimize utility costs. A $14.9MM total capital investment is required to yield an IRR of 21.97% and an NPV of $5,896,300 over a proposed twenty-year lifetime. Based on this base case, this proposal is a recommended investment, but investors should be cautious when revisiting the economics as the process depends on the assumed recycled LDPE selling prices, high utility requirements, and waste trash bag acquisition costs. Future investigation and experiments should look to solidify the ternary phase diagram between the three components and research should be dedicated to producing advanced filtration techniques to remove pigment and dye contamination.

2 Introduction and Objective-Time Chart

2.1. Introduction

Plastic items have been thoroughly incorporated into our daily lives. Single-use plastic items are tools of convenience that are commonly used every day. In 2017, plastic production reached almost 350 million metric tons or approximately 385 tons (Plastic Europe, 2018). The advantages to using plastics for packaging and manufactured articles, especially single-use plastic items, include their inherent strength and durability. However, these advantages in usage turn into disadvantages in disposal. As plastic items can take up to one thousand years to decompose, the accumulation of plastics have become an alarming environmental concern. One of the most common single-use plastic items is low-density polyethylene (LDPE) shopping bags, and the design of a techno-economically viable process to dispose of LDPE shopping bags is proposed.

Plastics are disposed of in numerous ways: recycling, landfilling, incineration, composting, and littering. The most sustainable method to dispose of plastic bags is recycling but less than 10% of plastic items are currently being recycled. There are a number of ways to recycle LDPE plastic bags, and thus it is important to understand the environmental and economical options for recycling post-consumer plastic bag waste. Presently, waste plastics are being recycled in two main ways: mechanical and chemical recycling. Mechanical recycling involves reprocessing plastic waste to plastic products using physical means. In comparison to chemical recycling, mechanical recycling consumes fewer resources and has a lower impact on global warming. However, the recycled plastic will not have a purity comparable to that of virgin LDPE plastic. Chemical recycling methods, that involve chemically degrading plastics, include two processes that decompose plastic waste into more useful forms: pyrolysis involves the thermal degradation of plastics to produce useful liquid products, while gasification involves heating plastic with air to produce syngas. These two chemical recycling methods result in more useful products and higher purity products, but the processes have a larger environmental impact. An additional chemical recycling method that is the focus of this design is the solvent-based separation of plastics to convert waste plastic bags to useful recycled LDPE products.

Solvent-based separation of plastics is a promising method of plastic recycling. The solvent extraction process involves dissolving plastics in a solvent then reprecipitating the plastic out of the solution using another solvent (the nonsolvent). LDPE shopping bags are often contaminated with food wastes, inks, other plastics, paper, and other materials. The impurities from the plastic wastes are removed during the dissolution process. The dissolution process involves using a selective solvent that will dissolve the target LDPE polymer to form a homogeneous solution. The LDPE plastic is then reprecipitated into a form a high purity solid end-product. Solvent-extraction processes operate at relatively low temperatures and pressures, which means lower operating costs and lesser negative environmental impact. The economic viabilities and profitability for developing an optimal commercial dissolution-reprecipitation process will be explored and analyzed in the project.

2.2. Objective-Time Chart

Specific Goals:

- Dissolution and Reprecipitation of LDPE
- Processes operating at low temperature and pressures
- Product Outputs: 99.99% pure LDPE
- Design of Solvent and Anti-Solvent recovery system

Project Scope:

- Capacity: 50 TPD LDPE Feed
- LDPE product polymer grade purity of >99.99%
- Input of post-consumer LDPE grocery bags
- Recycled polymer selling prices depending on target market and estimated by long term market trends
- CAPEX and OPEX optimization

Deliverables:

- Complete flowsheet illustrating the designed processes with mass and energy balances
- Block results for operating conditions of each unit
- Heat integration schemes
- Financial analysis with process and pricing sensitivity analysis, presented with IRR and NPV

Process Timeline

PHASE	DETAILS	
PROJECT TITLE	Chemical Recycling of Plastics by Dissolution	
Team Members	James Treacy, Conrad Urffer, Pensiri Naviroj	
Project Advisor	Dr. Matthew Targett	
Faculty Advisor	Professor Robert Riggleman	

	JAN		FEB				MAR				APR					MAY
Date	22	29	5	12	19	26	5	12	19	26	2	9	16	23	30	
Meeting #:	1	2	3	4	5	6		7	8	9	10	11				
Date Tracker + Deadlines #:													1	2	3	

Phase		Details	Timeline task
1	Preliminary Design	Meeting #3: Preliminary Designs completed	Narrowing down to 2-3 solvents + researching unit operations + details about waste
2	Process Synthesis	Meeting #6: 15 min Oral Progress Report to summarize progress	Create process flow sheet + do material and energy balances
		Meeting #7: Submit Material and Energy Balances for base case designs with process flow diagram	Heat integration + energy saving integration schemes
3	Unit Designs	Meeting #9: Most of detailed design of process units for plant completed + submit detailed design for key process unit	Design dissolution and reprecipitation vessels
		Meeting #10: All equipment designed	Design other equipments (pumps, filters, dryer)
4	Profitability Analysis	Meeting #11: Last meeting + Finances Completed	Calculate costing and finances
		Deadline #1: Written Reports Due	Written Report
		Deadline #2: Revised Report Due	Revisions
		Deadline #3: Presentation	Make Presentation

3 Innovation Map *(N/A)*

4 Market and Competitive Assessment

There exists a large potential market for the chemical recycling of plastics by dissolution. LDPE is one of the widest-produced plastics due to its use in packaging applications, with 100 million metric tons or 110 tons produced annually worldwide (Essential Chemistry Industry). However, LDPE bags and films in particular are purposely avoided in single-stream mechanical recycling processes due to the possibility of clogging in the shredding machines of those processes. As a result, there are limited processes that have designed an environmentally friendly and economically efficient process for recycling LDPE shopping bags.

There are few companies that have specialized in the recycling of LDPE grocery bags and LDPE post-consumer waste. Presently, the most common method of LDPE recycling is mechanical recycling. Novolex, a packaging company, currently runs the largest mechanical recycling plant for LDPE grocery bags at their Novolex Hilex Poly recycling center in North Vernon, Indiana. The Bag-2-Bag program at Hilex Poly recycling center currently processes over 22 million pounds of LDPE bags per year. The plant proposed in this design will recycle 50% more. Furthermore, solvent-based extraction practices are still in the early stages of commercialization, and the market has room for growth. Consumer goods companies such as P&G and Unilever have both partnered with technology firms and institutions to develop new chemical recycling technologies. P&G has partnered with PureCycle Technologies to come up with a process to recycle the "hard-to-recycle plastics" such as polypropylene (PP), polyethylene, and polyethylene terephthalate (PET). The PureCycle solvent-based technology removes color contamination and odor from recycled plastics. Unilever has worked with the Fraunhofer Institute to develop the CreaSolv Process. The CreaSolv Process technology targets recycling plastic sachets.

Although studies on plastic recycling by solvent extraction have been growing in recent decades, there has yet to be a report on successfully built commercial pilot plants. The project being proposed will be a novel detailed process design for a commercially optimal LDPE waste recycling facility, with the design based upon currently existing technologies from available patents and literature.

5 Customer Requirements

The two market segments for potential customers are based on the polymer grade purity and color of the end-product. Depending on the end-purity and color of the LDPE product, the selling-price of the product will vary accordingly. There is a market for different grades of LDPE, in which a sensitivity analysis will be conducted in Section 20 to see the effect of varying prices of LDPE product on the profitability of the process. For the higher purity and colorless end-product, the recycled LDPE product can be sold to plastic bag manufacturers and other manufacturers of LDPE plastic items that require colorless LDPE pellets as their feedstocks. For end-products that have color contamination and are off-white material, the recycled LDPE product can be sold to wood plastic composite (WPC) market to be used for decking material.

6 CTQ Variables *(N/A)*

7 Product Concepts *(N/A)*

8 Superior Product Concepts *(N/A)*

9 Competitive (Patent) Analysis *(N/A)*

10 Preliminary Process Synthesis

10.1. LDPE Assumptions

There were several assumptions established for the LDPE feed input into the process. Grocery bags generally are a mixture of the three basic types of polyethylene: LDPE, LLDPE (linear low-density polyethylene), and HDPE (high-density polyethylene). The actual compositional breakdown of the different types of polyethylene in plastic bags are kept confidential by each plastic bag manufacturer. Through further experimentation to find the actual percentage composition of the different types of polyethylene in grocery bags, the composition of LDPE as a percentage of the grocery bags can be adjusted accordingly. As a base case, other polymers are assumed to compose less than 1% of a clean grocery bag.

The grocery bags will also be highly contaminated by dirt, food, dyes, and other plastics. In the front-end process, 10% of the feed of waste grocery bags was assumed to be contaminants. The contaminants that constituted 10% of the initial feed is removed in the front-end process before the stream enters the dissolution vessel. The grocery bags will also have pigment and dye contamination. The stream entering the dissolution vessel was assumed to have 1.01% contamination, and 1% will be removed in the dissolution and reprecipitation process. The dyes that cannot get filtered out are assumed to be 0.01% of the stream entering the dissolution vessel. These pigments can be from the tinting of the color of the bag and the printing of logos and texts on the grocery bags.

10.2. Dissolution-Reprecipitation Technique

Dissolution and reprecipitation are the central mechanisms used in this process to remove contaminants and recycle the plastic. The mechanisms make use of the solubility difference of LDPE in two solvents. This technique requires less energy, and the recycled polymer will retain more of its virgin properties compared to other recycling methods.

The process is performed by first mixing the input LDPE into an appropriate solvent. Ideally, the polymer will dissolve completely while almost all contaminants will remain as solids in a separate phase, which can be filtered out from the slurry. After filtration, a nonsolvent, in which LDPE cannot dissolve in, will be added to the polymer-solvent solution.

This will cause the LDPE to precipitate into polymer granules that are at least 99.99% pure. It is assumed that the size of these granules is approximately 300 microns on average, a reasonable number based on literature (Nauman, 1994). The solid phase can then be removed from the solvent-nonsolvent solution, and the polymer granules will be separated from any remaining solvent through filtration and drying processes.

10.3. Thermodynamics of Polymer-Solvent-Nonsolvent Solution

To quantify the solubilities of the polymer and contaminants in each step of the process, research from previous studies was combined with thermodynamic data of each species. Important values here include the Hildebrand, Hansen, and Flory-Huggins Chi parameters. Equations involving these parameters can characterize the "like dissolves like" principle that governs solubility. Molecules with similar structures have intermolecular interactions with similar magnitudes of force, allowing molecules of different species to interchange and become miscible in a solution. If the intermolecular forces between the molecules of the same species are much stronger than those between different species, the different species will favor separate phases.

From preliminary research, good solvents for LDPE include paraffins like hexane and octane, as well as aromatics, like chlorobenzene, toluene and xylene. The polymer is not soluble in alcohols. A variety of alcohols were considered for as candidates for the nonsolvent. Based mostly on economic and safety factors, rather than effectiveness for dissolution-reprecipitation, toluene was chosen as the solvent and iso-propyl alcohol (isopropanol) as the nonsolvent. From values of the intermolecular force strengths in each species, equilibrium concentrations and phase diagrams can be determined.

The Hildebrand parameter, δ_d, is the square root of cohesive energy density. This is the energy per unit volume required to separate the molecules until they behave as non-interacting ideal gas, where the energy is from the attractive van der Waals forces. Since the parameter does not account for polarity or hydrogen bonding, the equations using the Hildebrand parameter more accurately represent the polymer and solvent interactions rather than the polymer and alcohol nonsolvent interactions. The equation for the

Hildebrand parameter is given by *Equation 10.3.1*, where ΔH_v is the enthalpy of vaporization and V_m is the molecular volume.

$$\delta\ (MPa)^{1/2} = \sqrt{(\Delta H_v - RT)/V_m} \qquad \textit{Equation 10.3.1}$$

For LDPE and toluene, the Hildebrand parameter is roughly equal to the total Hansen parameter. The total Hansen parameter adds energy terms to account for polarity and hydrogen bonds. Hansen parameters are more difficult to calculate, but the values can be looked up in databases. These values are 16.7 and 18.2 $MPa^{1/2}$, for LDPE and toluene respectively (Accu Dyne Test). The Hansen parameter of isopropanol, with dispersion, polarity, and hydrogen bond energy densities of respectively 15.8, 6.1, and 16.4 $MPa^{1/2}$, is 23.6 $MPa^{1/2}$ in total as shown in the MSDS sheets in Section 25.4.

Both steps in the dissolution-reprecipitation process can then be modeled with Flory-Huggins theory to determine LDPE solubility in each solvent for mass balances (Fredrickson, 2006). In the dissolution vessel, only the LDPE-toluene reaction occurs, and can be modeled with one χ parameter, given by *Equation 10.3.2*, where V_{seg} is the volume of a polymer segment, and each δ is the Hansen or Hildebrand parameter of a component.

$$\chi_{12} = \frac{V_{seg}(\delta_1 - \delta_2)^2}{RT} \qquad \textit{Equation 10.3.2}$$

This parameter describes the enthalpic component of mixing the two liquids; if the Hansen parameters are close, the term is close to zero and the phases are more miscible. From this it is expected that LDPE and toluene mix well. From Aspen software, toluene is fully miscible with isopropanol, despite the large difference in δ values. For each chemical interaction, the χ value is shown in Table 10.1. For the interaction between both solvents, the volume used for *Equation 10.4.2* was an average of both molecular volumes.

Table 10.1. χ parameters of each interaction in the system using the Flory-Huggins model.

Interaction	LDPE-toluene	LDPE-IPA	Toluene-IPA
X parameter	0.3944	1.4394	1.9362

Using the χ parameters as entropic mixing terms, the free energy of mixing can be plotted as a function of polymer volume fraction, Φ, from 0 to 1. This is given by *Equation 10.3.3*, where the '2' subscript denotes the polymer, and n is moles.

$$\Delta G_m = RT[n_1 \ln(\Phi_1) + \frac{n_2}{MW} \ln(\Phi_2) + n_1 \Phi_1 \chi_{12}] \qquad \textit{Equation 10.3.3}$$

When this equation plotted is convex up, the two components are miscible at any volume of LDPE dissolved, as it is with toluene. To model the 3-component process, a ternary phase diagram must be constructed. See Section 21.1 for further information on the theoretical basis of this system.

10.4. Product Separation and Recovery Process

Filtration and drying techniques are required to separate the liquid components from the solid granules in a slurry. From the precipitation vessel, a slurry is introduced to the filtration step. Several filtration options were compared including batch centrifugation, candle filters and screen separation before identifying the final choice. A rotary-drum vacuum filter was selected primarily because it operates continuously and can easily be modified to meet throughput requirements for filter cake thickness. Under the assumption that the granules formed from the precipitation vessel are approximately 300 microns in diameter, a rotary-drum vacuum filter performs well in separating the solids from the liquid solution.

For the drying step of the process, two major techniques were compared: direct and indirect heated dryers. The main difference between these two techniques is the mechanism by which the solid is dried (Parikh, 2014). For direct-heated dryers, a heated gas streams comes in direct contact with the solids to evaporate any liquids present through convection. For indirect-heat dryers, the solids are heated through conduction by tubes carrying steam. To limit flammability and dust safety concerns, the indirect-heated dryer technique was selected. Indirect-heated dryers also provide the upside of enhanced solvent recovery due to a limited amount of carrier gas interaction. An indirect-heat steam tube rotary dryer was selected because it can operate under high capacity, meets the requirement of an indirect-heated techniques and are more efficient compared to other industrial drying techniques. This allows for the high purity polymer product to be produced and recovered.

10.5. Solvent/Nonsolvent Recycle

To minimize the facility's economic and environmental toll in adding fresh solvent and nonsolvent to the process, it is important to recover and recycle the solvent and nonsolvent used to dissolve and precipitate the polymer. From the filtration and drying techniques, a solvent/nonsolvent mixture is separated and combined. This stream can then be separated using distillation. A key aspect in deciding the optimal solvent/nonsolvent pair was their ability to separate. After taking into consideration market prices and safety concerns, two solvents (toluene and xylene) and two non-solvents (isopropanol and n-propanol) were identified and ASPEN simulations were run to compare the heat duty requirements for separation. These simulations estimated a 3:1 nonsolvent to solvent ratio with a 1000 lb/hr feed basis and controlled the distillation column held at 2 atmospheres with 25 equilibrium stages. The distillation column was modeled to recover 99.99% of the nonsolvent and 0.1% of the solvent in the distillate. High separation is required to minimize the effect the nonsolvent plays when reintroduced with solvent in the dissolution vessel. The heating requirements are tabulated in Table 10.2.

Table 10.2. Solvent-nonsolvent pair heat duties. The amount of energy required of the condenser and reboiler for each pair was factored into the final decision to identify the optimal solvent-nonsolvent pair. ASPEN simulations were held constant with a 3:1 nonsolvent-solvent feed ratio at 80°C and a distillation column containing 25 equilibrium stages.

Solvent	Nonsolvent	Condenser Net Duty (BTU/hr)	Reboiler Net Duty (BTU/hr)
Toluene	n-propanol	-618,800	666,200
Toluene	Isopropanol	-378,400	405,500
Xylene	n-propanol	-436,300	489,400
Xylene	Isopropanol	-254,300	287,200

From Table 10.2, the best combination of solvent and nonsolvent in terms of an energy requirement is xylene and isopropanol. Between the two non-solvents, isopropanol was selected because of its lower energy requirement than its counterpart n-propanol.

However, further investigation into market prices and literature on the dissolution properties of the solvents was necessary to determine the optimal solvent. Toluene was selected as the optimal solvent even with its higher energy requirement in the ASPEN simulations because it can be purchased for less than xylene and has shown in experiments to dissolve at a rate slightly faster than xylene (Wong et al, 2013).

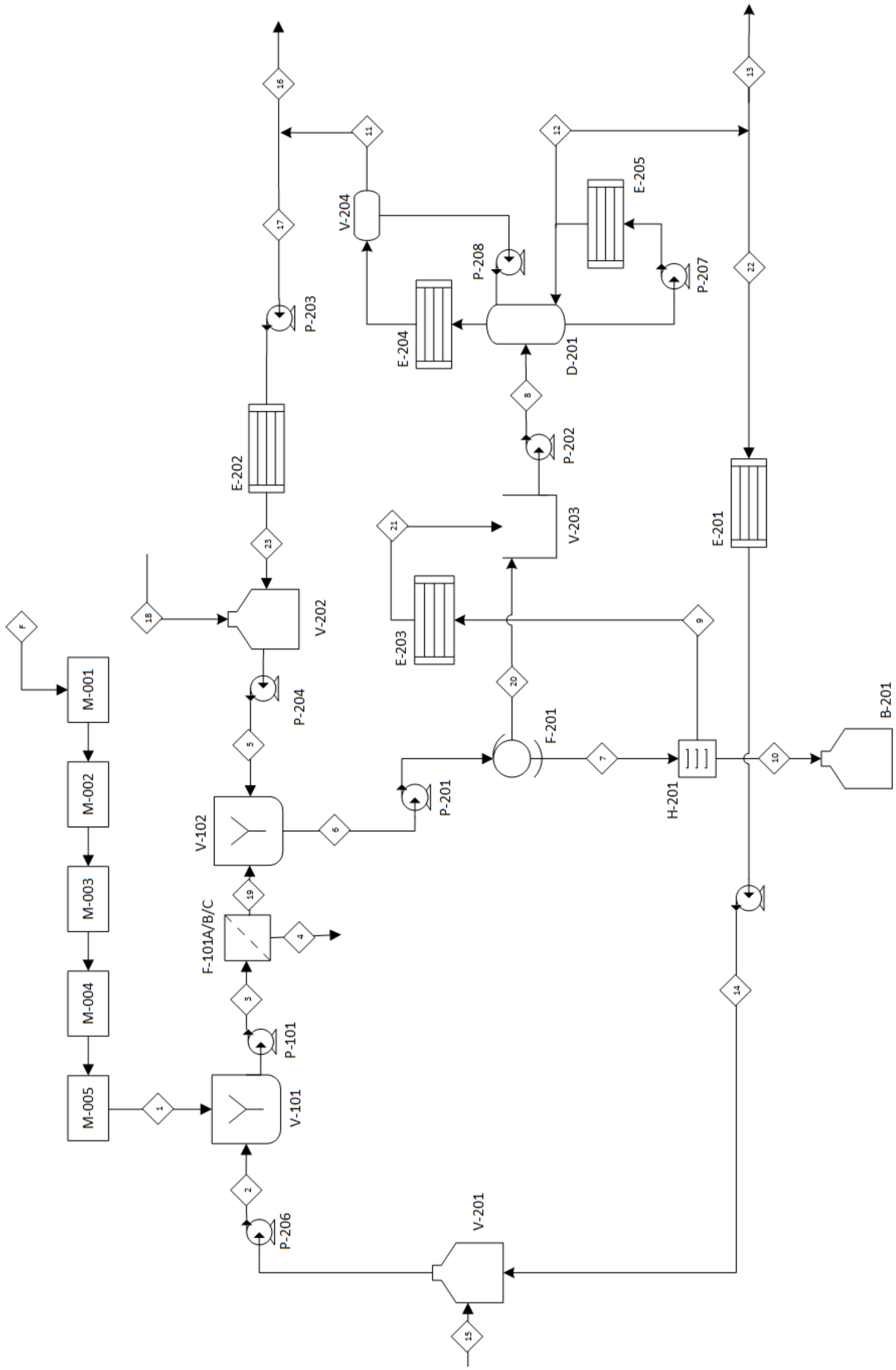
A high degree of separation is required within the distillation column. This is especially important because the solvent and nonsolvent are being recycled back to the dissolution and precipitation vessels, respectively. To minimize the amount of the nonsolvent in the dissolution vessel which may potentially affect the dissolution of LDPE, the recovery of the nonsolvent (as mentioned previously) must be high. The amount of contamination of solvent in the nonsolvent recycle stream is not of the highest concern due to it being recycled to the precipitation vessel that already contains solvent. In an effort to further minimize the unnecessary contamination entering both vessels, purge streams are included in both recycle streams.

11 Assembly of Database

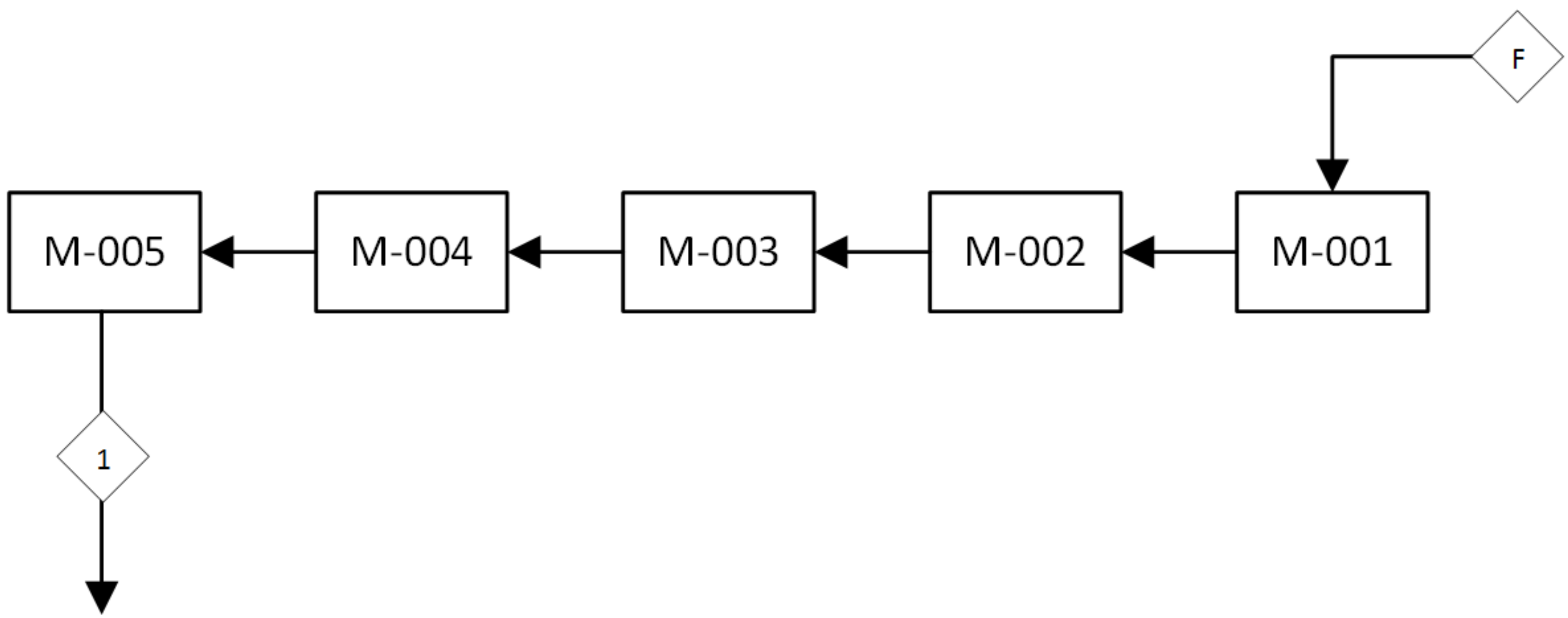
Compound	CAS#	Price $/ton	Molecular Weight (g/mol)	Density (g/L)	C_P (J/mol K)
Virgin LDPE	9002-88-4	1200	28.05	930	2.10
Toluene	108-88-3	635	92.14	867	1.70
Isopropanol	67-63-0	815	60.09	786	3.00

12 PFD and Material Balances

Overall Process Flow Diagram

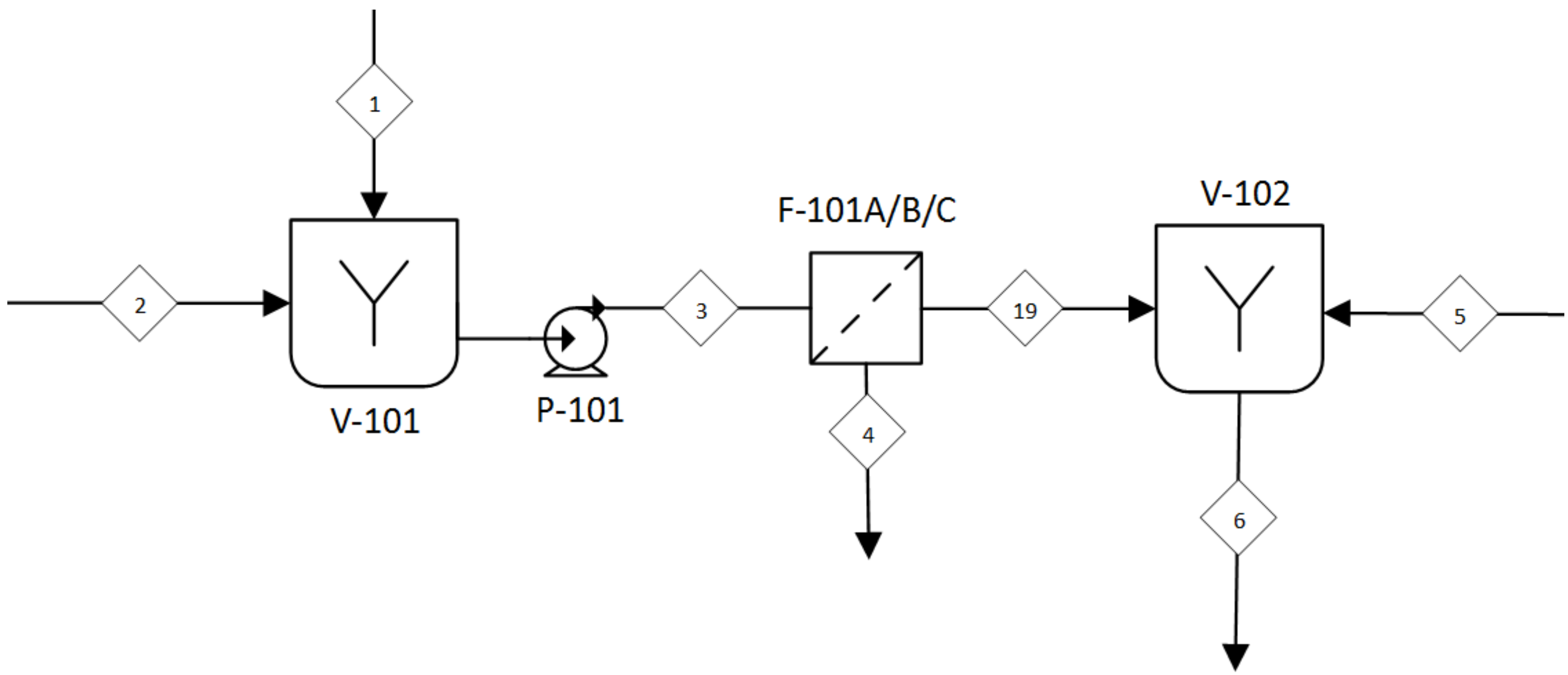


Section 000: Front End Process Flow Diagram



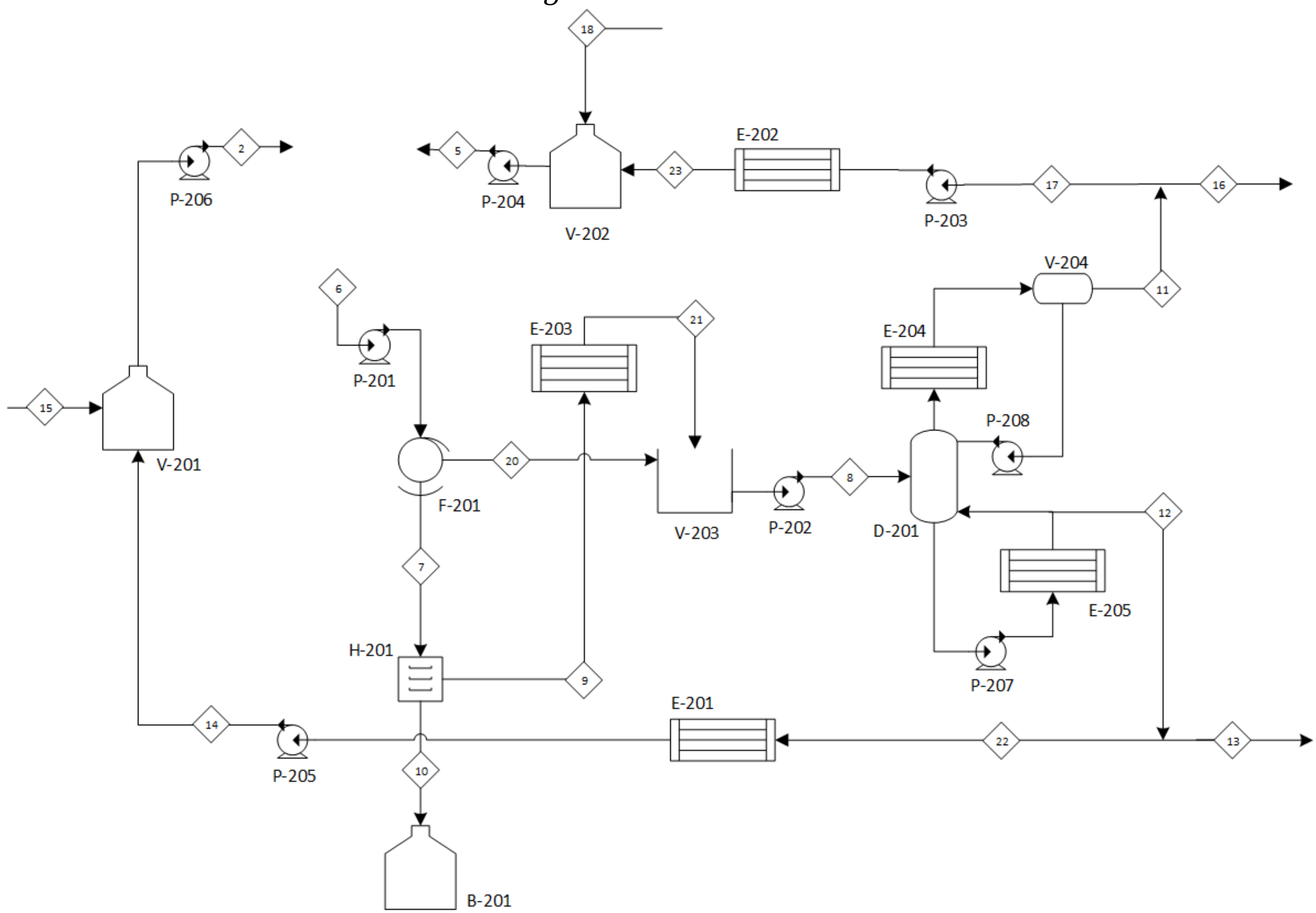
Stream Number	F	1
Temperature (°F)	71.0	77.0
Pressure (psia)	14.7	14.7
Vapor Fraction	0	0
Mass Flow (lb/hr)	4630.0	4167.0
Molar Flow (lbmol/hr)	165.1	148.6
Component Mass Flow (lb/hr)		
Low Density Polyethylene	4124.9	4124.9
Toluene	0	0
Isopropanol	0	0
Impurities	505.1	42.1

Section 100: Mid-Process Flow Diagram



Stream Number	1	2	3	4	5	6	19
Temperature (°F)	77	208.4	185	185	173.8	176	185
Pressure (psia)	14.7	29.4	29.4	14.7	29.4	29.4	29.4
Vapor Fraction	0	0	0	0	0	0	0
Mass Flow (lb/hr)	4167.0	23624.7	27791.7	41.7	70815.0	98565.0	27750.0
Molar Flow (lbmol/hr)	148.6	257.5	406.1	1.5	1178.4	1583.0	404.6
Component Mass Flow (lb/hr)							
Low Density Polyethylene	4124.9	41.6	4166.5	0	0	4166.5	4166.5
Toluene	0	23576.0	23576.0	0	21.2	23597.2	23576.0
Isopropanol	0	7.1	7.1	0	70793.8	70800.9	7.1
Impurities (Pigments/ Dyes)	42.1	0.00	42.1	41.7	0	0.4	0.4

Section 200: Back End Process Flow Diagram



Stream Number	2	5	6	7	8	9	10	11	12	13
Temperature (°F)	208.4	173.8	176.0	176.0	176.0	194.0	194.0	203.9	281.7	281.7
Pressure (psia)	29.4	29.4	29.4	29.4	29.4	7.4	14.7	29.4	29.4	29.4
Vapor Fraction	0	0	0	0	0	1	0	0	0	0
Mass Flow (lb/hr)	23624.7	70815.0	98565.0	4583.8	94439.8	458.6	4125.3	70815.0	23624.8	23.6
Molar Flow (lbmol/hr)	257.5	1178.4	1583.0	154.1	1435.8	7.0	147.1	1178.4	257.5	0.3
Component Mass Flow (lb/hr)										
Low Density Polyethylene	41.6	0	4166.5	4124.8	41.7	0	4124.9	0	41.7	0.04
Toluene	23576.0	21.2	23597.2	114.2	23597.2	114.2	0	21.2	23576.0	23.6
Isopropanol	7.1	70793.8	70800.9	344.4	70800.9	344.4	0	70793.8	7.1	0.01
Impurities (Pigments/ Dyes)	0.00	0	0.4	0.4	0	0	0.4	0	0	0

Stream Number	14	15	16	17	18	19	20	21	22	23
Temperature (°F)	208.6	77.0	203.9	203.9	77.0	185.0	176.0	176.0	281.7	174.0
Pressure (psia)	29.4	14.7	29.4	29.4	14.7	29.4	14.7	14.7	29.4	29.4
Vapor Fraction	0	0	0	0	0	0	0	0	0	0
Mass Flow (lb/hr)	23601.0	23.6	70.8	70744.2	70.8	27750.0	93981.3	458.6	23601.0	70744.2
Molar Flow (lbmol/hr)	257.2	0.3	1.2	1177.2	1.2	404.6	1428.9	7.0	257.2	1177.2
Component Mass Flow (lb/hr)										
Low Density Polyethylene	41.6	0	0	0	0	4166.5	41.6	0	41.6	0
Toluene	23552.4	23.6	0.02	21.2	0	23576.0	23483.0	114.2	23552.4	21.2
Isopropanol	7.1	0	70.8	70723.0	70.8	7.1	70457.1	344.4	7.1	70723.0
Impurities (Pigments/ Dyes)	0	0	0	0	0	0.4	0	0	0	0

13 Process Descriptions

13.1. Process Overview

The main goal of the dissolution-reprecipitation process is to recycle a capacity of 50 tons per day of waste LDPE at a purity of 99.99% or greater. This 50 TPD basis was taken as the total mass of waste plastic bags that enter the dissolution vessel in Stream 1 of the process flow diagrams in Section 12. This contains significantly more polymer by mass concentration than the original input before washing and shredding due to the feed stream having a 10% mass fraction of easily removed contaminants. The input will come largely from plastic bag reclamation centers.

From here the bags, with most debris and larger contaminants removed, enter the dissolution vessel. Here the LDPE dissolves into the toluene, while most remaining contaminants stay as suspended solids in the solution. The mixture is then pumped through Ettlinger filters to remove these contaminants. Then, in the precipitation vessel, a large amount of the nonsolvent, isopropanol, is added to induce precipitation of the polymer.

Almost all of the precipitated polymer is large enough to be separated. The stream leaving the precipitation vessel enters a rotary-drum vacuum filter next to rid the liquid phase, a 3:1 solution of mainly isopropanol and toluene. Then an indirect dryer is employed to evaporate the remaining liquid. This rids the LDPE of any toluene and isopropanol that it may be coated with. The final product is 49.5 TPD of at least 99.99% purity LDPE. The impurities here depend on research that must be done before a process is fully designed. Many will likely be colored pigments with molecular structures that allow them to dissolve in toluene and remain mixed with the LDPE as it precipitates. Discoloration of the final LDPE product due to pigment and dye contamination will affect the profitability of the proposed design.

13.2. Section 000 – Front End

13.2.1. Collection and Storage of Plastic Bags

The front end can be considered in two main parts: the retrieval and storage of LDPE plastic bags, and the preliminary plastic bag cleaning process. The recycling facility of the proposed project will be situated in the northeast of the United States and within the vicinity of a major city, such as New York City or Philadelphia. The facility is designed to be situated within close proximity to major cities to ensure that there would be enough for the 50 TPD of feedstock required. The population densities within urban areas generally translate to higher usage of LDPE grocery bags, and the close proximity would minimize the transportation distances and costs. The most economical method of transportation will be through the use of railcars. These freight rail services exist in both the states of New York and Pennsylvania. The LDPE grocery bags will be collected from reclamation centers at large supermarkets and retail grocery store chains. Assuming that only 89.1% of the grocery bags consists of LDPE, there needs to be a total input of 55.6 TPD of grocery bags to the cleaning process. The bags will be transported and stored in bales. These bales will require large floor space and hoppers for storage. The facility will have storage space to store one month's worth of inventory.

13.2.2. Cleaning Process

The LDPE bag cleaning process in the front end emulates the initial cleaning processes in mechanical recycling lines. There are a number of machines involved in this cleaning line, and the entire line can be bought from a single manufacturer. The machines can be bought from manufacturers such as ASG Plastic Recycling or Mooge Tech, companies both based in Jiangsu, China. These machines include a shredder, floatation tank, friction washer, dewatering machine, and a thermal dryer. The bales of grocery bags that arrive at the facility will have many contaminants (food wastes, inks, other plastics, paper, and others). The front-end initial cleaning process helps get rid of most of the contaminants, before the plastics enter the dissolution vessel. This preliminary cleaning helps reduce the amount of solvent needed to dissolve the grocery bags; however, the cleaning process for this design is not as intensive as the cleaning process in mechanical recycling processes since the LDPE shreds in this proposed design will enter the mid-process dissolution and reprecipitation vessels.

A shredder specifically designed to shred LDPE film or plastic bags is needed for the process. In general, films and plastic bags are more difficult to shred because the plastic tends to get caught in the revolving blades and cause blockages. After going through the shredder, the shredded bales then enter the floatation tank. The floatation tank is filled with water, and water acts as the medium to separate LDPE from different contaminants. This separation occurs due to the varying densities of the contaminants. With specific gravities greater than that of water, certain contaminants will sink (dirt, food, rocks, polystyrene, polyvinylchloride, and polyethylene terephthalate). While other contaminants (styrofoam, polypropylene, HDPE, and LLDPE) and LDPE are expected to float due to having densities less than 1 g/cm^3. The shredded LDPE and other floating contaminants then go through a friction washer to get rid of contaminants that remain on the surface of the shredded LDPE. The friction washer is a long fast-rotating shaft with many paddles attached. The paddles are rotated at high speeds to scrub the LDPE shreds, cleaning the surface of the shreds.

After the friction washer, the LDPE shreds then go through two steps to remove moisture. The dewatering machine is the initial step to remove water from the LDPE shreds. The machine uses centrifugal forces to remove water from the incoming flow of plastic shreds and water. The process helps removes large amounts of water to reduce the amount of energy needed for the thermal dryer. The machine consists of a rotating shaft with paddles attached and spins the shaft at a high speed. The shaft is surrounded by a mesh screen to collect the plastic shreds. The water that passes through the mesh screen can be recycled and used in the floatation tank, while the plastic shreds go enters the thermal dryer. The thermal dryer is second step in in removing the moisture from the LDPE shreds and the final step in the front end. The thermal dryer utilizes hot air in drying the plastic shreds. The plastic material travels through stainless steel tubing and ends at the cyclone separator. The cyclone separator brings in cold air to remove any dust on the material. The LDPE shreds then leaves the separator through a star valve, entering the mid-process.

13.3. Section 100 – Mid-Process

For safety reasons, as toluene and isopropyl are flammable (See Section 25.4), inert nitrogen will be run through the process to occupy space. To vent both the dissolution and reprecipitation vessels, flare disposal systems will be added to both tanks to burn off exhaust. Because operating pressures are low, seals will be placed between the tanks and flares to prevent flashback. Costs of these safety measures are included in the overall installation costs.

13.3.1. Dissolution Vessel

The dissolution vessel is modeled as a carbon steel ribbon mixer for solids handling, to be operated at 85°C and 2 atm. After the initial washing step, the cleaned LDPE is transported to the dissolution vessel with a Star Valve airlock. The total flowrate of this stream is 4167 lb/hr, with just over 1% impurities remaining. At the same time, heated and recycled toluene is pumped into the system, where a small amount of new solvent is added to make up for the purge. Small fractions of LDPE and isopropanol, leftover from the back end separation processes, also enter with the toluene. In the dissolution vessel, only .025% of the total mass is nonsolvent, which is assumed to not interfere with the polymer solubility.

From Flory-Huggins theory, LDPE and toluene are miscible at any composition. However, polymer solution viscosity increases exponentially with polymer fraction. For ease of stirring and pumping the solution, a weight fraction of 15% LDPE was chosen as the basis for the dissolution vessel. From *Figure 21.1*, which shows viscosity versus concentration for a methyl ester solvent, this weight fraction should prevent viscosity from increasing significantly. Conservatively, a solution viscosity of under 30 cP is estimated. Running the process at this viscosity will require less energy and maintenance.

Based on previous studies, a 30-minute residence time in the stirred tank is more than enough time for all LDPE to dissolve. Assuming perfect mixing of components and averaging densities, the volume of this tank must be 275 ft^3. At the back end of the process, described in Section 13.4.2, toluene exits the distillation column at a high temperature; some of this energy is used to heat the LDPE entering at air temperature to the required 85°C of the dissolution vessel.

13.3.2. Ettlinger Filters

The outlet of the dissolution vessel will be pumped evenly across three ERF 500 Ettlinger filters. Designed specifically for polymer solutions, these filters are energy efficient, and the contaminants can be automatically discharged into a waste receptacle. The ERF 500 can filter out unwanted polymers, and any other contaminants up to 80 µm. Screens require infrequent changing, as the filter surface is self-cleaning. The devices are also completely airtight.

13.3.3. Reprecipitation Vessel

The Ettlinger filters directly discharge the cleaned LDPE-toluene solution into the reprecipitation vessel. This ribbon mixer is similar in structure to the dissolution vessel, only significantly bigger. Isopropyl alcohol, with a small amount of toluene remaining from the distillation column, enters the tank along with a small fresh nonsolvent stream. From previous studies, a nonsolvent to solvent ratio of 3:1 will cause almost all the LDPE to fall out of solution within a few minutes. Again, a 30-minute residence time was chosen for the vessel, which could likely be lowered. Rounding up, the necessary volume is 1045 ft^3. Because the lack of precision in the thermodynamic modelling done, it is conservatively estimated that 99% LDPE can then be recovered as a solid, based off existing literature. Flory-Huggins theory indicates that the amount of LDPE still in the liquid phase is on the scale of parts per million; however, it is likely some of the solid polymer is too small to be separated in the following steps. Additionally, modelling shows that the solid phase will contain 5-10% of both solvents still mixed with LDPE (10% is used for the mass balance, see Section 21.1 for further information). The product is then pumped to the back end of the process for recovery and cleaning. Pilot experiments should be done to verify the exact phase distribution after precipitation.

13.4. Section 200 – Back End

The Back End of the process incorporates two main parts: (1) product recovery and (2) solvent and nonsolvent recovery with recycle. For safety reasons, as toluene and isopropanol are flammable (See Section 25.4), inert nitrogen will be run through the process to occupy space. To vent the vessels in the back end process, flare disposal systems will be added to the surge tanks, filter, and dryer to burn off exhaust. Because operating pressures are low, seals will be placed between the components and flares to prevent flashback. Costs of these safety measures are included in the overall installation costs.

13.4.1. Product Recovery

The stream leaving the precipitation vessel contains solid LDPE granules in a slurry with toluene and isopropanol. These LDPE particles are considered micro-granules with diameters of approximately 300 microns in size. The recovery of LDPE product with 99.99% purity requires two additional steps following the precipitation vessel: filtration and drying.

For the filtration step, a rotary-drum vacuum filter is employed to separate the solid LDPE from the solvent and nonsolvent. The rotary-drum vacuum filter was selected because it allows for continuous filtration and can easily be modified to control particle cake-thickness. The filter will be enclosed and pumped with inert nitrogen gas to prevent exposure to atmospheric air conditions thereby minimizing the danger of flammability. The enclosed filter will be held at a pressure of 2 atmospheres (29.4 psia) and the vacuum will pull the solvent/nonsolvent liquid mixture through the rotary drum using a pressure of 14.7 psia to a surge tank. The solid LDPE particles remaining on the filter area of the drum will be scraped off using a scraper blade and fall by gravity into a star valve. It is assumed that the wet particles contain a 10% impurity of the toluene-isopropanol mixture.

The star valve discharges the wet solids by gravity into the second step of the recovery process: the drying step. A star valve is used because it allows for the pressure drop between the filter and dryer to be controlled. An indirect-heat steam tube dryer pulling vacuum at 7.4 psia (0.5 atmospheres) dries the incoming wet solid stream at 194°F. An indirect dryer was selected because like the filter, the exposure to atmospheric air must be zero to prevent the risk of flammability. The pressure is reduced to less than atmospheric to decrease the boiling points of the toluene and isopropanol (See Section 25.8 for T-xy diagrams) thereby minimizing the total heat duty requirement of the dryer. Low pressure steam (50 psig) is run through 14 tubes in the dryer to heat up the LDPE and evaporate the toluene and isopropanol (See Section 15.7 for design of dryer). The vaporized solvent/nonsolvent mixture is sent to a condenser before entering the same surge tank from the filtration step. The solid LDPE is dropped by gravity into another star valve before dropping into a storage bin. The process produces 4125.3 lb/hr of 99.99% LDPE product – the 0.01% being impurities in the form of pigments and dyes.

13.4.2. Solvent/Nonsolvent Recovery

To maintain an economical process, it was decided early on to recycle the solvent and nonsolvent back into the process to minimize overall raw material costs. From the rotary-drum vacuum filter, the solvent/nonsolvent mixture with 1% of the non-precipitated LDPE is sent to a surge tank. It is combined with the condensed vapor from the drying process. This surge tank is maintained at atmospheric pressure and a temperature of 176°F. This surge tank is designed to maintain continuous operation of the process in case of temporary downtime on either side of the tank (See Section 15.4 for surge tank specifications).

The liquid in the surge tank is then pumped to a distillation column at 29.4 psia (2 atmospheres). This distillation column separates the toluene from the isopropanol with 99.97% recovery of isopropanol in the distillate (nonsolvent recycle stream) and a 99.8% mass composition of toluene in the bottoms (solvent recycle stream). The remaining composition of the bottoms solvent recycle stream is 0.17% LDPE and 0.03% isopropanol. If the previous assumption of only 99% polymer precipitation in the precipitation vessel is reevaluated to be a higher percentage precipitation, the mass composition in the bottoms stream will also increase as less polymer will make up that stream. See Section 15.5 for the design of the distillation column.

The distillate vapor stream at the top of the column passes through a total condenser and is separated between the reflux reentering the distillation column and the nonsolvent recycle stream using the reflux accumulator. It is held at 29.4 psia and 203.9°F. The recycle stream is purged 0.1% to remove any impurity build-up before entering a heat exchanger where it is cooled using cooling water to 174.0°F. This cooled nonsolvent stream is combined with fresh isopropanol nonsolvent at 77°F in the nonsolvent feed tank. The tank is well-insulated, pressurized to 29.4 psia and remains at 173.8°F (See Section 14.1 for Energy Integration). Like the earlier surge tank, the nonsolvent feed tank is modeled to facilitate continuous operation in the case that part of the process if forced to temporarily shut down. The hot nonsolvent recycle is then pumped to the precipitation vessel.

The bottoms liquid stream passes through a partial reboiler where part of the stream is sent back to the distillation column and the other to the solvent recycle loop. The recycle stream is purges 0.1% to remove any impurity build-up before entering a heat exchanger. This heat exchanger cools the toluene-majority stream to 208.6°F before being sent the solvent feed tank. Like the nonsolvent feed tank, the solvent feed tank combines fresh solvent with the recycle loop, is pressurized to 29.4 psia and is maintained at a temperature of 208.4°F due to good insulation and energy integration as described in Section 14.1. It is similarly designed to maintain continuous operation in the case of temporary shutdown. The solvent recycle stream is then pumped to the dissolution vessel.

14 Energy Balance and Utility Requirements

14.1. Energy Integration Method

An integral part of reducing the overall operating cost of this process is to reduce the total utility requirement. By enhancing the energy integration throughout the process, operating costs could be minimized, and the profitability of the process would increase. In the process, the dissolution vessel (V-101) and the precipitation vessel (V-102) are modeled to be held at 185°F (85°C) and 176°F (80°C), respectively. They are both well-insulated and it is assumed that energy loss due to conduction and convection is negligible. Therefore, the energy is either lost or gained in each of the vessels due to the stream additions. See Section 25.7 for detailed energy integration calculations.

For the dissolution vessel, the LDPE-majority feed stream is added to the process at room temperature, or 77°F (25°C), and must be heated to the temperature that the dissolution vessel is maintained. To maintain equilibrium within the vessel, the energy lost from heating up this stream is set equal to the energy input from the solvent recycle stream. This stream is calculated to be 208.4°F (98.0°C), which is enough to compensate for the heating of the LDPE. The Solvent Feed Tank (V-201) just before the dissolution vessel is then modeled to be at 208.4°F to prevent any unnecessary heating utility requirements. The vessel is similarly modeled to be well-insulated such that conduction and convection heat loss is minimal. The fresh toluene solvent is added to the process at room temperature (77°F). The heat lost from the addition of this stream is set equal to the heat added from the addition of a hotter solvent recycle stream. This solvent recycle stream was determined to enter the feed tank at 208.6°F (98.1°C) to maintain equilibrium within the tank. This temperature is used to properly model heat exchanger E-201 and to optimize the amount of cooling water required of that exchanger.

For the precipitation vessel, the stream coming from the dissolution vessel is 185°F. Because the precipitation vessel is held at a lower temperature, the stream must be balanced with a cooler stream (the nonsolvent recycle stream). To maintain an equilibrium temperature of 176°F in the precipitation vessel, the nonsolvent recycle stream was calculated to be 173.8°F (78.8°C) to compensate for the added heat from the dissolution vessel exit stream. Like the Solvent Feed Tank, the Nonsolvent Feed Tank (V-202) is modeled to be well-insulated such that conduction and convection heat loss is minimal. The fresh isopropanol nonsolvent is added to the process at room temperature and thus the hotter nonsolvent recycle stream must make up for the heating of this fresh stream. The nonsolvent recycle stream entering the feed tank was determined to be 174.0°F (78.9°C). This temperature was used to properly model heat exchanger E-202 and to optimize the amount of cooling water required of that heat exchanger.

In future investigations, the assumption of a well-insulated vessel should be revisited to identify a more accurate heat loss due to conduction to the outside environment. A more accurate estimation will result in a slightly different energy integration scheme.

14.2. Utilities

The following tables expand on the utility requirements for the process. The total utility requirements are given per pound of LDPE produced in Table 14.1. In Table 14.1, the hourly and annual utility requirements of each component of the process are shown. The hourly utility requirements are based on continuous operation and the annual utility requirements are calculated using the industrial standard of a 0.9 annual operating factor.

Table 14.1. Total utility requirement per pound of LDPE produced.

Utility	**Required ratio**	
Cooling Water	37.161	gal per lb of LDPE
Process Water	0.291	gal per lb of LDPE
Waste Treatment	0.033	lb per lb of LDPE
150 psig Stream	10.432	lb per lb of LDPE
50 psig Steam	0.043	lb per lb of LDPE
Electricity	0.177	kW-hr per lb of LDPE

Table 14.2. Total utility requirement per piece of equipment. (Note: MM = Million)

Utility	**Unit Number**	**Per Hour**	**Per Year**
Cooling Water (gal)	E-201	2,805	
	E-202	7,010	
	E-203	449	
	E-204	143,035	
	Total	**153,299**	**1,208.6 MM**
Process Water (gal)	Mooge Tech Line	**1,202**	**9.5 MM**
Waste Treatment (lb)	Stream 4	24	
	Stream 13	71	
	Stream 16	42	
	Total	**137**	**1.1 MM**
150 psig Steam (lb)	E-205	**43,034**	**339.3 MM**
50 psig Steam (lb)	H-201	**179**	**1.4 MM**
Electricity (kW-hr)	P-101	3.2	
	P-201	6.8	
	P-202	6.6	
	P-203	5.2	
	P-204	5.2	
	P-205	2.4	
	P-206	2.4	
	P-207	15.6	
	P-208	5.1	
	V-101	0.8	
	V-102	2.9	
	V-201	7.5	
	V-202	24.8	
	V-203	32.3	
	F-201	7.5	
	H-201	1.7	
	Mooge Tech Line	600	
	Total	**729.7**	**5.8 MM**

15 Equipment List and Unit Descriptions

15.1. Mooge Tech Line

Mooge Tech Line

Unit ID: Mooge Tech Line	Temperature: 71°F
Type: LDPE Washing Line	Pressure: 14.7 psia
Operators: 4 individuals	Ground Area: 1,453 ft^2
Costing Data: Table 17.1	Power Consumption: 335 hp
	Water Consumption: 5 tons/hr

The Mooge Tech Line or the LDPE washing line includes the shredder, floatation tank, friction washer, dewatering machine, and thermal dryer. The five machines can be purchased as an entire line from Mooge Tech, Jiangsu, China. The cost of purchase for the entire line will be $85,000. Detailed operating information for each of the five machines are listed below.

Shredder

Unit ID: M-001	Main Motor Power: 121 hp
Type: Shredder	Rotary Diameter: 500 mm
Costing Data: Table 17.1	Rotary Speed: 70 rpm
	Hydraulic Motor Power: 7.4 hp

The single-shaft shredder is designed to shred a wide range of materials including plastics, paper, and wood. As the LDPE shopping bags are fed to the shredder, the hydraulic motor pushes the material against the shredding rotor. The material is shredded until it becomes the size of the screen filter that is fitted beneath the cutting chamber. The shredder is purchased as part of the Mooge Tech Line.

Floatation Tank

Unit ID: M-002	Screw Conveyor Motors: 12.3 hp
Type: Floatation Tank	Rotary Drum Motors: 3.5 hp
Material: 308 Stainless Steel, Carbon Steel	Interior Width: 2 m
Costing Data: Table 17.1	

The floatation tank is a large tank filled with water. The water serves as the medium to separate the shredded plastic bags and the contaminants. Any material with densities greater than water will sink, while the LDPE and other contaminants with densities lesser than water will float. As the shredded material enters the floatation tank, the rotating drum moves the material and water through the tank. The floatation tank is purchased as part of the Mooge Tech Line.

Friction Washer

Unit ID: M-003	Main Shaft Diameter: 750 mm
Type: Friction Washer	Rotating Speed: 1080 rpm
Material: 308 Stainless Steel, Carbon Steel	Motor Power: 74 hp
Costing Data: Table 17.1	

The friction washer involves cleaning contaminants off the surface of the shredded LDPE by scrubbing the surface of the LDPE with the paddles. The paddles are attached to the main shaft, which is rotating a high-speeds. There is a mesh screen surrounding the shaft to filter out small contaminants, as well as water jets directed at the mesh screen. The friction between each plastic piece, as the washer rotates at high-speeds, helps scrub off dirt and debris. The friction washer is purchased as part of the Mooge Tech Line.

Dewatering Machine

Unit ID: M-004	Main Shaft Diameter: 750 mm
Type: Dewatering Machine	Rotating Speed: 1080 rpm
Material: 308 Stainless Steel, Carbon Steel	Motor Power: 74 hp
Costing Data: Table 17.1	

The dewatering machine is a low-energy consuming equipment that uses centrifugal forces to remove water from the flowing stream of shredded LDPE in water. The machine has a similar construction to the friction washer; the dewatering machine also has a long shaft with many paddles, with a surrounding mesh screen. However, the machine is meant to throw the LDPE shreds towards the mesh screen and let the water out through the mesh to be recycled. The dewatering machine is purchased as part of the Mooge Tech Line.

Thermal Dryer

Unit ID: M-005	Main Shaft Diameter: 159 mm
Type: Friction Washer	Air Blowing Power: 7.4 hp
Pipe Material: 304 Stainless Steel	Heating Power: 48 hp
Costing Data: Table 17.1	

The thermal dryer uses hot air to remove moisture from the LDPE shreds. The plastic LDPE shreds are transported into the thermal dryer through a vacuum and the shreds mix with hot air. The shredded LDPE and hot air stream travels through the long set of stainless-steel tubing that winds back and forth. The LDPE is dehydrated through traveling through the long length, and the LDPE shreds then enter a cyclone separator that is mixes in cool air. The thermal dryer is purchased as part of the Mooge Tech Line.

15.2. Dissolution and Reprecipitation Vessels

Dissolution Vessel

Unit ID: V-101	Temperature: 185°F
Type: Ribbon Mixer	Pressure: 29.4 psia
Material: Carbon Steel	Volume: 275 ft^3
Specification Sheet: Section 16	Propeller Energy: 1.03 hp
Costing Data: Table 17.1	Design Calculations: 25.2.1

The dissolution vessel, modeled as a ribbon mixer for solids handling, takes the feed LDPE and mixes it with recycled toluene to dissolve the polymer while leaving most contaminants, around 1% of the feed, in a separate phase. The solution is 15% LDPE. The vessel is well-mixed and heated by the toluene, which arrives at a higher temperature than LDPE. Size calculations were based off a 30-minute residence time. For safety precautions, inert nitrogen will be pumped through the vessel and a flare will be used to vent the system. Its purchase cost is $70,804.

Precipitation Vessel

Unit ID: V-102	Temperature: 176°F
Type: Ribbon Mixer	Pressure: 29.4 psia
Material: Carbon Steel	Volume: 1045 ft^3
Specification Sheet: Section 16	Propeller Energy: 3.9 hp
Costing Data: Table 17.1	Design Calculations: 25.2.1

The precipitation vessel, also modeled as a ribbon mixer for solids handling, takes the LDPE-toluene solution and adds in recycled isopropanol (3 times the amount of toluene) to precipitate the polymer. Almost 100% of the LDPE precipitates into a solid phase, but for mass balance calculations it is assumed that 99% of the particles can then be separated. Less than 5% of the mass in this solution is polymer, so the viscosity is low. The temperature is lowered to increase precipitation and keep the nonsolvent from evaporating. Nitrogen and a flare vent are also used here. The cost of purchase is $157,548.

15.3. Heat Exchangers

Heat Exchanger 1

Unit ID: E-201	Temperature: 281.7 °F
Type: Counter-current Heat Exchanger	Pressure: 29.4 psia
Material: Carbon Steel	Area: 55.8 ft^2
Specification Sheet: Section 16	Heat Duty: 700,775 BTU/hr
Costing Data: Table 17.1	Design Calculations: Section 25.2.2

This unit of equipment is used to cool the bottoms stream from the distillation column (D-201) enough to regulate and maintain the temperature of the Solvent Feed Tank (see Section 14.1). More specifically, it is a counter-current, floating head heat exchanger with one shell pass that cools the liquid solvent recycle stream from 281.7°F to 208.6°F. The temperature of the cooling water increases from 90°F to 120°F. Using equations from Section 25.2.2, the heat transfer area required to meet this heat duty is 55.8 ft^2 using an LMTD of 139.0°F and a heat transfer coefficient estimated at 100 BTU/hr.ft^2.°F. Assuming a tube velocity if 6 ft/s and an outer tube diameter of ¾-inches (with 1-inch square pitch), there will need to be 8 tubes of length 20 feet. The number of passes per tube is required to be 2. The inner shell diameter is 8 inches. Carbon steel can be used as the material of construction for both the shell and tubes due to the relatively low temperature of the hot side inlet stream. The purchase cost of the heat exchanger is $23,571.

Heat Exchanger 2

Unit ID: E-202	Temperature: 208.6 °F
Type: Counter-current Heat Exchanger	Pressure: 29.4 psia
Material: Carbon Steel	Area: 217.9 ft^2
Specification Sheet: Section 16	Heat Duty: 1,751,648 BTU/hr
Costing Data: Table 17.1	Design Calculations: Section 25.2.2

This unit of equipment is used to cool the distillate stream from the distillation column enough to regulate and maintain the temperature of the Nonsolvent Feed Tank (see Section 14.1). More specifically, it is a counter-current, floating head heat exchanger with one shell pass that cools the liquid nonsolvent recycle stream from 203.9°F to 174.0°F. The temperature of the cooling water increases from 90°F to 120°F. Using equations from Section 25.2.2, a LMTD of 86.3 °F and a heat transfer coefficient estimated at 100 BTU/hr.ft^2.°F, the heat transfer area required to meet this heat duty is 217.9 ft^2. Assuming a tube velocity of 4 ft/s and an outer tube diameter of ¾-inches (with 1-inch square pitch), there will need to be 49 tubes of length 20 feet. The number of passes per tube is required to be 2. The inner shell diameter is 10 inches. Carbon steel can be used as the material of construction for both the shell and tubes due to the relatively low temperature of the hot side inlet stream. The purchase cost of the heat exchanger is $22,818.

Heat Exchanger 3

Unit ID: E-203	Temperature: 194.0 °F
Type: Counter-current Heat Exchanger	Pressure: 14.7 psia
Material: Carbon Steel	Area: 14.4 ft^2
Specification Sheet: Section 16	Heat Duty: 112,288 BTU/hr
Costing Data: Table 17.1	Design Calculations: Section 25.2.2

This unit of equipment is used to condense and cool the vapor stream coming from the dryer before entering the surge tank. More specifically, it is a counter-current, fixed head heat exchanger with one shell pass that cools the liquid nonsolvent recycle stream from 194.0°F to 174.0°F. The temperature of the cooling water increases from 90°F to 120°F. Using equations from Section 25.2.2, a LMTD of 79.8°F and a heat transfer coefficient estimated at 100 BTU/hr.ft^2.°F, the heat transfer area required to meet this heat duty is 14.4 ft^2. Assuming a tube velocity of 4 ft/s and an outer tube diameter of ¾-inches (with 1-inch square pitch), there will need to be 2 tubes of length 20 feet. The number of passes per tube is required to be 2. The inner shell diameter is 8 inches. Carbon steel can be used as the material of construction for both the shell and tubes due to the relatively low temperature of the hot side inlet stream. The purchase cost of the heat exchanger is $17,006.

Distillation Column Condenser

Unit ID: E-204	Temperature: 203.9 °F
Type: Counter-current Heat Exchanger	Pressure: 29.4 psia
Material: Carbon Steel	Area: 3641.7 ft^2
Specification Sheet: Section 16	Heat Duty: 35,738,969 BTU/hr
Costing Data: Table 17.1	Design Calculations: Section 25.2.2

This unit of equipment is used at the top of the distillation column (D-201) to completely condense the vapor leaving the top try to a liquid stream. More specifically, it is a counter-current, fixed head heat exchanger with one shell pass that condenses the vapor to liquid at 203.9°F. The temperature of the cooling water increases from 90°F to 120°F. Using equations from Section 25.2.2, a LMTD of 98.1°F and a heat transfer coefficient estimated at 100 BTU/hr.ft^2.°F, the heat transfer area required to meet this heat duty is 3641.7 ft^2. Assuming a tube velocity of 5 ft/s and an outer tube diameter of ¾-inches (with 1-inch square pitch), there will need to be 192 tubes of length 20 feet. The number of passes per tube is required to be 2. The inner shell diameter is 18 inches. Carbon steel can be used as the material of construction for both the shell and tubes due to the relatively low temperature of the hot side inlet stream. The purchase cost of the heat exchanger is $38,759.

Distillation Column Reboiler

Unit ID: E-205	Temperature: 281.7 °F
Type: Counter-current Heat Exchanger	Pressure: 29.4 psia
Material: Carbon Steel	Area: 3191.5 ft^2
Specification Sheet: Section 16	Heat Duty: 38,397,728 BTU/hr
Costing Data: Table 17.1	Design Calculations: Section 25.2.2

This unit of equipment is used at the bottom of the distillation column (D-201) to partially reboil the bottoms product back to the column. This partial Reboiler acts as the final equilibrium stage in the distillation column. It is a counter-current, kettle vaporizer heat exchanger with one shell pass that partially reboils the bottoms product at 281.7°F. High pressure steam at 150 psig is required. Carbon steel can be used as the material of construction due to the relatively low temperature of the hot side inlet stream. Assuming a maximum heat flux of 12000 BTU/hr.ft^2 to avoid film boiling, a heat transfer area required to meet this heat duty is 3191.5 ft^2. Assuming a tube velocity of 3 ft/s and an outer tube diameter of ¾-inches (with 1-inch square pitch), there will need to be 157 tubes of length 20 feet. The number of passes per tube is required to be 2. The inner shell diameter is 17 inches. Carbon steel can be used as the material of construction for both the shell and tubes due to the relatively low temperature of the hot side inlet stream. The purchase cost of the heat exchanger is $76,818.

15.4. Pumps

If it is not explicitly stated, each of the pumps are solely in place to compensate for any small pressure or head losses between major process components and through the piping system rather than for increasing pressure between components. In Section 16, the specification sheets use a 5 psig pressure increase between the inlet and the outlet to show some change between the two streams.

Mid Process Pump

Unit ID: P-101	Temperature: 185°F
Type: Pump	Pressure: 29.4 psia
Material: Carbon Steel	Work: 4.28 hp
Specification Sheet: Section 16	Head: 124 ft
Costing Data: Table 17.1	Design Calculations: Section 25.2.3-4

This pump requires slightly more head than the others in the back end process. It is used after the dissolution vessel, to split the outlet into three streams in parallel and send the solution through the filters. Extra costs are included for the more complex design of this pump. The pump efficiency is 48.5% and the electric motor efficiency is 83.8%. The purchase cost of the pump and motor are $13,710. A spare pump with an electric motor is included in the equipment costs to ensure continuous operation.

Pump 1

Unit ID: P-201	Temperature: 176.0°F
Type: Pump	Pressure: 29.4 psia
Material: Carbon Steel	Work: 9.05 hp
Specification Sheet: Section 16	Head: 100 ft
Costing Data: Table 17.1	Design Calculations: Section 25.2.3-4

This unit of equipment is used to pump the slurry from the precipitation vessel (V-102) to the Rotary Drum Vacuum Filter (F-201), which has a flow rate of 98,565 lb/hr. The pressure is to be maintained at 2 atmospheres, or 29.4 psia and is modeled to have a head of 100 feet to account for any pressure or head loss. This number was approved by industrial consultants and considered to be conservative. The pump will be VSC orientation with 1 stage, a shaft rpm of 3600 rpm and a maximum motor horsepower of 75. An electric motor with a power consumption of 9.05 hp is required to operate this pump. The pump has an efficiency of 64.1% and the electric motor has a motor efficiency of 85.8%. Carbon steel can be used as the material of construction due to the relatively low temperature of the inlet stream. The purchase cost of the pump and motor is $11,618. A spare pump with an electric motor is included in the equipment costs to ensure continuous operation.

Pump 2

Unit ID: P-202	Temperature: 176.0°F
Type: Pump	Pressure: 29.4 psia
Material: Carbon Steel	Work: 8.74 hp
Specification Sheet: Section 16	Head: 100 ft
Costing Data: Table 17.1	Design Calculations: Section 25.2.3-4

This unit of equipment is used to pump the liquid stream from the surge tank (V-203) to the distillation column (D-201), which has a flow rate of 94,440 lb/hr. The pressure is to be raised from one to two atmospheres (or from 14.7 to 29.4 psig) and is modeled to have a head of 100 feet to account for this pressure change and other pressure or head losses. This number was approved by industrial consultants and considered to be conservative. The pump will be VSC orientation with 1 stage, a shaft rpm of 3600 rpm and a maximum motor horsepower of 75. An electric motor with a power consumption of 8.74 hp is required to operate this pump. The pump has an efficiency of 63.7% and the electric motor has a motor efficiency of 85.7%. Carbon steel can be used as the material of construction due the relatively low temperature of the inlet stream. The purchase cost of the pump and motor is $11,518. A spare pump with an electric motor is included in the equipment costs to ensure continuous operation.

Pump 3

Unit ID: P-203	Temperature: 203.9°F
Type: Pump	Pressure: 29.4 psia
Material: Carbon Steel	Work: 6.91 hp
Specification Sheet: Section 16	Head: 100 ft
Costing Data: Table 17.1	Design Calculations: Section 25.2.3-4

This unit of equipment is used to pump the liquid distillate stream from the distillation column (D-201) after the nonsolvent purge to the nonsolvent feed tank (V-202), which has a flow rate of 70,744 lb/hr. The pressure is to be maintained at two atmospheres, or 29.4 psia and is modeled to have a head of 100 feet to account for any other pressure or head losses. This number was approved by industrial consultants and considered to be conservative. The pump will be VSC orientation with 1 stage, a shaft rpm of 3600 rpm and a maximum motor horsepower of 75. An electric motor with a power consumption of 6.91 hp is required to operate this pump. The pump has an efficiency of 60.8% and the electric motor has a motor efficiency of 85.1%. Carbon steel can be used as the material of construction due the relatively low temperature of the inlet stream. The purchase cost of the pump and motor is $10,970.

Pump 4

Unit ID: P-204	Temperature: 173.8°F
Type: Pump	Pressure: 29.4 psia
Material: Carbon Steel	Work: 6.92 hp
Specification Sheet: Section 16	Head: 100 ft
Costing Data: Table 17.1	Design Calculations: Section 25.2.3-4

This unit of equipment is used to pump the liquid stream from the nonsolvent purge to the nonsolvent feed tank (V-202) to the precipitation vessel (V-102), which has a flow rate of 70,815 lb/hr. The pressure is to be maintained at two atmospheres, or 29.4 psia and is modeled to have a head of 100 feet to account for any other pressure or head losses. This number was approved by industrial consultants and considered to be conservative. The pump will be VSC orientation with 1 stage, a shaft rpm of 3600 rpm and a maximum motor horsepower of 75. An electric motor with a power consumption of 6.92 hp is required to operate this pump. The pump has an efficiency of 60.8% and the electric motor has a motor efficiency of 85.1%. Carbon steel can be used as the material of construction due the relatively low temperature of the inlet stream. The purchase cost of the pump and motor is $10,971. A spare pump with an electric motor is included in the equipment costs to ensure continuous operation for pumps P-203 and P-204.

Pump 5

Unit ID: P-205	Temperature: 208.6°F
Type: Pump	Pressure: 29.4 psia
Material: Carbon Steel	Work: 3.18 hp
Specification Sheet: Section 16	Head: 100 ft
Costing Data: Table 17.1	Design Calculations: Section 25.2.3-4

This unit of equipment is used to pump the liquid bottoms stream from the distillation column (D-201) after the solvent purge stream to the solvent feed tank (V-201), which has a flow rate of 23,601 lb/hr. The pressure is to be maintained at two atmospheres, or 29.4 psia and is modeled to have a head of 100 feet to account for any other pressure or head losses. This number was approved by industrial consultants and considered to be conservative. The pump will be VSC orientation with 1 stage, a shaft rpm of 3600 rpm and a maximum motor horsepower of 75. An electric motor with a power consumption of 3.18 hp is required to operate this pump. The pump has an efficiency of 45.2% and the electric motor has a motor efficiency of 82.9%. Carbon steel can be used as the material of construction due the relatively low temperature of the inlet stream. The purchase cost of the pump and motor is $10,276.

Pump 6

Unit ID: P-206	Temperature: 208.4°F
Type: Pump	Pressure: 29.4 psia
Material: Carbon Steel	Work: 3.18 hp
Specification Sheet: Section 16	Head: 100 ft
Costing Data: Table 17.1	Design Calculations: Section 25.2.3-4

This unit of equipment is used to pump the liquid stream from the solvent purge stream to the dissolution vessel (V-101), which has a flow rate of 23,625 lb/hr. The pressure is to be maintained at two atmospheres, or 29.4 psia and is modeled to have a head of 100 feet to account for any other pressure or head losses. This number was approved by industrial consultants and considered to be conservative. The pump will be VSC orientation with 1 stage, a shaft rpm of 3600 rpm and a maximum motor horsepower of 75. An electric motor with a power consumption of 3.18 hp is required to operate this pump. The pump has an efficiency of 45.2% and the electric motor has a motor efficiency of 82.9%. Carbon steel can be used as the material of construction due the relatively low temperature of the inlet stream. The purchase cost of the pump and motor is $10,276. A spare pump with an electric motor is included in the equipment costs to ensure continuous operation for pumps P-205 and P-206.

<u>Distillation Column Reboiler Pump</u>

Unit ID: P-207	Temperature: 281.7°F
Type: 1 Stage, VSC, 3600 Shaft rpm Pump	Pressure: 29.4 psia
Material: Carbon Steel	Work: 20.83 hp
Specification Sheet: Section 16	Head: 100 ft
Costing Data: Table 17.1	Design Calculations: Section 25.2.3-4

This unit of equipment is used to pump the liquid bottoms stream from the distillation column (D-201) to the partial Reboiler (E-205), which has a flow rate of 264,482 lb/hr as modeled by Aspen. The pressure is to be maintained at two atmospheres, or 29.4 psia and is modeled to have a head of 100 feet to account for any other pressure or head losses. This number was approved by industrial consultants and considered to be conservative. The pump will be VSC orientation with 1 stage, a shaft rpm of 3600 rpm and a maximum motor horsepower of 75. An electric motor with a power consumption of 20.83 hp is required to operate this pump. The pump has an efficiency of 73.1% and the electric motor has a motor efficiency of 87.7%. Carbon steel can be used as the material of construction due the relatively low temperature of the inlet stream. The purchase cost of the pump and motor is $15,430.

Distillation Column Reflux Pump

Unit ID: P-208	Temperature: 203.9°F
Type: 1 Stage, VSC, 3600 Shaft rpm Pump	Pressure: 29.4 psia
Material: Carbon Steel	Work: 6.74 hp
Specification Sheet: Section 16	Head: 100 ft
Costing Data: Table 17.1	Design Calculations: Section 25.2.3-4

This unit of equipment is used to pump the liquid distillate reflux stream from the reflux accumulator (V-204) to the distillation column (D-201), which has a flow rate of 70,378 lb/hr as modeled by Aspen. The pressure is to be maintained at two atmospheres, or 29.4 psia and is modeled to have a head of 100 feet to account for any other pressure or head losses. This number was approved by industrial consultants and considered to be conservative. The pump will be VSC orientation with 1 stage, a shaft rpm of 3600 rpm and a maximum motor horsepower of 75. An electric motor with a power consumption of 6.74 hp is required to operate this pump. The pump has an efficiency of 72.1% and the electric motor has a motor efficiency of 85.0%. Carbon steel can be used as the material of construction due the relatively low temperature of the inlet stream. The purchase cost of the pump and motor is $11,141.

15.5. Horizontal Pressure Vessels/Tanks and Storage Bin

Solvent Feed Tank

Unit ID: V-201	Temperature: 208.4°F
Type: Horizontal Surge Tank	Pressure: 29.4 psia
Material: Carbon Steel	Diameter: 12 ft
Specification Sheet: Section 16	Length: 24 ft
Design Calculations: Section 25.2.5	Agitator Work: 10 hp
Costing Data: Table 17.1	

This unit of equipment is used to provide intermediate storage from the solvent recycle stream; therefore, the dissolution vessel (V-101) can continue to run if part of the process is down. The surge tank is modeled to have a residence time of 3 hours and to be half-full for safety. Using the time capacity of three hours and the safety factor of 2, the volume of the tank will be 2,619 ft^2 (19,591 gal). Assuming an L/D ratio of 2, the diameter will be 12 feet and the length will be 24 feet. The tank will be made of carbon steel with a thickness of 0.625 inches. A turbine agitator that requires 10 hp of work will be included in the tank and the tank will be pressurized to 29.4 psia and maintained at 208.4°F (see Section 14.1). The purchase cost of the tank and agitator is $72,576.

<u>Nonsolvent Feed Tank</u>

Unit ID: V-202	Temperature: 173.8°F
Type: Horizontal Surge Tank	Pressure: 29.4 psia
Material: Carbon Steel	Diameter: 18 ft
Specification Sheet: Section 16	Length: 36 ft
Design Calculations: Section 25.2.5	Agitator Work: 33 hp
Costing Data: Table 17.1	

This unit of equipment is used to provide intermediate storage from the nonsolvent recycle stream; therefore, the precipitation vessel (V-102) can continue to run if part of the process is down. The surge tank is modeled to have a residence time of 3 hours and to be half-full for safety. Using the time capacity of three hours and the safety factor of 2, the volume of the tank will be 8,659 ft^2 (64,773 gal). Assuming an L/D ratio of 2, the diameter will be 18 feet and the length will be 36 feet. The tank will be made of carbon steel with a thickness of 0.625 inches. A turbine agitator that requires 33 hp of work will be included in the tank and the tank will be pressurized to 29.4 psia and maintained at 173.8°F (see Section 14.1). The purchase cost of the tank and agitator is $121,700.

<u>Surge Tank after Filter and Dryer</u>

Unit ID: V-203	Temperature: 176°F
Type: Horizontal Surge Tank	Pressure: 14.7 psia
Material: Carbon Steel	Diameter: 19 ft
Specification Sheet: Section 16	Length: 38 ft
Design Calculations: Section 25.2.5	Agitator Work: 43 hp
Costing Data: Table 17.1	

This unit of equipment is used to provide intermediate storage from solvent/nonsolvent streams from the filter (F-201) and dryer (H-201); therefore, the distillation column (D-201) can continue to run if part of the process is down. The surge tank is modeled to have a residence time of 3 hours and to be half-full for safety. Using the time capacity of three hours and the safety factor of 2, the volume of the tank will be 11,548 ft^2 (86,385 gal). Assuming an L/D ratio of 2, the diameter will be 19 feet and the length will be

38 feet. The tank will be made of carbon steel with a thickness of 0.625 inches. A turbine agitator that requires 43 hp of work will be included in the tank and the tank will be held at atmospheric pressure and at 176°F (see Section 14.1). The purchase cost of the tank and agitator is $137,632.

Reflux Accumulator

Unit ID: V-204	Temperature: 203.9°F
Type: Horizontal Surge Tank	Pressure: 29.4 psia
Material: Carbon Steel	Diameter: 7 ft
Specification Sheet: Section 16	Length: 14 ft
Costing Data: Table 17.1	Design Calculations: Section 25.2.5

This unit of equipment is used to provide the distillation column reflux and nonsolvent recycle streams the proper volume. The reflux accumulator is modeled to have a residence time of 5 minutes and to be half-full for safety. Using the time capacity of 5 minutes and the safety factor of 2, the volume of the tank will be 541 ft^2 (4,047 gal). Assuming an L/D ratio of 2, the diameter will be 7 feet and the length will be 14 feet. The tank will be made of carbon steel with a thickness of 0.625 inches. The vessel will be pressurized to 2 atmospheres, or 29.4 psia, and maintained at 176°F. The purchase cost of the tank is $30,775.

LDPE Storage Bin

Unit ID: B-201	Temperature: 100°F
Type: Solid Storage Bin	Pressure: 14.7 psia
Material: Carbon Steel	Cross-Sectional Areas: Top (588 ft^2), Ground (392 ft^2)
Specification Sheet: Section 16	Height and Thickness: 28 ft, 42 ft
Costing Data: Table 17.1	Design Calculations: Section 25.2.6

This unit of equipment is used to store the LDPE product coming out of the dryer (H-201). The storage bin is modeled to have a holding capacity of 7 days. Using the time capacity of 7 days, the volume of the storage bin will be 12,805 ft^2 (95,788 gal). Design calculations for the appropriate dimensions are found in Section 25.2.6. The bin will be made of carbon steel with a thickness of 0.625 inches. The purchase cost of the storage bin is $54,403.

15.6. Distillation Column

Distillation Column

Unit ID: D-201	Temperature: Bottoms (281.7°F), Distillate (203.9°F)
Type: Distillation Column	Pressure: 29.4 psia
Material: Carbon Steel	Diameter: 12 ft
Specification Sheet: Section 16	Height: 60 ft
Costing Data: Table 17.1	Design Calculations: Section 25.2.7

This unit of equipment is used to separate the solvent (toluene) from the nonsolvent (isopropanol) for the purpose of recycling both and reducing fresh solvent and nonsolvent costs. The feed stream enters the column at a rate of 94,440 lb/hr, a temperature of 176°F and a pressure of 29.4 psia. The distillate stream leaving the top of the column is vapor sent to a total condenser (E-204) and the bottoms stream is liquid being sent to a partial reboiler (E-205). The distillation column was modeled using ASPEN with 25 equilibrium stages resulting in a reflux ratio of 0.99383 and column diameter of 12 feet. The number of trays used was 24 resulting in a height of 60 feet (4 feet added for sump space and 10 feet added for headspace) and a thickness of 0.625 inches. The condenser pressure and reboiler pressure were maintained at equal 29.4 psia pressures resulting in a negligible pressure drop across the column. All parts of the column will be made out of carbon steel. The reflux accumulator (V-204), reflux pump (P-208), total condenser (E-204), partial reboiler (E-205) and reboiler pump (P-209) were all modeled using results from the distillation column. The purchase cost of the distillation column is $305,889.

15.7. Filters

Ettlinger Filters

Unit ID: F-101	Temperature: 185°F
Type: Continuous Melt Filter	Pressure: 29.4 psia
Costing Data: Table 17.1	Filter Size: 50 μm

Between the dissolution and precipitation vessels, the LDPE-toluene solution is divided into three streams. These run in parallel through the three Ettlinger filters, which are the company's highest capacity product. In total, 41.7 lb/hr of undissolved contaminants from the feed are expelled from the system and disposed of as impurities. From the manufacturer, the purchase cost of a filter is approximately $260,000 and three are required for continuous operation. Though maintenance is low, a fourth filter will be purchased as a spare and is included in the equipment costs.

Rotary-Drum Vacuum Filter

Unit ID: F-201	Temperature: 176°F
Type: Distillation Column	Pressure: 29.4 psia
Material: Carbon Steel	Diameter: 8 ft
Specification Sheet: Section 16	Length: 10 ft
Design Calculations: Section 25.2.8	Power Requirement: 10 hp
Costing Data: Table 17.1	

The unit of equipment is used to filter the stream leaving the precipitation vessel (V-101), which has a flow rate of 98,565 lb/hr. It is designed to remove the solid LDPE granules from the solvent/nonsolvent liquid mixture. The rotary-drum is modeled with an eight-foot diameter and a ten-foot length resulting in a total filter area of 251 ft^2. The vacuum system will be pulling the liquid at 14.7 psia compared to the 29.4 psia of the rotary-drum. The drum requires an estimate 10 hp to operate. For safety, the rotary-drum vacuum filter will be contained – free from exposure to the atmosphere. The purchase cost of the filter is $272,457.

15.8. Dryers

Indirect-heat Steam Tube Rotary Dryers

Unit ID: H-201	Temperature: 194°F
Type: Indirect-heated Dryer	Pressure: 7.4 psia
Material: Carbon Steel	Length: 20 ft
Specification Sheet: Section 16	Heat Transfer Mechanism: 14 144-mm diameter tubes
Design Calculations: Section 25.2.9	Heat Duty: 66,317 BTU/hr
Costing Data: Table 17.1	Power Requirement: 2.2 hp

This unit of equipment is used to dry and remove any remaining solvent and nonsolvent contamination from the final LDPE solid product. The input flow rate is 4167 lb/hr. Modeled from the Perry's Chemical Engineers' Handbook, the mechanism of heat transfer will be 14 144-mm diameter tubes carrying low pressure 50 psig steam with a 20-foot length, which results in a total heat transfer area of 353 ft^2. The temperature of the stream entering the dryer will be 176°F and will increase to 194°F. For safety, an indirect-heat steam tube rotary dryer was selected because the solvent and nonsolvent have strict flammability limits when exposed to the atmosphere. The dryer will operate at a vacuum pressure of 7.4 psia to lower the boiling points of the solvent and nonsolvent to limit the heat duty. The purchase cost of the indirect-heat steam tube rotary dryer is $180,119.

16 Specification Sheets

DISSOLUTION VESSEL				
Identification: Item: Dissolution Vessel; Item No.: V-101; No. requried: 1			Date: *16 April 2019*	By: *PJC*
Function: Dissolve LDPE polymer in toluene solvent.				
Operation: Continuous				
Materials Handled:		Inlet 1	Inlet 2	Outlet
Stream ID		1	2	3
Temperature (°F)		77.0	208.4	185.0
Pressure (psia)		14.7	29.4	29.4
Vapor Fraction		0	0	0
Mass Flow (lb/hr)		4167.0	23624.7	27791.7
Molar Flow (lbmol/hr)		148.6	257.5	406.1
Component Mass Flow (lb/hr)				
	Low Density Polyethylene	4124.9	41.6	4166.5
	Toluene	-	23576.0	23576.0
	Isopropanol	-	7.1	7.1
	Pigments and Dyes	42.1	0	42.1
	Water	-	-	-

Design Data:
Type: Ribbon Mixer for solids handling
Material of Construction: Carbon Steel
Residence Time: 30 min
Pressure: 29.4 psia
Temperature: 185.0°F
Total Storage Volume: 275 cuft (2,057 gal)
Agitator Type: Propeller
Power Consumption: 1.01 hp

Utilities: 0.77 kW-hr per hour of Electricity

Comments: See Section 12 Process Flow Diagram

PRECIPITATION VESSEL

Identification:	Item	Precipitation Vessel		Date: *16 April 2019*
	Item No.	V-102		
	No. requried	1		By: *PJC*

Function: Precipiate LDPE polymer toluene solvent solution by adding isopropanol nonsolvent.

Operation: Continuous

Materials Handled:	Inlet 1	Inlet 2	Outlet
Stream ID	19	5	6
Temperature (°F)	185.0	173.8	176.0
Pressure (psia)	29.4	29.4	29.4
Vapor Fraction	0	0	0
Mass Flow (lb/hr)	27750.0	70815.0	
Molar Flow (lbmol/hr)	404.6	1178.4	
Component Mass Flow (lb/hr)			
Low Density Polyethylene	4166.5	-	4166.5
Toluene	23576.0	21.2	23597.2
Isopropanol	7.1	70793.8	70800.9
Pigments and Dyes	0.4	-	0.4
Water	-	-	-

Design Data:
Type: Ribbon Mixer for solids handling
Material of Construction: Carbon Steel
Residence Time: 30 min
Pressure: 29.4 psia
Temperature: 176.0°F
Total Storage Volume: 1,045 cuft (7,817 gal)
Agitator Type: Propeller
Power Consumption: 3.9 hp

Utilities: 2.91 kW-hr per hour of Electricity

Comments: See Section 12 Process Flow Diagram

HEAT EXCHANGER 1

Identification:	Item	Heat Exchanger 1		Date: *16 April 2019*		
	Item No.	E-201				
	No. requried	1		By: *PJC*		
Function: Cool Solvent Recycle stream with cooling water before Solvent Feed Tank.						
Operation: Continuous						
Materials Handled:			Cold In	Cold Out	Hot In	Hot Out
Stream ID			-	-	22	14
Temperature (°F)			90	120	281.7	208.6
Pressure (psia)			14.7	14.7	29.4	29.4
Vapor Fraction			0	0	0	0
Mass Flow (lb/hr)			23336	23336	23601.0	23601.0
Molar Flow (lbmol/hr)			1295	1295	257.2	257.2
Component Mass Flow (lb/hr)						
	Low Density Polyethylene		-	-	41.6	41.6
	Toluene		-	-	23552.4	23552.4
	Isopropanol		-	-	7.1	7.1
	Pigments and Dyes		-	-	0	0
	Water		23336	23336	-	-

Design Data:
Type: Shell-in-Tube, Floating Head
Effective Surface Area: 55.8 sqft
LMTD: 139.0°F
Heat Duty: 700,775 BTU/hr
Heat Transfer Coefficient: 100 BTU/hr.sqft.°F
Tube Side Material of Construction: Carbon Steel
Shell Side Material of Construction: Carbon Steel
No. of Tubes/pass: 8
Tube Length: 20 ft
No. of Tube Passes: 2
Shell Diameter: 8 in

Utilities: 23336 lb/hr (2,805 gal/hr) of Cooling Water

Comments: See Section 12 Process Flow Diagram

HEAT EXCHANGER 2

Identification:	Item	Heat Exchanger 2		Date: *16 April 2019*		
	Item No.	E-202				
	No. requried	1		By: *PJC*		
Function: Cool Nonsolvent Recycle stream with cooling water before Nonsolvent Feed Tank.						
Operation: Continuous						
Materials Handled:			Cold In	Cold Out	Hot In	Hot Out
Stream ID			-	-	17	23
Temperature (°F)			90	120	208.6	174.0
Pressure (psia)			14.7	14.7	29.4	29.4
Vapor Fraction			0	0	0	0
Mass Flow (lb/hr)			58330	58330	70744.2	70744.2
Molar Flow (lbmol/hr)			3237	3237	1177.2	1177.2
Component Mass Flow (lb/hr)						
	Low Density Polyethylene		-	-	-	-
	Toluene		-	-	21.2	21.2
	Isopropanol		-	-	70723.0	70723.0
	Pigments and Dyes		-	-	-	-
	Water		58330	58330	-	-

Design Data:
Type: Shell-in-Tube, Floating Head
Effective Surface Area: 217.9 sqft
LMTD: 86.3°F
Heat Duty: 1,751,648 BTU/hr
Heat Transfer Coefficient: 100 BTU/hr.sqft.°F
Tube Side Material of Construction: Carbon Steel
Shell Side Material of Construction: Carbon Steel
No. of Tubes/pass: 49
Tube Length: 20 ft
No. of Tube Passes: 2
Shell Diameter: 10 in

Utilities: 58,330 lb/hr (7,010 gal/hr) of Cooling Water

Comments: See Section 12 Process Flow Diagram

HEAT EXCHANGER 3

Identification:	Item	Heat Exchanger 3			Date: *16 April 2019*	
	Item No.	E-203				
	No. requried	1			By: *PJC*	
Function: Cool and condense the vapor stream from the dryer before entering the surge tank.						
Operation: Continuous						
Materials Handled:			Cold In	Cold Out	Hot In	Hot Out
Stream ID			-	-	9	21
Temperature (°F)			90	120	194.0	176.0
Pressure (psia)			14.7	14.7	7.4	14.7
Vapor Fraction			0	0	0	0
Mass Flow (lb/hr)			3739	3739	458.6	458.6
Molar Flow (lbmol/hr)			207	207	7	7
Component Mass Flow (lb/hr)						
Low Density Polyethylene			-	-	-	-
Toluene			-	-	114.2	114.2
Isopropanol			-	-	344.4	344.4
Pigments and Dyes			-	-	-	-
Water			3739	3739	-	-

Design Data: Type: Shell-in-Tube, Fixed Head
Effective Surface Area: 14.4 sqft
LMTD: 79.8°F
Heat Duty: 112,288 BTU/hr
Heat Transfer Coefficient: 100 BTU/hr.sqft.°F
Tube Side Material of Construction: Carbon Steel
Shell Side Material of Construction: Carbon Steel
No. of Tubes/pass: 2
Tube Length: 20 ft
No. of Tube Passes: 2
Shell Diameter: 8 in

Utilities: 3,739 lb/hr (449 gal/hr) of Cooling Water

Comments: See Section 12 Process Flow Diagram

DISTILLATION COLUMN CONDENSER

Identification:	Item	Distillation Column Condenser		Date: *16 April 2019*		
	Item No.	E-204				
	No. requried	1		By: *PJC*		

Function: Condense the vapor distillate stream coming from the distillation column

Operation: Continuous

Materials Handled:	Cold In	Cold Out	Hot In	Hot Out
Stream ID	-	-	-	-
Temperature (°F)	90	120	203.9	203.9
Pressure (psia)	14.7	14.7	29.4	29.4
Vapor Fraction	0	0	1	0
Mass Flow (lb/hr)	1190109	1190109	141193.1	141193.1
Molar Flow (lbmol/hr)	66044	66044	2346.3	2346.3
Component Mass Flow (lb/hr)				
Low Density Polyethylene	-	-	-	-
Toluene	-	-	42.3	42.3
Isopropanol	-	-	141150.8	141150.8
Pigments and Dyes	-	-	-	-
Water	1190109	1190109	-	-

Design Data:
Type: Shell-in-Tube, Fixed Head
Effective Surface Area: 3641.7 sqft
LMTD: 98.1°F
Heat Duty: 35,738,969 BTU/hr
Heat Transfer Coefficient: 100 BTU/hr.sqft.°F
Tube Side Material of Construction: Carbon Steel
Shell Side Material of Construction: Carbon Steel
No. of Tubes/pass: 192
Tube Length: 20 ft
No. of Tube Passes: 2
Shell Diameter: 18 in

Utilities: 1,190,109 lb/hr (143,035 gal/hr) of Cooling Water

Comments: See Section 12 Process Flow Diagram

DISTILLATION COLUMN REBOILER

Identification:	Item	Distillation Column Reboiler	Date: *16 April 2019*
	Item No.	E-205	
	No. requried	1	By: *PJC*

Function: Partially reboil the bottoms from the distillation column.

Operation: Continuous

Materials Handled:	Hot In	Hot Out	Cold In	Cold Out 1	Cold Out 2
Stream ID	-	-	-	-	12
Temperature (°F)	326.7	326.7	281.7	281.7	281.7
Pressure (psia)	164.7	164.7	29.4	29.4	29.4
Vapor Fraction	1	0	0	1	0
Mass Flow (lb/hr)	42034	42034	264482.0	240898.9	23624.8
Molar Flow (lbmol/hr)	2332.6	2332.6	2935.1	2677.6	257.5
Component Mass Flow (lb/hr)					
Low Density Polyethylene	-	-	41.7	-	41.7
Toluene	-	-	253298.6	229722.6	23576.0
Isopropanol	-	-	11183.4	11176.3	7.1
Pigments and Dyes	-	-	0	-	0
Water (Steam)	42034	42034	-	-	-

Design Data: Type: Kettle Vaporizer
Effective Surface Area: 3191.5 sqft
Heat Duty: 38,397,728 BTU/hr
Heat Flux: 12,000 BTU/hr.sqft
Tube Side Material of Construction: Carbon Steel
Shell Side Material of Construction: Carbon Steel
No. of Tubes/pass: 157
Tube Length: 20 ft
No. of Tube Passes: 2
Shell Diameter: 17 in

Utilities: 42,034 lb/hr of 150 psig steam

Comments: See Section 12 Process Flow Diagram. Cold Out 1 sent back to distillation column, Cold Out 2 is solvent recycle stream.

MID PROCESS PUMP

Identification:	Item	Mid Process Pump	Date: *16 April 2019*	
	Item No.	P-101		
	No. requried	2 (includes Spare)	By: *PJC*	

Function: Pump stream from dissolution vessel to Ettlinger filters in parallel.

Operation: Continuous

Materials Handled:	Inlet	Outlet
Stream ID	3	3
Temperature (°F)	185.0	185.0
Pressure (psia)	28.9	29.4
Vapor Fraction	0	0
Mass Flow (lb/hr)	27791.7	27791.7
Molar Flow (lbmol/hr)	406.1	406.1
Component Mass Flow (lb/hr)		
Low Density Polyethylene	4166.5	4166.5
Toluene	23576.0	23576.0
Isopropanol	7.1	7.1
Pigments and Dyes	42.1	42.1
Water	-	-

Design Data:
Type: Centrifugal Pump
Orientation: VSC
Shaft rpm: 3600
Material of Construction: Carbon Steel
Maximum Motor Horsepower: 75 hp
Motor Type: Explosion-Proof
Power Consumption: 4.28 hp
Pump Efficiency: 48.5%
Motor Efficiency: 83.8%
Head: 124 ft
Flow Rate: 62.7 gpm

Utilities: 3.21 kW-hr per hour of Electricity

Comments: See Section 12 Process Flow Diagram. Additional head is required to split the outlt into three streams in parallel.

PUMP 1

Identification:	Item	Pump 1	Date: *16 April 2019*
	Item No.	P-201	
	No. requried	2 (includes Spare)	By: *PJC*

Function: Move slurry from precipitation vessel to rotary-drum vacuum filter and maintain pressure.

Operation: Continuous

Materials Handled:	Inlet	Outlet
Stream ID	6	6
Temperature (°F)	176.0	176.0
Pressure (psia)	28.9	29.4
Vapor Fraction	0	0
Mass Flow (lb/hr)	98565.0	98565.0
Molar Flow (lbmol/hr)	1583.0	1583.0
Component Mass Flow (lb/hr)		
Low Density Polyethylene	4166.5	4166.5
Toluene	23597.2	23597.2
Isopropanol	70800.9	70800.9
Pigments and Dyes	0.4	0.4
Water	-	-

Design Data:
Type: Centrifugal Pump
Orientation: VSC
Shaft rpm: 3600
Material of Construction: Carbon Steel
Maximum Motor Horsepower: 75 hp
Motor Type: Explosion-Proof
Power Consumption: 9.05 hp
Pump Efficiency: 64.1%
Motor Efficiency: 85.8%
Head: 100 ft
Flow Rate: 242.6 gpm

Utilities: 6.79 kW-hr per hour of Electricity

Comments: See Section 12 Process Flow Diagram, a 5 psig increase is an approximation for potential head loss to show difference between inlet and outlet.

PUMP 2

Identification:	Item: Pump 2 Item No.: P-202 No. requried: 2 (includes Spare)		Date: *16 April 2019* By: *PJC*
Function: Pump stream from surge tank to dissolution vessel and raise pressure.			
Operation: Continuous			
Materials Handled:		Inlet	Outlet
Stream ID		8	8
Temperature (°F)		176.0	176.0
Pressure (psia)		14.7	29.4
Vapor Fraction		0	0
Mass Flow (lb/hr)		94439.8	94439.8
Molar Flow (lbmol/hr)		1435.8	1435.8
Component Mass Flow (lb/hr)			
	Low Density Polyethylene	41.7	41.7
	Toluene	23597.2	23597.2
	Isopropanol	70800.9	70800.9
	Pigments and Dyes	0	0
	Water	-	-

Design Data:
Type: Centrifugal Pump
Orientation: VSC
Shaft rpm: 3600
Material of Construction: Carbon Steel
Maximum Motor Horsepower: 75 hp
Motor Type: Explosion-Proof
Power Consumption: 8.74 hp
Pump Efficiency: 63.7%
Motor Efficiency: 85.7%
Head: 100 ft
Flow Rate: 232.9 gpm

Utilities: 6.56 kW-hr per hour of Electricity

Comments: See Section 12 Process Flow Diagram.

PUMP 3

Identification:	Item	Pump 3	Date: *16 April 2019*
	Item No.	P-203	
	No. requried	1	By: *PJC*

Function: Pump distillate stream from distillation column to nonsolvent feed tank and maintain pressure.

Operation: Continuous

Materials Handled:	Inlet	Outlet
Stream ID	17	17
Temperature (°F)	203.9	203.9
Pressure (psia)	28.9	29.4
Vapor Fraction	0	0
Mass Flow (lb/hr)	70744.2	70744.2
Molar Flow (lbmol/hr)	1177.2	1177.2
Component Mass Flow (lb/hr)		
Low Density Polyethylene	-	-
Toluene	21.2	21.2
Isopropanol	70723.0	70723.0
Pigments and Dyes	-	-
Water	-	-

Design Data:
Type: Centrifugal Pump
Orientation: VSC
Shaft rpm: 3600
Material of Construction: Carbon Steel
Maximum Motor Horsepower: 75 hp
Motor Type: Explosion-Proof
Power Consumption: 6.91 hp
Pump Efficiency: 60.8%
Motor Efficiency: 85.1%
Head: 100 ft
Flow Rate: 179.7 gpm

Utilities: 5.19 kW-hr per hour of Electricity

Comments: See Section 12 Process Flow Diagram, a 5 psig increase is an approximation for potential head loss to show difference between inlet and outlet.

PUMP 4

Identification:	Item	Pump 4	Date: *16 April 2019*
	Item No.	P-204	
	No. requried	2 (includes Spare)	By: *PJC*

Function: Pump stream from nonsolvent feed tank to precipitation vessel and maintain pressure.

Operation: Continuous

Materials Handled:	Inlet	Outlet
Stream ID	5	5
Temperature (°F)	173.8	173.8
Pressure (psia)	28.9	29.4
Vapor Fraction	0	0
Mass Flow (lb/hr)	70815.0	70815.0
Molar Flow (lbmol/hr)	1178.4	1178.4
Component Mass Flow (lb/hr)		
Low Density Polyethylene	-	-
Toluene	21.2	21.2
Isopropanol	70793.8	70793.8
Pigments and Dyes	-	-
Water	-	-

Design Data:
Type: Centrifugal Pump
Orientation: VSC
Shaft rpm: 3600
Material of Construction: Carbon Steel
Maximum Motor Horsepower: 75 hp
Motor Type: Explosion-Proof
Power Consumption: 6.92 hp
Pump Efficiency: 60.8%
Motor Efficiency: 85.1%
Head: 100 ft
Flow Rate: 179.9 gpm

Utilities: 5.19 kW-hr per hour of Electricity

Comments: See Section 12 Process Flow Diagram, a 5 psig increase is an approximation for potential head loss to show difference between inlet and outlet.

PUMP 5

Identification:	Item	Pump 5	Date: *16 April 2019*
	Item No.	P-205	
	No. requried	1	By: *PJC*

Function: Pump bottoms stream from distillation column to solvent feed tank and maintain pressure.

Operation: Continuous

Materials Handled:	Inlet	Outlet
Stream ID	14	14
Temperature (°F)	208.6	208.6
Pressure (psia)	28.9	29.4
Vapor Fraction	0	0
Mass Flow (lb/hr)	23601.0	23601.0
Molar Flow (lbmol/hr)	257.2	257.2
Component Mass Flow (lb/hr)		
Low Density Polyethylene	41.6	41.6
Toluene	23552.4	23552.4
Isopropanol	7.1	7.1
Pigments and Dyes	0	0
Water	-	-

Design Data:
Type: Centrifugal Pump
Orientation: VSC
Shaft rpm: 3600
Material of Construction: Carbon Steel
Maximum Motor Horsepower: 75 hp
Motor Type: Explosion-Proof
Power Consumption: 3.19 hp
Pump Efficiency: 45.2%
Motor Efficiency: 82.9%
Head: 100 ft
Flow Rate: 54.4 gpm

Utilities: 2.39 kW-hr of per hour of Electricity

Comments: See Section 12 Process Flow Diagram, a 5 psig increase is an approximation for potential head loss to show difference between inlet and outlet.

PUMP 6

Identification:	Item	Pump 6	Date: *16 April 2019*
	Item No.	P-206	
	No. requried	2 (includes Spare)	By: *PJC*

Function: Pump stream from solvent feed tank to dissolution vessel and maintain pressure.

Operation: Continuous

Materials Handled:	Inlet	Outlet
Stream ID	2	2
Temperature (°F)	208.4	208.4
Pressure (psia)	28.9	29.4
Vapor Fraction	0	0
Mass Flow (lb/hr)	23624.7	23624.7
Molar Flow (lbmol/hr)	257.5	257.5
Component Mass Flow (lb/hr)		
Low Density Polyethylene	41.6	41.6
Toluene	23576.0	23576.0
Isopropanol	7.1	7.1
Pigments and Dyes	0	0
Water	-	-

Design Data:
Type: Centrifugal Pump
Orientation: VSC
Shaft rpm: 3600
Material of Construction: Carbon Steel
Maximum Motor Horsepower: 75 hp
Motor Type: Explosion-Proof
Power Consumption: 3.18 hp
Pump Efficiency: 45.2%
Motor Efficiency: 82.9%
Head: 100 ft
Flow Rate: 54.4 gpm

Utilities: 2.39 kW-hr per hour of Electricity

Comments: See Section 12 Process Flow Diagram, a 5 psig increase is an approximation for potential head loss to show difference between inlet and outlet.

DISTILLATION COLUMN REBOILER PUMP

Identification:	Item	Distillation Column Reboiler Pump	Date: *16 April 2019*
	Item No.	P-207	
	No. requried	1	By: *PJC*

Function: Pump stream leaving bottoms tray to partial reboiler and maintain pressure.

Operation: Continuous

Materials Handled:	Inlet	Outlet
Stream ID	-	-
Temperature (°F)	281.7	281.7
Pressure (psia)	28.9	29.4
Vapor Fraction	0	0
Mass Flow (lb/hr)	264482.0	264482.0
Molar Flow (lbmol/hr)	2935.1	2935.1
Component Mass Flow (lb/hr)		
Low Density Polyethylene	41.7	41.7
Toluene	253298.6	253298.6
Isopropanol	11183.4	11183.4
Pigments and Dyes	0	0
Water	-	-

Design Data:
Type: Centrifugal Pump
Orientation: VSC
Shaft rpm: 3600
Material of Construction: Carbon Steel
Maximum Motor Horsepower: 75 hp
Motor Type: Explosion-Proof
Power Consumption: 20.83 hp
Pump Efficiency: 73.1%
Motor Efficiency: 87.7%
Head: 100 ft
Flow Rate: 609.2 gpm

Utilities: 15.62 kW-hr per hour of Electricity

Comments: See Section 12 Process Flow Diagram, a 5 psig increase is an approximation for potential head loss to show difference between inlet and outlet.

DISTILLATION COLUMN REFLUX PUMP

Identification:	Item	Distillation Column Reflux Pump	Date: *16 April 2019*	
	Item No.	P-208		
	No. requried	1	By: *PJC*	

Function: Pump reflux stream from reflux accumulator to distillation column.

Operation: Continuous

Materials Handled:	Inlet	Outlet
Stream ID	-	-
Temperature (°F)	203.9	203.9
Pressure (psia)	28.9	29.4
Vapor Fraction	0	0
Mass Flow (lb/hr)	70378.1	70378.1
Molar Flow (lbmol/hr)	1167.9	1167.9
Component Mass Flow (lb/hr)		
Low Density Polyethylene	-	-
Toluene	21.1	21.1
Isopropanol	70357.0	70357.0
Pigments and Dyes	-	-
Water	-	-

Design Data:
Type: Centrifugal Pump
Orientation: VSC
Shaft rpm: 3600
Material of Construction: Carbon Steel
Maximum Motor Horsepower: 75 hp
Motor Type: Explosion-Proof
Power Consumption: 20.83 hp
Pump Efficiency: 72.1%
Motor Efficiency: 85.0%
Head: 100 ft
Flow Rate: 201.6 gpm

Utilities: 5.06 kW-hr per hour of Electricity

Comments: See Section 12 Process Flow Diagram, a 5 psig increase is an approximation for potential head loss to show difference between inlet and outlet.

SOLVENT FEED TANK

Identification:	Item	Solvent Feed Tank		Date: *16 April 2019*	
	Item No.	V-201			
	No. requried	1		By: *PJC*	

Function: Provide intermediate storage from solvent recycle stream.

Operation: Continuous

Materials Handled:	Inlet 1	Inlet 2	Outlet
Stream ID	15	14	2
Temperature (°F)	77.0	208.6	208.4
Pressure (psia)	14.7	29.4	29.4
Vapor Fraction	0	0	0
Mass Flow (lb/hr)	23.6	23601.0	23624.7
Molar Flow (lbmol/hr)	0.3	257.2	257.5
Component Mass Flow (lb/hr)			
Low Density Polyethylene	-	41.6	41.6
Toluene	23.6	23552.4	23576.0
Isopropanol	-	7.1	7.1
Pigments and Dyes	-	0	0
Water	-	-	-

Design Data:
Type: Horizontal Pressure Vessel
Material of Construction: Carbon Steel
Residence Time: 3 hours
Diameter: 12 ft
Length: 24 ft
Pressure: 29.4 psia
Temperature: 208.4°F
Total Storage Volume: 2,619 cuft (19,591 gal)
Agitator Type: Turbine
Power Consumption: 10 hp

Utilities: 7.50 kW-hr per hour of Electricity

Comments: See Section 12 Process Flow Diagram.

NONSOLVENT FEED TANK

Identification:	Item	Nonsolvent Feed Tank	Date: *16 April 2019*	
	Item No.	V-202		
	No. requried	1	By: *PJC*	

Function: Provide intermediate storage from nonsolvent recycle stream.

Operation: Continuous

Materials Handled:	Inlet 1	Inlet 2	Outlet
Stream ID	18	23	5
Temperature (°F)	77.0	174.0	173.8
Pressure (psia)	14.7	29.4	29.4
Vapor Fraction	0	0	0
Mass Flow (lb/hr)	70.8	70744.2	23624.7
Molar Flow (lbmol/hr)	1.2	1177.2	257.5
Component Mass Flow (lb/hr)			
Low Density Polyethylene	-	-	-
Toluene	-	21.2	21.2
Isopropanol	70.8	70723.0	70793.8
Pigments and Dyes	-	-	-
Water	-	-	-

Design Data:
Type: Horizontal Pressure Vessel
Material of Construction: Carbon Steel
Residence Time: 3 hours
Diameter: 18 ft
Length: 36 ft
Pressure: 29.4 psia
Temperature: 173.8°F
Total Storage Volume: 8,659 cuft (64,773 gal)
Agitator Type: Turbine
Power Consumption: 33 hp

Utilities: 24.75 kW-hr per hour of Electricity

Comments: See Section 12 Process Flow Diagram.

SURGE TANK

Identification:	Item	Surge Tank		Date: *16 April 2019*	
	Item No.	V-203			
	No. requried	1		By: *PJC*	
Function: Provide intermediate storage of solvent/nonsolvent-majority streams from filter and dryer.					
Operation: Continuous					
Materials Handled:			Inlet 1	Inlet 2	Outlet
Stream ID			21	20	8
Temperature (°F)			176.0	176.0	176.0
Pressure (psia)			14.7	14.7	14.7
Vapor Fraction			0	0	0
Mass Flow (lb/hr)			458.6	93981.3	94439.8
Molar Flow (lbmol/hr)			7.0	1428.9	257.5
Component Mass Flow (lb/hr)					
	Low Density Polyethylene		-	41.6	41.6
	Toluene		114.2	23483.0	23597.2
	Isopropanol		344.4	70457.1	70801.6
	Pigments and Dyes		-	0	0
	Water		-	-	-

Design Data:
Type: Horiztonal Pressure Vessel
Material of Construction: Carbon Steel
Residence Time: 3 hours
Diameter: 19 ft
Length: 38 ft
Pressure: 14.7 psia
Temperature: 176.0°F
Total Storage Volume: 11,548 cuft (86,385 gal)
Agitator Type: Turbine
Power Consumption: 43 hp

Utilities: 32.25 kW-hr per hour of Electricity

Comments: See Section 12 Process Flow Diagram.

REFLUX ACCUMULATOR

Identification:	Item	Reflux Accumulator	Date: *16 April 2019*
	Item No.	V-204	
	No. requried	1	By: *PJC*

Function: Provide intermediate storage of condensed distillate before rentry into column or to nonsolvent recycle stream.

Operation: Continuous

Materials Handled:	Inlet	Outlet 1	Outlet 2
Stream ID	-	-	11
Temperature (°F)	203.9	203.9	203.9
Pressure (psia)	29.4	29.4	29.4
Vapor Fraction	0	0	0
Mass Flow (lb/hr)	141193.1	70378.1	70815.0
Molar Flow (lbmol/hr)	2346.3	1167.9	1178.4
Component Mass Flow (lb/hr)			
Low Density Polyethylene	-	-	-
Toluene	42.3	21.1	21.2
Isopropanol	141150.8	70357.0	70793.8
Pigments and Dyes	-	-	-
Water	-	-	-

Design Data:
Type: Horizontal Pressure Vessel
Material of Construction: Carbon Steel
Residence Time: 5 minutes
Diameter: 7 ft
Length: 14 ft
Pressure: 29.4 psia
Temperature: 203.9°F
Total Storage Volume: 541 cuft (4,047 gal)

Utilities: None

Comments: See Section 12 Process Flow Diagram. Outlet 1 back to Distillation Column, Outlet 2 is nonsolvent recycle stream.

LDPE STORAGE BIN

Identification:	Item	LDPE Storage Bin	Date: *16 April 2019*
	Item No.	B-201	
	No. requried	1	By: *PJC*

Function: Provide storage for final LDPE product arriving from dryer.

Operation: Continuous

Materials Handled:	To Bin
Stream ID	10
Temperature (°F)	194.0
Pressure (psia)	14.7
Vapor Fraction	0
Mass Flow (lb/hr)	4125.3
Molar Flow (lbmol/hr)	147.1
Component Mass Flow (lb/hr)	
Low Density Polyethylene	4124.9
Toluene	-
Isopropanol	-
Pigments and Dyes	0.4
Water	-

Design Data: Type: Storage Bin with Hopper
Material of Construction: Carbon Steel
Storage Time: 7 days
Height: 28 ft
Length: 42 ft
Total Storage Volume: 12,085 cuft (95,788 gal)
Top Cross-Sectional Area: 588 sqft
Ground Cross-Sectional Area: 392 sqft

Utilities: None

Comments: See Section 12 Process Flow Diagram.

DISTILLATION COLUMN

Identification:	Item	Distillation Column		Date: *16 April 2019*	
	Item No.	D-201			
	No. requried	1		By: *PJC*	
Function: Separate solvent from nonsolvent for recycle streams.					
Operation: Continuous					
Materials Handled:			Feed	Distillate	Bottoms
Stream ID			8	-	-
Temperature (°F)			176.0	203.9	281.7
Pressure (psia)			29.4	29.4	29.4
Vapor Fraction			0	1	0
Mass Flow (lb/hr)			94439.8	141193.1	264482.0
Molar Flow (lbmol/hr)			1583.0	2346.3	2935.1
Component Mass Flow (lb/hr)					
	Low Density Polyethylene		41.7	-	41.7
	Toluene		23597.2	42.3	253298.6
	Isopropanol		70800.9	141150.8	11183.4
	Pigments and Dyes		0	-	0
	Water		-	-	-

Design Data:
Type: Vertical Pressure Vessel
Material of Construction: Carbon Steel
Number of Trays: 24
Tray Type: Sieve
Tray Spacing: 24 inches
Feed Stage: 11
Total Height: 60 ft
Diameter: 12 ft
Thickness: 0.625 inches
Reflux Ratio: 0.99383

Utilities: None.

Comments: See Section 12 Process Flow Diagram. Distillate and Bottoms represent the streams flowing from the top and bottom trays, respectively (not the exit streams from reflux accumulator/partial reboiler).

ROTARY-DRUM VACUUM FILTER

Identification:	Item	Rotary-Drum Vacuum Filter		Date: *16 April 2019*
	Item No.	F-201		
	No. requried	1		By: *PJC*

Function: Filter the stream leaving the precipitation vessel to remove solid LDPE granules.

Operation: Continuous

Materials Handled:	Inlet	Outlet 1	Outlet 2
Stream ID	6	20	7
Temperature (°F)	176.0	176.0	281.7
Pressure (psia)	29.4	14.7	29.4
Vapor Fraction	0	0	0
Mass Flow (lb/hr)	98565.0	93981.3	4583.8
Molar Flow (lbmol/hr)	1583.0	1428.9	154.1
Component Mass Flow (lb/hr)			
Low Density Polyethylene	4166.5	41.6	4124.9
Toluene	23597.2	23483.0	114.2
Isopropanol	70800.9	70457.1	344.4
Pigments and Dyes	0.4	0	0.4
Water	-	-	-

Design Data: Type: Rotary Drum Vacuum Fikter
Diameter: 8 ft
Length: 10 ft
Total Filter Area: 251 sqft
Vacuum System: Pulls at 14.7 psia
Power Requirement: 10 hp

Utilities: 7.50 kW-hr per hour of Electricity

Comments: See Section 12 Process Flow Diagram.

DRYER

Identification:	Item	Dryer		Date: *16 April 2019*	
	Item No.	H-201			
	No. requried	1		By: *PJC*	
Function: Dry and remove any remaining solvent and nonsolvent before final LDPE product.					
Operation: Continuous					
Materials Handled:			Inlet	Outlet 1	Outlet 2
Stream ID			7	9	10
Temperature (°F)			176	194.0	194.0
Pressure (psia)			29.4	7.4	14.7
Vapor Fraction			0	1	0
Mass Flow (lb/hr)			4583.8	458.6	4125.3
Molar Flow (lbmol/hr)			154.1	7.0	147.1
Component Mass Flow (lb/hr)					
Low Density Polyethylene			4124.9	-	4124.9
Toluene			114.2	114.2	-
Isopropanol			344.4	344.4	-
Pigments and Dyes			0.4	-	0.4
Water				-	-

Design Data:
Type: Indirect-heat Steam Tube Rotary Dryer
Number of Tubes: 14 144-mm OD tubes
Tube Length: 20 ft
Total Heat Transfer Area: 353 sqft
Temperature: 194.0°F
Heat Duty: 66,317 BTU/hr
Power Requirement: 2.2 hp

Utilities: 171 lb/hr of 50 psig steam, 1.65 kW-hr per hour of Electricity

Comments: See Section 12 Process Flow Diagram

17 Equipment Cost Summary

Table 17.1 displays the estimated purchase cost for each piece of equipment, as well as bare module factors for piping and installation. This includes spare pumps, surge tanks for the recycled solvents and a storage bin for the final product. Multiplying the bare module factors by the purchase cost and summing the individual bare module costs for each unit, the total bare module cost of the process is $8,011,104. The distillation column for solvent separation is the single most expensive piece of equipment by far, but the value of recycling the solvents will make up for this investment. Other major pieces equipment including the dryer, filters, surge tanks and mixing vessels where dissolution and precipitation occur also contribute significantly to this cost. In comparison, the pumps and heat exchangers are fairly cheap.

Table 17.1. Total Bare Module Cost summary for each piece of equipment. The Bare Module Factor includes the required piping and other installation costs.

Unit ID	Type	Purchase Cost	Bare Module Factor	Bare Module Cost
P-101	Process Machinery	$13,710	3.30	$45,243
P-101X	Spares	$13,710	3.30	$45,243
P-201	Process Machinery	$11,618	3.30	$38,339
P-201X	Spares	$11,618	3.30	$38,339
P-202	Process Machinery	$11,518	3.30	$38,009
P-202X	Spares	$11,518	3.30	$38,009
P-203	Process Machinery	$10,971	3.30	$36,204
P-204	Process Machinery	$10,971	3.30	$36,204
P-204X	Spares	$10,971	3.30	$36,204
P-205	Process Machinery	$10,276	3.30	$33,911
P-206	Process Machinery	$10,276	3.30	$33,911
P-206X	Spares	$10,276	3.30	$33,911
P-207	Process Machinery	$11,141	3.30	$36,765
P-208	Process Machinery	$15,430	3.30	$50,919
B-201	Storage	$54,403	4.00	$217,612
M-001-005	Process Machinery	$85,000	3.21	$272,850
F-101A	Process Machinery	$260,000	2.32	$603,200
F-101B	Process Machinery	$260,000	2.32	$603,200
F-101C	Process Machinery	$260,000	2.32	$603,200
F-101X	Spares	$260,000	2.32	$603,200
E-101	Fabricated Equipment	$23,571	3.17	$74,720
E-102	Fabricated Equipment	$22,818	3.17	$72,333
E-103	Fabricated Equipment	$17,006	3.17	$53,909
E-104	Fabricated Equipment	$38,759	3.17	$122,866
E-105	Fabricated Equipment	$76,818	3.17	$243,513
V-101	Fabricated Equipment	$70,804	3.05	$215,952
V-102	Fabricated Equipment	$157,548	3.05	$480,521
V-201	Fabricated Equipment	$72,576	3.05	$221,357
V-202	Fabricated Equipment	$121,700	3.05	$371,185
V-203	Fabricated Equipment	$137,632	3.05	$419,778
V-204	Fabricated Equipment	$30,775	3.05	$93,864
F-201	Fabricated Equipment	$272,457	2.03	$553,088
H-201	Fabricated Equipment	$180.119	2.06	$371,045
D-201	Fabricated Equipment	$305,889	4.16	$1,272,498
Total	**Fabricated Equipment**			**$4,566,629**
Total	**Process Machinery**			**$2,431,956**
Total	**Spares**			**$794,907**
Total	**Storage**			**$217,612**

Total Bare Module Costs **$8,011,104**

18 Fixed Capital Investment Summary

The total capital investment for this project is $14.9MM. Guidelines from *Seider et. al.* were used to estimate the fixed capital investment, with the assumption that all permanent investment will be paid at the project's onset. The process is shown below in Table 18.1.

Table 18.1. Relationship between Total Capital Investment (TCI), Total Permanent Investment (TPI) and estimated equipment purchase costs. [Seider et al., 2017]

Total bare module costs for fabricated equipment	C_{FE}					
Total bare module costs for process machinery	C_{PM}					
Total bare module costs for spares	C_{spare}					
Total bare module costs for storage and surge tanks	$C_{storage}$					
Total bare module costs for initial catalyst charges	$C_{catalyst}$					
Total bare module costs for computers and software	C_{comp}					
Total Bare Module Investment (TBM)		C_{TBM}				
Cost of site preparations		C_{site}				
Cost of service facilities		C_{serv}				
Allocated costs for utility plants and related facilities		C_{alloc}				
Total of Direct Permanent Investment (DPI)			C_{DPI}			
Cost of contingencies and contractor's fee			C_{cont}			
Total Depreciable Capital (TDC)				C_{TDC}		
Cost of land				C_{land}		
Cost of royalties				C_{royal}		
Cost of plant startup				$C_{startup}$		
Total Permanent Investment (TPI)					C_{TPI}	
Working Capital					C_{WC}	
Total Capital Investment (TCI)						C_{TCI}

The bare-module costs tabulated in Section 17 were added to estimated costs for site preparation and service facilities, each 5% of total bare module cost, to obtain a Direct Permanent Investment of $8,812,215. For contingencies and contractor fess, 18% of the Direct Permanent Investment is assumed and added to estimate Total Depreciable Capital, $10,398,413. The costs of land and plant startup, 2% and 10% of the Total Depreciable Capital respectively, are added to the previous Total Depreciable Capital fixed cost to find the unadjusted Total Permanent Investment. This number is then multiplied by 1.1 to adjust for the facility's location in the Northeast United States to obtain the Total Permanent Investment of $12,810,845. As shown in in Table 18.1, the Total Capital Investment is calculated by adding the TPI with the working capital. Table 18.2 shows this total calculation to find the total permanent investment of $14,862,529.

Table 18.2. Fixed cost investment summary. All fixed costs are added to estimate total permanent investment for the process, using industry-accepted values for costs of land, services, and preparation.

Investment Summary			
Total Bare Module Costs			
Fabricated Equipment	$4,566,629		
Process Machinery	$2,431,956		
Spares	$794,907		
Storage	$217,612		
Other Equipment	-		
Catalysts	-		
Computers, Software, Etc.	-		
Total Bare Module Costs			**$8,011,104**
Direct Permanent Investment			
Cost of Site Preparations	$400,555		
Cost of Service Facilities	$400,555		
Allocated Costs for utility plants and related facilities	-		
Direct Permanent Investment			**$8,812,215**
Total Depreciable Capital			
Cost of Contingencies & Contractor Fees	$1,586,199		
Total Depreciable Capital			**$10,398,413**
Total Permanent Investment			
Cost of Land	$297,968		
Cost of Royalties	-		
Cost of Plant Start-Up	$1,039,841		
Total Permanent Investment (unadjusted)			$11,646,223
Site Factor		1.10	
Total Permanent Investment			**$12,810,845**

Working Capital	**2020**	**2021**	**2022**
Accounts Receivable	$577,410	$288,705	$288,705
Cash Reserves	$268,591	$134,296	$134,296
Accounts Payable	$(124,386)	$(62,193)	$(62,193)
LDPE Inventory	$577,410	$288,705	$288,705
Raw Materials	$2,479	$1,239	$1,239
Total	**$1,301,504**	**$650,752**	**$650,752**
Present Value at 15%	*$1,131,742*	*$492,062*	*$427,880*
Total Capital Investment	**$14,862,529**		

19 Operating Cost—Cost of Manufacture

19.1. Variable Costs

The techniques describe by *Seider et. al*. were used to estimate operating costs of utilities, labor, maintenance, and other expenses, while considering depreciation. Variable operating costs amount to $5.17MM annually and are tabulated in Table 19.1 below.

Table 19.1. Summary of variable costs estimated for this process design on an annual basis.

Variable Cost Summary				
General Expenses				
Selling / Transfer Expenses	$468,344			
Direct Research	$749,350			
Allocated Research	$78,057			
Administrative Expense	$312,229			
Management Incentive	$195,143			
Total General Expenses			**$1,803,123**	
Raw Materials	$0.008831	per lb of LDPE		$287,211
Byproducts	-	per lb of LDPE		-
Utilities	$0.140911	per lb of LDPE		$3,075,822
Total Variable Costs				**$5,166,156**

Raw materials costs are very low because the waste plastic bags are assumed to have an acquisition cost of zero and the solvent and nonsolvent are recycled to minimize fresh solvent and nonsolvent streams to the process. The costs of General Expenses are explained in Table 19.2.

Table 19.2. Annual general expenses data required for plant operation.

Selling / Transfer Expenses	3.00%	of Sales
Direct Research	4.80%	of Sales
Allocated Research	0.50%	of Sales
Administrative Expense	2.00%	of Sales
Management Incentive Compensation	1.25%	of Sales

Utility requirements are the largest variable cost within this process. The utilities required for full plant operation include steam, waste treatment, cooling water, process water and electricity and are more thoroughly shown in Table 19.3 as a required ratio with amount of LDPE produced.

Table 19.3. Utility costs for each of the required utilities in the process. Using the industrial standard of plant operation at 90% per year, the annual utility requirement is $3,075,822.

Utility	**Required ratio**		**Utility Cost ($)**	
Cooling Water	37.161	gal per lb of LDPE	0.0001	per gal
Process Water	0.291	gal per lb of LDPE	0.0008	per gal
Waste Treatment	0.033	lb per lb of LDPE	0.1500	per lb
150 psig Stream	10.432	lb per lb of LDPE	0.0070	per lb
50 psig Steam	0.043	lb per lb of LDPE	0.0060	per lb
Electricity	0.177	kW-hr per lb of LDPE	0.0700	per kW-hr
Total Weighted Average		**$0.095**	**per lb LDPE produced**	

19.2. Fixed Costs

The total amount of fixed costs is $4.19MM annually. This includes the cost for operations, maintenance and operating overhead as well as property taxes and insurance. The estimated total fixed costs are summarized in Table 19.4. Recommendations from *Seider et al* were used to calculate the fixed costs below.

Table 19.4. Summary of total fixed costs estimated for this process design on an annual basis.

Fixed Cost Summary		
<u>Operations</u>		
Direct Wages and Benefits	$1,456,000	
Direct Salaries and Benefits	$218,400	
Operating Supplies and Services	$87,360	
Technical Assistance to Manufacturing	$300,000	
Control Laboratory	$325,000	
Total Operations		**$2,386,760**
<u>Maintenance</u>		
Wages and Benefits	$467,929	
Salaries and Benefits	$116,982	
Materials and Services	$467,929	
Maintenance Overhead	$23,396	
Total Maintenance		**$1,076,236**
<u>Operating Overhead</u>		
General Plant Overhead	$160,411	
Mechanical Department Services	$54,223	
Employee Relations Department	$133,299	
Business Services	$167,189	
Total Operating Overhead		**$515,123**

<u>Property Taxes and Insurance</u>		
Property Taxes and Insurance		**$207,968**
<u>Other Annual Expenses</u>		
Rental Feeds (Office and Lab Space)	-	
Licensing Feeds	-	
Miscellaneous	-	
Total Other Annual Expenses		-
<u>Total Fixed Costs</u>		**<u>$4,186,087</u>**

Five operators are needed for the plant per shift: four for the more labor-intensive front end process and one for maintaining the more automated back end processes. The average direct wages and benefits will be $28/hour per operator. The process is modeled to have 5 shifts. Additional costs are added to this for salaries, supplies, training, and control laboratory to include one engineer and one supervisor on duty for each shift. A total fixed cost for operations on an annual basis is $2,386,760.

For fixed costs pertaining to maintenance, wages and benefits are 4.50% of Total Depreciable Capital for solids-fluids handling. Additional maintenance costs come in the form of salaries and benefits (25% of maintenance wages and benefits), materials and serves (100% of maintenance wages and benefits) and maintenance overhead (5% of maintenances wages and benefits). The total fixed cost for maintenance is $1,076,236 annually.

Additional expenses include property taxes (2% of Total Depreciable Capital) and operating overhead. For the various departments, the operating overhead included general plant overhead (7.10% of Maintenance and Operations Wages and Benefits (M&O Wages and Benefits)), mechanical department services (2.40% of M&O Wages and Benefits), employee relations department (5.90% of M&O Wages and Benefits) and business services (7.40% of M&O Wages and Benefits). The total fixed cost of operating overhead is $207,968 annually.

20 Profitability Analysis

The profitability of the proposed process design and product yield is evaluated under five cases. The first case is considered the base case. The second case analyzes the profitability of changing the discount price of the LDPE product. The third case discusses the effect of variable costs on the overall profitability. The fourth case analyzes the profitability of changing the plastic bag acquisition. The fifth and final case analyzes the situation in which the filter process between the dissolution and precipitation vessel is replaced with a more technologically-advanced filtration process over time.

20.1. Case 1: Base Case

The base case for this process design and product yields was determined to yield a 21.97% internal rate of return (IRR), with a net present value (NPV) of $5,896,300 in 2019 when using a nominal interest rate of 15% over twenty years. In addition, its return on investment (ROI) was found to equal 20.93% after the third production year, when the plant is in its first year of full operating capacity. A summary of the profitability measures is shown in Table 20.1.

The base case assumes a LDPE selling price of $0.48/lb (which is equivalent to a 20% discount from virgin LDPE) due to potential discoloration from the dyes and pigments present. Virgin LDPE was found to be priced at approximately $0.60/lb. Noteworthy is the fact that this price of LDPE is relatively conservative in value. Several sources indicate the market for LDPE in the United States sells for upwards of $0.70/lb (ICIS, 2018). Changing the price to be discounted from the higher virgin LDPE price would significantly raise the profitability of this venture. However, for the purpose of this model and for the following sensitivity analysis, the conservative pricing choice of $0.60/lb for virgin LDPE will be employed. This case also assumes that the cost incurred from acquiring the trash bags is $0/lb. This acquisition cost is assumed to include any costs or revenues associated with procuring and transporting the trash bags to the facility. See Section 20.1.3 for the more detailed rational for the little to no cost of acquiring feed material for the process.

Table 20.1. Summary of the profitability measures for the base case of this design process. These measures were attained using a 15% nominal interest rate.

Profitability Measures	
IRR	21.97%
NPV	$5,896,300
ROI Analysis (Third Production Year)	
Annual Sales	14,050,310
Annual Costs	(8,835,627)
Depreciation	(1,024,868)
Income Tax	(963,657)
Net Earnings	3,226,157
Total Capital Investment	15,413,853
ROI	20.93%

The table above demonstrates that the base case of this process is investor-friendly. This is because the IRR exceeds the cost of capital (15%) leading to a positive NPV. This process makes a profit and is an economically-smart investment because it is value creating. However, the IRR only slightly exceeds the cost of capital and thus investors should be interested but also wary of any potential changes to prices in the process.

The project will require the remainder of the current calendar year for detailed process design, followed by one year of plant construction before any LDPE can be produced. A one-year plant construction was selected because this is a smaller plant in comparison to other facilities throughout the industry. The value of the project was estimated over twenty years. The first two years of production require a work-up period before reaching full capacity in the remaining 16 years. The lifetime of the project is shown in Table 20.2. A detailed cash flow summary is also provided in Table 20.3.

Table 20.2. Chronological lifetime of the process design. One year is required for a completed design and an additional year is required for construction. The plant will then operate for 18 years with a two-year work-up period. A 5-year MACRS depreciation schedule is implemented.

Process Lifetime					
Year	**Action**	**Distribution of Permanent Investment**	**Production Capacity**	**Depreciation Schedule**	**Product Price**
2019	Design		0.0%		
2020	Construction	100%	0.0%		
2021	Production	0%	45.0%	20.00%	$0.48
2022	Production	0%	67.5%	32.00%	$0.48
2023	Production		90.0%	19.20%	$0.48
2024	Production		90.0%	11.52%	$0.48
2025	Production		90.0%	11.52%	$0.48
2026	Production		90.0%	5.76%	$0.48
2027	Production		90.0%		$0.48
2028	Production		90.0%		$0.48
2029	Production		90.0%		$0.48
2030	Production		90.0%		$0.48
2031	Production		90.0%		$0.48
2032	Production		90.0%		$0.48
2033	Production		90.0%		$0.48
2034	Production		90.0%		$0.48
2035	Production		90.0%		$0.48
2036	Production		90.0%		$0.48
2037	Production		90.0%		$0.48
2038	Production		90.0%		$0.48

Table 20.3. Summary of the cash flows for the lifetime of the process. The summary includes the sales, capital, fixed and variable costs along with depreciation and taxes.

Cash Flow Summary

Year	Percentage of Design Capacity	Product Unit Price	Sales	Capital Costs	Working Capital	Var Costs	Fixed Costs	Depreciation	Depletion Allowance	Taxible Income	Taxes	Net Earnings	Cash Flow	Cumulative Net Present Value at 15%
2019	0%		-	-	-	-	-	-	-	-	-	-	-	-
2020	0%		-	(12,810,800)	(1,301,500)	-	-	-	-	-	-	-	(14,112,300)	(12,271,600)
2021	45%	$0.48	7,025,200	-	(650,800)	(2,324,800)	(4,186,100)	(2,079,700)	-	(1,565,400)	360,000	(1,205,300)	223,600	(12,102,500)
2022	68%	$0.48	10,537,700	-	(650,800)	(3,487,200)	(4,186,100)	(3,327,500)	-	(463,000)	106,500	(356,500)	2,320,200	(10,577,000)
2023	90%	$0.48	14,050,300	-	-	(4,649,500)	(4,186,100)	(1,996,500)	-	3,218,200	(740,200)	2,478,000	4,474,500	(8,018,600)
2024	90%	$0.48	14,050,300	-	-	(4,649,500)	(4,186,100)	(1,197,900)	-	4,016,800	(923,900)	3,092,900	4,290,800	(5,885,400)
2025	90%	$0.48	14,050,300	-	-	(4,649,500)	(4,186,100)	(1,197,900)	-	4,016,800	(923,900)	3,092,900	4,290,800	(4,030,300)
2026	90%	$0.48	14,050,300	-	-	(4,649,500)	(4,186,100)	(598,900)	-	4,615,700	(1,061,600)	3,554,100	4,153,100	(2,469,000)
2027	90%	$0.48	14,050,300	-	-	(4,649,500)	(4,186,100)	-	-	5,214,700	(1,199,400)	4,015,300	4,015,300	(1,156,400)
2028	90%	$0.48	14,050,300	-	-	(4,649,500)	(4,186,100)	-	-	5,214,700	(1,199,400)	4,015,300	4,015,300	(15,000)
2029	90%	$0.48	14,050,300	-	-	(4,649,500)	(4,186,100)	-	-	5,214,700	(1,199,400)	4,015,300	4,015,300	977,500
2030	90%	$0.48	14,050,300	-	-	(4,649,500)	(4,186,100)	-	-	5,214,700	(1,199,400)	4,015,300	4,015,300	1,840,600
2031	90%	$0.48	14,050,300	-	-	(4,649,500)	(4,186,100)	-	-	5,214,700	(1,199,400)	4,015,300	4,015,300	2,591,100
2032	90%	$0.48	14,050,300	-	-	(4,649,500)	(4,186,100)	-	-	5,214,700	(1,199,400)	4,015,300	4,015,300	3,243,700
2033	90%	$0.48	14,050,300	-	-	(4,649,500)	(4,186,100)	-	-	5,214,700	(1,199,400)	4,015,300	4,015,300	3,811,100
2034	90%	$0.48	14,050,300	-	-	(4,649,500)	(4,186,100)	-	-	5,214,700	(1,199,400)	4,015,300	4,015,300	4,304,600
2035	90%	$0.48	14,050,300	-	-	(4,649,500)	(4,186,100)	-	-	5,214,700	(1,199,400)	4,015,300	4,015,300	4,733,700
2036	90%	$0.48	14,050,300	-	-	(4,649,500)	(4,186,100)	-	-	5,214,700	(1,199,400)	4,015,300	4,015,300	5,106,800
2037	90%	$0.48	14,050,300	-	-	(4,649,500)	(4,186,100)	-	-	5,214,700	(1,199,400)	4,015,300	4,015,300	5,431,300
2038	90%	$0.48	14,050,300	-	2,603,000	(4,649,500)	(4,186,100)	-	-	5,214,700	(1,199,400)	4,015,300	6,618,300	5,896,300

20.2. Case 2: Discounted Price Sensitivity Analysis

The first sensitivity analysis carried out on the base case pertains to the selling price of LDPE in the process. Our process was modeled to achieve 99.99% LDPE purity as the final product. The remaining 0.01% of the final product is associated with dyes and pigments unable to be removed through the process. Due to these impurities, the final color of the product is predicted to be discolored and not the normal clear-whitish color of LDPE. For this reason, we decided a 20% discount of virgin LDPE would be a more accurate selling price for our model.

A sensitivity analysis was carried out on the discount value of the selling price and is shown in Figure 20.1. The final selling prices were compared from discounts of 0% (virgin LDPE price) to 35%. The IRR for each of the different discounted prices was calculated and the blue line in the figure represents these values. The red line is held at 15% to represent the cost of capital. If the IRR is above the line, the process is considered investor-friendly and value-creating. The break-even point, where the IRR equals exactly the cost of capital, occurs at a selling price of $0.4158/lb. Any price greater than this will result in a value-creating design.

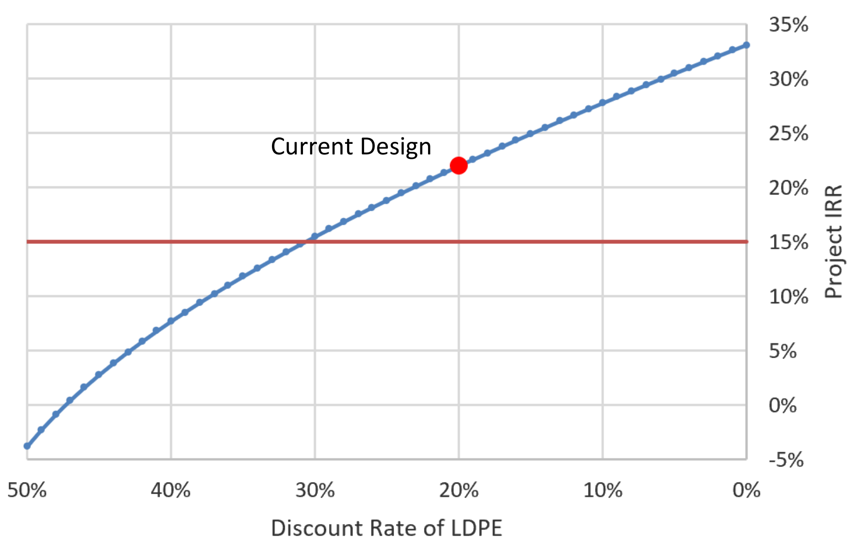


Figure 20.1. Effect of LDPE selling price on IRR of the project. Any region below the red line represents prices of LDPE for which the IRR is less than the cost of capital. The current price of $0.48/lb (or a 20% discount) yields a 21.97% IRR. However, the process ceases to be investor-friendly once the selling price falls below $0.4158/lb (or rises above a 30.7% discount).

From this analysis, it is shown that the selling price of recycled LDPE plays an important factor in the profitability. Less than a cent reduction in the modeled selling price of LDPE will result in an unfriendly process design. This analysis reveals that while the project is profitable when using the base case pricing assumptions, it quickly becomes an unfriendly design for investors should the price and value of recycled LDPE require a greater discount. Therefore, the previous profitability metrics mentioned in the base case should be read with caution.

20.3. Case 3: Variable Cost Sensitivity Analysis

To more fully understand where the costs of the process are affecting the profitability of the process, the variable costs from Section 19.1 were investigated more in depth. Figure 20.2 shows the breakdown of the variable costs for the base case.

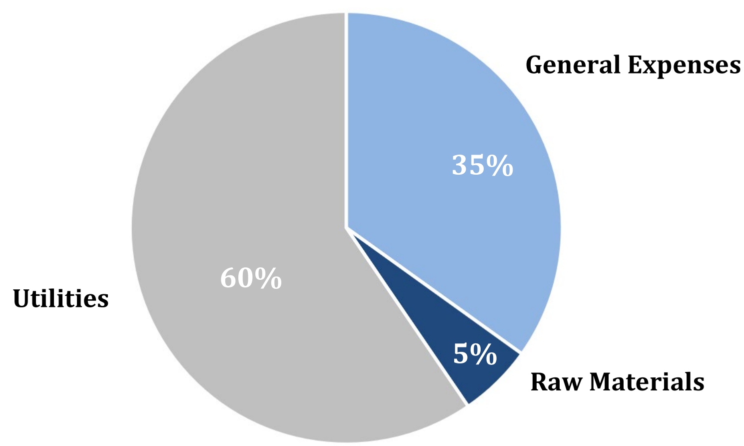


Figure 20.2. Annual variable cost distribution breakdown. The utility requirement plays the largest role in the variable costs on an annual basis.

From the above figure, it is shown that utilities play the largest role in the variable cost to this design. The annual cost of raw materials is held at such a small percentage because of the process' recycle of solvent and nonsolvent along with the assumption that the acquisition cost of waste trash bags is zero (to be discussed in the following case in Section 20.4). Additionally, this report has worked to provide an accurate approximation for the total utility requirement and to limit the amount of utilities required through heat and energy integration. By breaking up the utility requirements into their overall annual costs, Figure 20.3 demonstrates that high pressure steam is the largest factor in the annual utility cost requirement and therefore affect the profitability the most out of all variable costs.

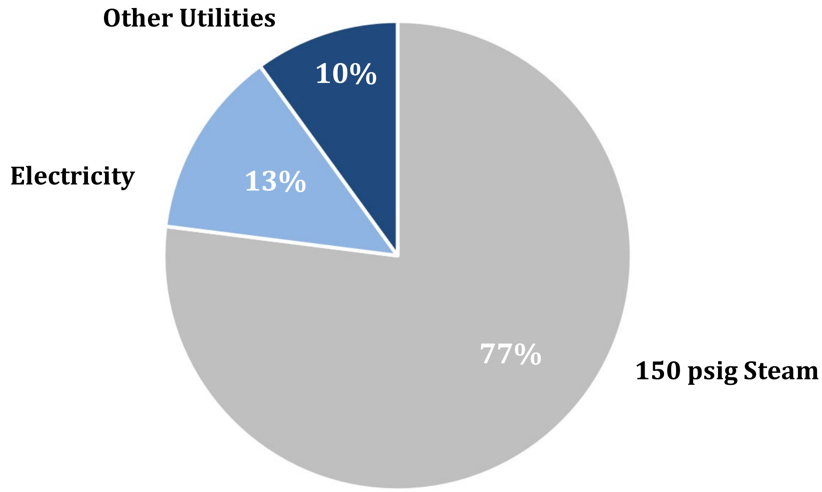


Figure 20.3. Breakdown of the annual utility requirement by annual cost. As expected, high pressure steam requires the greatest annual cost.

While this design strived to provide realistic estimations and approximations for the utility requirements, there are sure to be changes with the upscale to and startup of actual operational capacity. For this reason, a sensitivity analysis was carried out on the variable costs and how they would affect the profitability of the project. This analysis was carried out in junction with varying the selling price of LDPE final product as both factors play a significant role in the overall profitability. The analysis can be found below in Table 20.4.

Table 20.4. IRR as a function of both annual variable costs ($MM per year) and LDPE selling price ($ per pound). The red shaded region represents IRR that falls below the cost of capital and are therefore unprofitable. The current annual variable cost ($5.17 MM per year) and LDPE selling price ($0.48 per pound) yields an IRR of 21.97%. This profitability can be increased by raising the price of LDPE (Section 20.2) or lowering the annual variable costs.

	Annual Variable Costs ($ MM/yr)										
	3.87	**4.13**	**4.39**	**4.65**	**4.91**	**5.17**	**5.42**	**5.68**	**5.94**	**6.20**	**6.46**
$0.36	12%	10%	9%	8%	7%	5%	4%	2%	0%	-2%	-4%
$0.38	15%	14%	13%	12%	10%	9%	8%	7%	5%	4%	2%
$0.41	18%	17%	16%	15%	14%	13%	12%	10%	9%	8%	7%
$0.43	21%	2%	19%	18%	17%	16%	15%	14%	13%	12%	10%
$0.46	24%	23%	22%	21%	20%	19%	18%	17%	16%	15%	14%
$0.48	27%	26%	25%	24%	23%	22%	21%	20%	19%	18%	17%
$0.50	29%	28%	27%	27%	26%	25%	24%	23%	22%	21%	20%
$0.53	32%	31%	30%	29%	28%	27%	26%	26%	25%	245	23%
$0.55	34%	33%	33%	32%	31%	30%	29%	28%	27%	26%	26%
$0.58	37%	36%	35%	34%	33%	33%	32%	31%	30%	29%	28%
$0.60	39%	38%	37%	37%	36%	35%	34%	33%	32%	32%	31%

The table confirms that raising the annual variable costs will decrease the overall profitability of the process. Just a 15% increase in annual variable costs will drop the IRR of this project from 21.97% to 19.02%. Just as the selling price of LDPE significantly affects the profitability, so too do the variable costs. As pointed out in Figure 20.3, investors should revisit the utility requirements of steam and electricity as they are the major factors affecting the profitability of this venture.

20.4. Case 4: Plastic Bag Acquisition Cost Sensitivity Analysis

To be more specific, a sensitivity analysis was carried out on the base case pertaining to the variable cost of the acquisition cost of trash grocery bags. Our process assumes that the cost to acquire these grocery bags is $0/lb. This price includes the procurement and transportation to the plant. Having this plant located in the Northeast near New York City and Philadelphia allows for the availability of trash grocery bags to not be an issue. New York City uses 23 billion plastic bags annually (which is approximately 190 TPD) and Philadelphia's annual usage is just larger than 860 million plastic bags (approximately 15 TPD). For a process requiring 50 TPD of thoroughly sorted and cleaned trash bags from the first step of the process, there is an abundance of the feed material in the nearby vicinity of this process. Additionally, the transportation cost is minimized considering the closeness of the trash bag usage. In many cases, like the plastic recycling plant from AGILYX in Portland, Oregon, there is no other place for this plastic waste to go besides the landfill (CBS News, 2019). Therefore, our process, like AGILYX, will most likely either incur zero cost in the acquisition of the processing feed material or will paid to remove plastic waste. A low acquisition cost or positive revenue is therefore an appropriate assumption.

Shown in Figure 20.4 is the sensitivity analysis on how the acquisition cost of trash grocery bags affects the overall profitability of the process. The acquisition cost of this feed was compared from a revenue of $100/ton to a cost of $100/ton. The IRR for each of these costs was calculated and is represented by the blue line. The red line is held at 15% to represent the cost of capital. If the IRR is above the line, the process is considered value-creating. The break-even point, where the IRR equals exactly the cost of capital, occurs at a cost of $98/ton (or $0.049/lb of trash bags). Any cost greater than this will result in a non-profitable process.

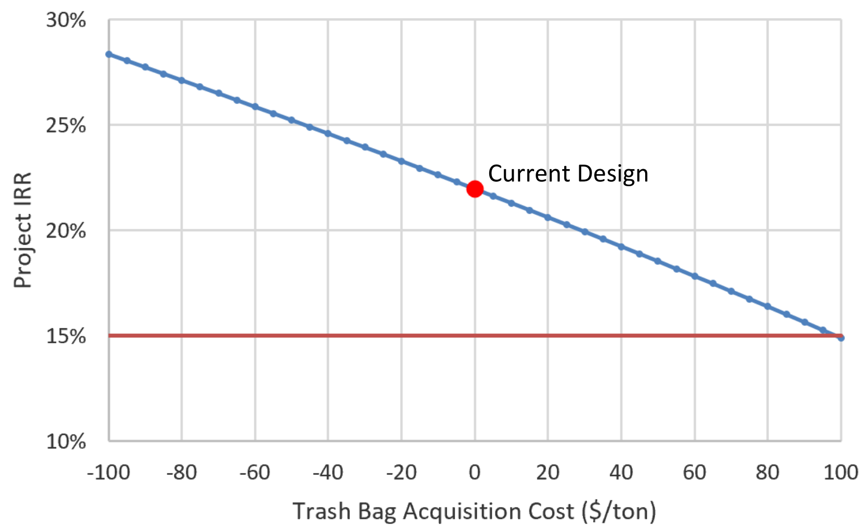


Figure 20.4. Effect of Trash Bag acquisition cost on IRR of the project. Any region below the red line represents acquisition costs for which the IRR is less than the cost of capital. The current modeled cost of $0/ton yields a 21.97% IRR. However, the process ceases to be profitable once the acquisition cost rises above $98/ton (or rises above $0.049/lb).

From this analysis, it is similarly shown that the acquisition cost of trash grocery bags plays an important role in the overall profitability of this endeavor. This analysis reveals that the project remains profitable when using the base case costing assumptions and also for large increases in the acquisition cost of trash bags. If the material is able to be acquired as a revenue, there is strong upside and potential for making the process even more profitable. Therefore, the previous profitability metrics mentioned in the base case should be read with caution.

20.5. Case 5: Filter Enhancement Sensitivity Analysis

The final sensitivity analysis carried out on the base case pertains to enhancing the filtration step between the dissolution vessel and precipitation vessel. As mentioned previously, the final product output is 99.99% pure LDPE with the impurities coming from dyes and pigments. Due to this impurity, the venture loses out on potential for greater profitability due to a required discount in the selling price of recycled LDPE. As demonstrated in Section 19.1, research is incorporated into the operations of this facility. If most of this research is directed towards enhancing the filtration process to remove these dyes and pigments, it is possible that a higher quality product can be achieved. This higher quality product would be free from the discoloration that forces a discounted selling price and would thus be able to be sold at a price equivalent to virgin LDPE. The current base case model does no incorporate the application of research towards an enhanced filtration implementation in the lifetime of the process.

This sensitivity analysis, as shown in Figure 20.5, shows how an implementation of a better filtration process at certain points in the lifetime of the process affect the profitability of the process. The implementation of this advanced technology leads to a higher selling price of the LDPE for that year of implementation and for the remainder of the lifetime of the process. The blue points represent the IRR for the year in which the advanced technology is added to the design. The red line represents the IRR of the base case. As expected, the sooner a possible technological advancement is implemented into the process, the greater the profitability will be. Therefore, it is important that when implementing this process design, the management and supervision devote research towards achieving more technologically-advanced filtration techniques.

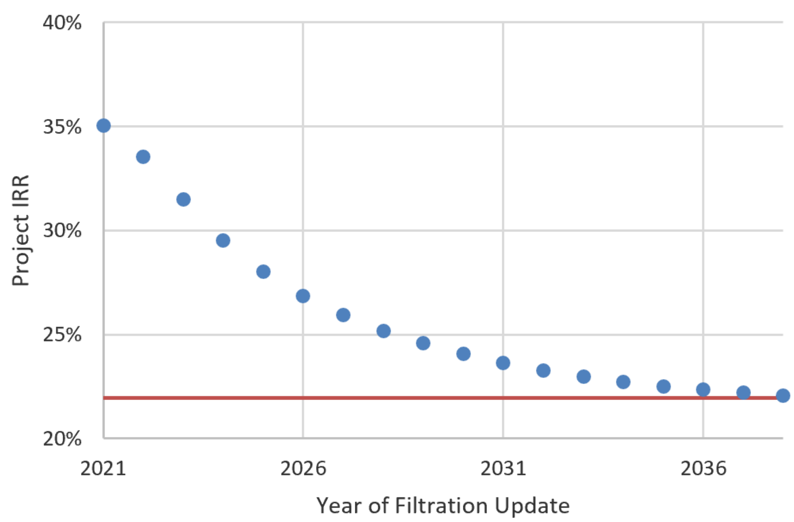


Figure 20.5. Effect of Implementing Advanced Filtration Technology on IRR of the project. The red line represents the current model that does not include an enhanced filter implementation. Each of the blue dots represent the lifetime IRR of a process for a filter implementation in that year of operation. The sooner the advancement is incorporated, the more profitable the process will be.

21 Other Important Considerations

21.1. Further Experimentation Prior to Building Pilot Plant

21.1.1. Solubility Modeling

Due to research limitations, the exact thermodynamics of the ternary system in the precipitation vessel could not be studied. The mass balance was designed using numbers that were successful for similar processes in other experiments (Achilias, 2009; Pappa, 2001; Zhou, 2017). Key assumptions were based on similar LDPE processes in a wide variety of solvents.

All previous processes were run near 85°C for dissolution, which should allow for a fast residence time in the vessel without vaporizing any components. It was also assumed that 99% of LDPE could be recovered as a precipitate, based on Achilias's research in polymer recycling. Based on the Flory-Huggins model, this number is likely higher. *Equation 10.3.3* holds true for all three interactions. The approximate ternary phase diagram is based on a model of the free energy for a ternary system given by

$$\frac{\Delta G}{RT} = \frac{\phi_P}{N_P}\log\phi_P + \phi_S\log\phi_S + \phi_N\log\phi_N + \chi_{PS}\phi_S\phi_P + \chi_{PN}\phi_P\phi_N + \chi_{NS}\phi_N\phi_S\,.$$

Here ϕ_I represents the volume fraction of component I, where $I = P, N$ or S for the polymer (polyethylene), non-solvent (isopropanol), and solvent (toluene); N_P is the degree of polymerization of the polymer, which was fixed at $N_P = 250$; and χ_{IJ} is the Flory "chi" parameter that represents the enthalpy of mixing components I and J. These values were calculated using Hansen parameters as a measure of cohesive energy density, discussed in Section 10.

Professor Riggleman used programs developed in his research group to minimize the free energy of mixtures. These mixtures had varying overall compositions, and the program identified coexisting phases and their compositions. The data from the program was used to construct the ternary phase diagram shown in Figure 21.1. The procedure to minimize the free energy with respect to the phase compositions used standard self-consistent field theory techniques, the description of which are beyond the scope of this project (Fredrickson, 2006). Note that N_P used in the calculations is significantly smaller than the values expected in experiments to keep the calculations tractable. The tests of the effect of increasing N_P indicate that as N_P increases, the amount of solvent remaining in the polymer-rich phase decreases. As a result, the concentrations of solvent in the polymer-rich phase should be taken as an upper bound.

The ternary diagram is shown below, where points closer to the origin contain increasingly larger fractions of LDPE. Tie lines were only constructed for low overall solvent concentrations that were relevant to this process, which was 24% by volume. For a given starting composition, the solution separates into two phases because of the immiscibility between LDPE and isopropanol. Mass fractions of the polymer and nonsolvent in the reprecipitation vessel are 0.042 and 0.715 respectively, marked by an "X" on the graph. By approximating the values between the tie lines, the separation into a nonsolvent rich-phase has about 75% isopropanol, 25% toluene, and about 1 ppm of LDPE. The polymer-rich phase in the bottom-right of the figure should have about 90% polymer mixed with the solvent and non-solvent. The solvent and non-solvent are separated from the polymer in the back-end of the overall process. Due to the imprecise nature of modelling polymers this way, further lab experimentation on the act system should be conducted before the plant begins operation.

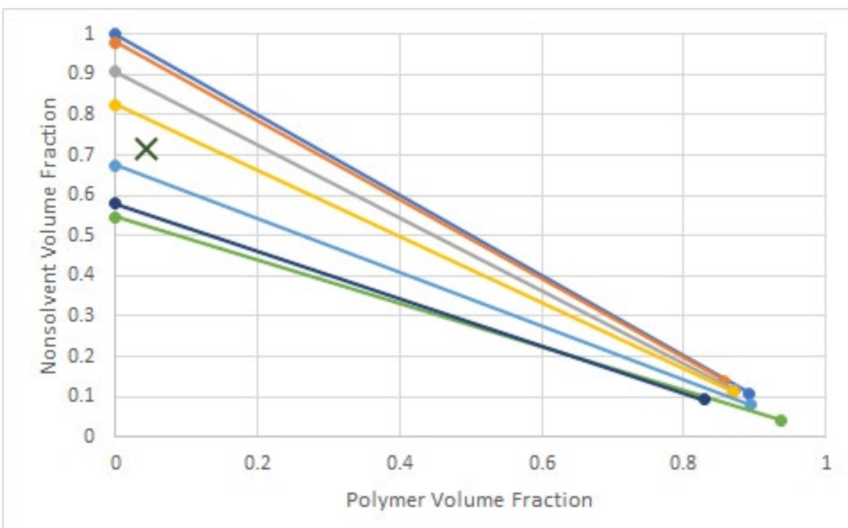


Figure 21.1. Preliminary Ternary Phase Diagram of LDPE-Toluene-Isopropanol System. Tie lines were generated for several initial concentrations of the system. The two phases are a solvent-nonsolvent dominant phases and a polymer-dominants phase with approximately 10% solvent and nonsolvent. Further experimentation is required to determine a truer and more accurate ternary phase diagram.

21.1.2. Viscosity

Further experimentation to find the viscosity data of LDPE dissolved in toluene would be useful, though not necessary, before building the pilot plant. The viscosity data will better help predict the polymer's molecular weight distribution, as well as confirm or modify the assumptions made in the design of the process. Furthermore, with the viscosity data of LDPE in toluene solution, a sensitivity analysis can also be conducted to find the optimal operating point. This point would balance the costs to run the pumps at higher viscosities with the costs of using less solvent in the dissolution process. Figure 21.2 shows experimental viscosity for LDPE in methyl ester at a range of temperatures (Zhang, 2009). Since the methyl ester is a different solvent, it cannot be used to accurately estimate the viscosity in this process. However, methyl esters are significantly more viscous than toluene, so it is expected the viscosity inside the dissolution vessel will be lower than those shown here. In the figure, at 85°C and 15% LDPE, viscosity is under 5 cP. No data was found for LDPE in other solvents. Nevertheless, this chart justifies the assumption that at higher temperatures and LDPE concentrations lower than 20%, viscosity remains at workable levels. The experiment to measure and verify the exact viscosity of the toluene-LDPE system at 85°C should be relatively simple and likely to increase profits.

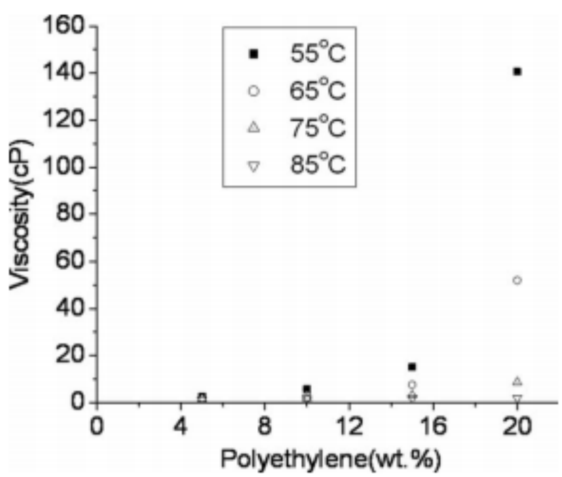


Figure 21.2. Viscosity of Polyethylene as a function of temperature and weight percentage. As the weight percentages of polymer increase, the viscosity starts to dramatically increase. This process holds the weight percentage of polymer at 15% to prevent a large increase in solution viscosity.

21.1.3. Presence of Other Polymers

For mass balance purposes, HDPE was assumed to be less than 1% of the total plastic bag mass. Further experimentation to find the composition of bag samples from various manufacturers could help identify the exact polymer composition of the grocery bags. The current process design could handle these other polymers, namely LLDPE and HDPE, with slight modifications. All these forms of polyethylene have similar properties; the presence of a small amount of LLDPE in the final product will not affect the quality. Should a significant amount of HDPE be found in the feed, the mass balance will have to be altered to include a higher rate of contaminant filtration in Stream 4 of the flowsheet. While HDPE is soluble in toluene, it dissolves an order of magnitude slower than LDPE (Pappa et al., 2001). The residence time in the dissolution vessel could then be lowered to closer to 15 minutes, where essentially all LDPE would still dissolve, and almost all HDPE would stay in a solid phase.

If the amount of HDPE content is significant enough, the HDPE can be collected as another recycled product. The process would become a temperature-controlled selective dissolution process. The process would separate the different polymers, based on solubility differences as temperature changes (Pappa et al., 2001). A new filtration system might also be necessary, as the Ettlinger filters used in this experiment can handle a throughput composed of up to 18% contaminants. Recycling other polymers is outside the scope of this paper, but such a technique could conceivably handle a wide variety of plastic waste from many sources with little manual sorting.

21.2. Research and Development for New Filter Technology

Currently the Ettlinger technology available only allows for filtration of particles up to 50 μm. In order to properly filter out the pigments used to label plastic bags, technology needs to be improved to eliminate these nanoparticles. Pigments common in shopping bags included diarylide yellow, phthalocyanine blue, dianisidine orange, and napthol red. All have similar structures to toluene, so it is likely many will remain mixed with the LDPE as it precipitates. A pilot experiment can verify this claim and quantify the exact amount of impurities remaining in the final product. However, any amount of these strong pigments will pose a problem, likely turning the product brown. By filtering out pigments and getting rid of discoloration of the recycled LDPE pellets, revenues from this proposed process design could increase by 33% as mentioned in Section 20.5.

Additionally, the Ettlinger company, though it seems like the ideal filter for this plant, does not yet have the technology to increase filter capacity beyond 6000 kg/hr. This contributes a fair amount to capital investment because just over 12000 kg/hr of material must be filtered. The company is developing newer products, and within a few years there could be one filter that could handle the entire system proposed.

21.3. Safety and Health Concerns

The solvents involved in the mid-process and back end process both have safety and health concerns. Both toluene and isopropanol are highly flammable. Inert nitrogen must be run through the mid-process and back end process to occupy space, and consultants agreed that a flare system in the mid-process to dispel waste vapors was a sufficient safety measure. Toluene also poses health hazards. The safety and health precautions for the handling of toluene and isopropanol have been included with the MSDS provided in Section 25.4.

21.4. Environmental Impact

To minimize the environmental impact of the mid-process and back end process, the method of disposing the purge streams and the method of letting flare out to the atmosphere should both be taken into consideration. The handling of toluene and isopropanol disposal have been included with the MSDS provided in Section 25.4.

21.5. Lower Demand for LDPE

21.5.1. LLDPE Market

Although there is currently a large market for selling LDPE, LDPE has been losing market share to LLDPE. LLDPE is one of the main components of grocery bags, and LLDPE has been replacing or blending with LDPE to form LLDPE-LDPE composites. LDPE has grown to account of 52-53% of the combined LDPE-LLDPE market (ICIS 2010). LLDPE can be dissolved and reprecipitated with the solvent and anti-solvent proposed. Through further experimentation to test the dissolution and reprecipitation LLDPE, the proposed design can be modified to account for higher percentages of LLDPE composition in plastic bags.

21.5.2. Single-Use Plastic Bag Ban Legislations

Due to the trend to reduce plastic waste, single-use plastic bag legislations have been enacted in several states (California, New York, etc.). Other states are likely to follow suit, and this can result in difficulties in finding sufficient feedstock for the proposed process. This is not a large concern for the next few decades, as it is unlikely that there will be a complete elimination of single-use grocery bags. However, it could be a concern in the future.

22 Conclusions and Recommendations

Through analysis of the proposed design, this process which employs the dissolution-precipitation technique for recycling waste trash bags warrants further investigation. This process is economically viable and makes sense considering the large abundance of plastic prevalent in this country. In this design, 50 tons per day of cleaned low density polyethylene waste trash bags are processed to produce recycled low density polyethylene polymer with 99.99% purity. For economic and safety concerns, toluene was selected as the solvent and isopropanol was chosen as the nonsolvent.

Economic analysis estimated a NPV of $5,896,300 with an IRR of 21.97% over a 20-year process lifetime. This return is based off an initial $14.9 MM total capital investment with recycle LDPE being sold at a 20% discount ($0.48 per pound) due to potential discoloration and waste trash bags being acquired at no cost. Sensitivity analyses were run on profitability of the system for selling price of the recycled LDPE, the acquisition cost of the waste trash grocery bags and variable costs. Holding each of the respective components constant, the current model maintains profitability only when recycled LDPE can be sold for greater than $0.4158 per pound (a 30.7% discount) and waste trash grocery bags can be acquired for less than $98 per ton. Important to note is that annual variable costs, especially the utility requirements of electricity and high pressure steam, which can play a significant role in these profitability metrics. When further analyzing this design, one should look more closely at each of these economic factors to confirm the base case profitability measures.

Additionally, several other assumptions must be revisited prior to scaling this process up to its intended operational capacity. First, the ternary phase diagram between the toluene, isopropanol and LDPE must be adequately tested to ensure that the two major assumptions in the precipitation and filtration process components are correct. It was assumed that 99% of the polymer precipitates and there is 10% contamination in the polymer-dominant solid stream entering the dryer. Further testing should seek to determine the phase compositions of these two phases produced from the precipitation vessel. Second, the residence times of both the dissolution and precipitation vessels were approximated. More research into the rate of dissolution would enhance the thoroughness of the process. Third, discussed throughout the process is the requirement of added nitrogen inert gas to the process to limit flammability concerns. The inclusion of pressure relief systems and proper ventilation is included in the overall cost of this venture but must be investigated more thoroughly. Lastly, we recommend that a considerable amount of research be dedicated to finding an advanced filtration technology to replace the Ettlinger filters. The purpose of this advanced filtration technology would be to remove the pigments and dyes from the polymer solution so as increase the purity and reduce the discoloration of the final product. Each of these areas must be revisited should investors seek to invest in this process, yet with these factors considered we believe that this design must warrant further attention.

23 Acknowledgements

This project could not have been completed without the help of many individuals throughout the course of the semester. We would like to thank Dr. Riggleman and Professor Vrana for their guidance throughout the design project. Additionally, we would like to thank Dr. Targett for proposing this project, his willingness to provide resources and his professional knowledge in aiding our process design. We would also like to thank Professor Fabiano for initially working with us in attempting to model the simulation in ASPEN. Lastly, we greatly appreciate the guidance and helpful input during the design meeting from the following industrial consultants: Dr. Richard Bockrath, Dr. Arthur Etchells, Dr. P.C. Gopalratnam, Dr. Daniel Green and Dr. Michael Grady.

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25 Appendix

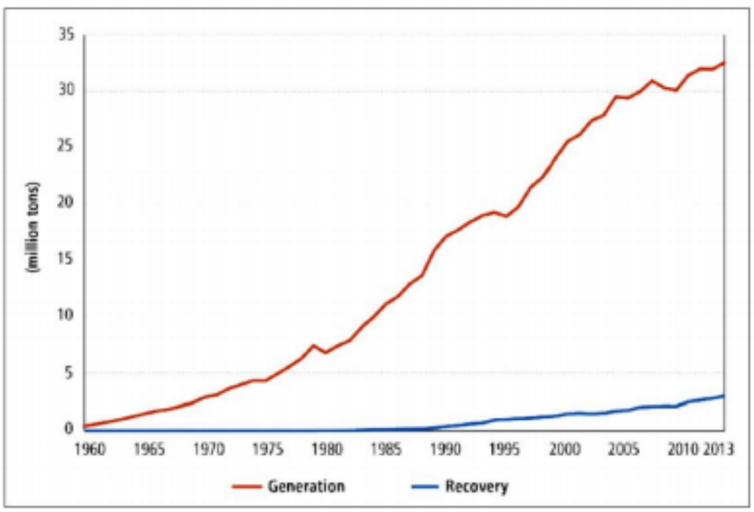
25.1. Project Statement

9. Chemical Recycling of Plastics by Dissolution (Recommended by Dr. Matthew Targett, SpruceWorks LLC)

Overview

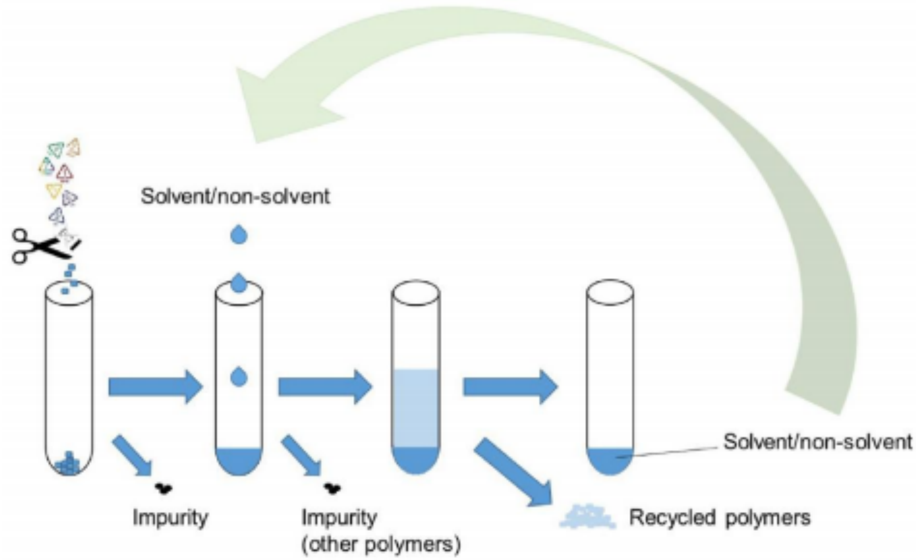
Plastic items are a critical part of modern society and they are used in almost every aspect of our lives. One of the values of plastics for packaging and as manufactured articles is their inherent strength and durability. However, this means that plastics remain durable after use and continue to accumulate in the environment indefinitely. As we use more and more plastic, we also discard an ever-growing amount of plastic that will last for centuries.

Today, plastics are disposed of in several ways including recycling, landfilling, incineration, composting and littering. In the US, nearly 90% of plastics are being discarded into landfills. To be more sustainable, it is important to understand what our environmental and economical options are for waste plastic recycling and embrace techno-economically viable methods that will address these issues.



Plastics Generation and Recovery via Recycling
Source: US EPA

Dissolution and reprecipitation of plastic wastes has been considered for a number of polymer types over the past several decades as a means of reconstituting and purifying the polymeric feedstock material. See [1] Zhao et al., 2018 where the following schematic is reported.



Schematic Drawing of the Dissolution/Precipitation Technique. Source: [1] Zhao etal, 2018.

	Solvent extraction	Primary mechanical recovery
Procedures	(1) Cut and remove the pollutant and impurity. (2) Dissolve to the highest possible concentration. (3) Re-precipitate the polymer in solvents by adding nonsolvents (add supercritical fluids to extract solvents) (4) Filter, wash, and dry the obtained polymer (5) Separate and recover solvent/nonsolvent (solvent/supercritical fluids).	(1) Shred (grind) plastic in a suitable form (2) Wash the plastics by water (3) Agglutinated by pigments and additives (4) Extrusion (5) Quenching (6) Granulation
Advantages	(1) Obtained in accepted form, such as granules and powder. (2) Remove the additives and insoluble contaminants. (3) No further degradation occurs except heating for a fully dissolution. (4) The properties of the recycled product are competitive compared with virgin products. (5) A massive decrease in the bulk volume.	(1) The properties of the recycled product are competitive compared with virgin products. (2) Simple operation
Disadvantages	(1) Relatively high technical requirements (2) Relatively high costs	(1) Degradation of recovered product (2) Limited applications

General Comparison of Dissolution/Precipitation Technique with Primary Mechanical Recovery Technique. Source: [1] Zhao et al., 2018.

For the purposes of this project, the objective will be to determine the optimal commercial dissolution-reprecipitation process configuration for converting waste polyethylene (PE) to useful recycle polymer products. It is recommended to base the main conversion process directly on the experimental data reported in [2] Pappa et al, 2001 or [3] Achilias et al, 2009. If any other new work involving super critical CO_2 as the reprecipitaion solvent is found in the literature, then it should also be considered as a viable alternative for comparison.

- Dissolution-Reprecipitation of waste PE shopping bags (customer drop off at stores such as Walmart, other)
- Temperature ranges and residence times for Dissolution and Reprecipitation and Drying as indicated, but challenge the kinetic rates of these processes which may be improved based on accepted industrial practices.
- Product Outputs: mainly purified PE, and also non-PE residue (inks, other plastics, paper, tramp materials, etc.)

Polymer	Strong solvents	Weak solvents	Experimental conditions	References
PE	xylene	propanol	30 L xylene was added into a mixture of 3 kg PE and 3 kg PP with stirring for 1 h at 85 °C, and PE was dissolved, precipitated by 90 L propanol, and dried at 80 °C for 6 h.	(Pappa et al., 2001)
PE	xylene	n-hexane methanol	1 g PE was dissolved in 20 mL solvent with heating (100 °C) for 30 min, reprecipitated, and dried at 89 °C for 24 h.	(Achilias et al., 2009b)

Example Dissolution-Reprecipitation Schemes, from [2] Pappa et al 2001, and [3] Achilias et al 2009.

In terms of a rigorous and detailed project structure, the following approach is recommended at the outset. The key to a techno-economic evaluation success is a sufficiently accurate process simulation model covering major processing steps; namely, dissolution, filtration, solvent recycle, reprecipitation, filtration, reprecipitation solvent recovery (drying), and recycle polymer pelletization. The main refining steps of solvent(s) recovery need to take into account integrated energy saving heat integration schemes. The process simulation model should take into account user-defined Key Input Variables (KIVs) and have the ability to predict Key Output Variables (KOVs). Some of the key input variables will be fixed.

Project Statement – defined criteria

- Capacity: 50 TPD PE waste bag feed
- Polymer Product Purity, polymer grade purity of >99.99%
- Polymer selling prices, to be estimated by analysis of long term market trends
- Waste polymer purchase costs, assume small nominal payment (as this material may be sent to landfill currently at a cost to the retailer)
- Waste polymer delivery costs, assume market based shipping fees

Key Input Variables – to be varied for the purposes of determining lowest Capex-Opex operation
- Types of solvent recovery systems (filters, dryers, distillation, etc.)
- Process temperatures (dissolution, reprecipitation, drying, etc.)
- Heat integration

Key Output Variables – to be determined by modelling/optimization via varying of Key Input Variables
- OPEX cost, $ per ton of products
- Capex investment, $ per ton of annual PE consumption
- IRR/NPV

Note

The author of this project is not based in Philadelphia. Many or all interactions with the author will be through SKYPE, phone and/or email. Over many years, the author has provided many excellent design projects for CBE 459 design groups and has been an active design consultant.

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[3] Achilias, D.S., Giannoulis, A., Papageorgiou, G.Z., **Recycling of Polymers from Plastic Packaging Materials Using the Dissolution-Reprecipitation Technique**. Polym. Bull. 63: 449-465, 2009

25.2. Sizing and Costing Calculations

25.2.1. Dissolution and Reprecipitation Vessels

Sample calculations for dissolution vessel V-101. Both vessels are modeled as ribbon mixers for solids and fluids handling.

Sizing

$$Mass\ Flow = Density * Volumetric\ Flow$$

For toluene, $Q = \frac{23576\ ^{lb}/_{hr}}{51\ ^{lb}/_{ft^3}} * \frac{7.48\ gallon}{cubic\ foot} * \frac{1\ hr}{60\ min} = 57.63\ gpm$

Adding the LDPE flowrate, calculated the same way, Q_{total}= 68.42 gpm (put into gpm for pump calculations)

For the reprecipitation vessel, the IPA flowrate was also included

At the desired residence time, $Volume_{vessel} = 68.42\ \frac{gal}{min} * \frac{cubic\ ft}{7.48\ gal} * 30\ \text{min} = 274.4\ ft^3$

For a ribbon mixer, $Cp = \frac{616\ index}{567\ index} * 2410 * [V(in\ ft^3)]^{.6} = \$70{,}804$

25.2.2. Heat Exchangers

Equations are taken from Seider et. al. Chapter 12, Section 2, Pages 371-374 and Chapter 16, Section 5, Pages 461-463.

Heat Exchanger Sample Calculation shown for E-201

Sizing

The density and specific heat capacity of the stream entering the heat exchanger is a weighted average of the component densities and specific heat capacities.

$$Q = m_{14} C_P \Delta \text{T}$$

$$Q = \left(23601 \frac{lb}{hr}\right)\left(0.4063 \frac{btu}{lb \cdot F}\right)(208.58 - 281.66)F = -700{,}775\ btu/hr$$

$$A = \frac{-Q}{U \cdot F_T \cdot LMTD}$$

$$U = 100\ btu/(F \cdot ft^2 \cdot hr) \text{ estimated from Table 12.5}$$

$$F_T = \frac{\sqrt{R^2+1}\ \ln(\frac{1-S}{1-RS})}{(R-1)\ \ln(\frac{2-S(R+1-\sqrt{R^2+1}}{2-S(R+1+\sqrt{R^2+1}})}$$

$$R = \frac{T_{H,in} - T_{H,out}}{T_{C,out} - T_{C,in}} = \frac{281.66 - 208.58}{120 - 90} = 2.436$$
$$S = \frac{T_{C,out} - T_{C,in}}{T_{H,in} - T_{C,in}} = \frac{120 - 90}{281.66 - 90} = 0.253$$
Plugging in R and S into equation, $F_T = 0.903$
$$LMTD = \frac{\left(T_{H,in} - T_{C,out}\right) - \left(T_{H,out} - T_{C,in}\right)}{\ln\left(\frac{T_{H,in} - T_{C,out}}{T_{H,out} - T_{C,in}}\right)} = \frac{(281.66 - 120) - (208.58 - 90)}{\ln\left(\frac{281.66 - 120}{208.58 - 90}\right)} = 139.0\ °F$$
$$A = \frac{700{,}775}{(100)(0.903)(139.0)} = \mathbf{55.826\ ft^2}$$

Costing

$$C_P = F_P F_M F_L C_B$$
$$F_P = 1.00$$
$$F_M = 1.00 \text{ for Carbon Steel/Carbon Steel}$$
$$F_L = 1.00 \text{ for Tube Length of 20ft}$$
$$C_B = \exp\{12.0310 - 0.8709(\ln A) + 0.09005(\ln A)^2\} \text{ for Floating Head Heat Exchanger}$$
$$C_B = \exp\{12.0310 - 0.8709(\ln(55.826)) + 0.09005(\ln(55.826))^2\} = \$21{,}696$$
$$C_P = (1.00)(1.00)(1.00)(\$21696) = \$21{,}696$$
To convert a CE Index of 567 to 616, the final purchase cost is:

$$C_{p,616} = \left(\frac{616}{567}\right) C_{P,567} = \left(\frac{616}{567}\right)(\$21{,}696) = \$\mathbf{23{,}571}$$

For a Fixed Head Heat Exchanger, use:
$$C_B = \exp\{11.4185 - 0.9228(\ln A) + 0.09861(\ln A)^2\}$$
For a Kettle Vaporizer Heat Exchanger, use:
$$C_B = \exp\{12.3310 - 0.8709(\ln A) + 0.09005(\ln A)^2\}$$

25.2.3. Pumps
Equations are taken from Seider et. al. Chapter 16, Section 5, Pages 451-456.

Pump Sample Calculation shown for P-201

Sizing
Based off recommendations from industrial consultants and the simple pump requirement for moving liquid, a head of 100 feet was selected. The density of the stream entering the pump is a weighted average of the component densities.

$$S = Q(H)^{0.5}$$
$$S = (242.6\ gpm)(100\ ft)^{0.5} = \mathbf{2{,}426\ gpm \cdot ft^{1/2}}$$

Costing

$$C_P = F_T F_M C_B$$
$$F_T = 1.00 \text{ for XXX}$$
$$F_M = 2.00 \text{ for Stainless Steel}$$
$$C_B = \exp\{12.1656 - 1.1448(\ln S) + 0.0862(\ln S)^2\}$$
$$C_B = \exp\{12.1656 - 1.1448(\ln(2426)) + 0.0862(\ln(2426))^2\} = \$4{,}184$$
$$C_P = (1.00)(2.00)(\$4184) = \$9{,}629$$

To convert a CE Index of 567 to 616, the final purchase cost is:

$$C_{p,616} = \left(\frac{616}{567}\right) C_{P,567} = \left(\frac{616}{567}\right)(\$9{,}629) = \$\mathbf{10,461}$$

25.2.4. Electric Motors

Equations are taken from Seider et. al. Chapter 16, Section 5, Pages 451-456.

Electric Motor Sample Calculation shown for P-201

Sizing

$$\text{Pump Efficiency} = \eta_P = -0.316 + 0.24015(\ln Q) - 0.01199(\ln Q)^2$$
$$\eta_P = -0.316 + 0.24015(\ln(242.6)) - 0.01199(\ln(242.6))^2 = 0.641$$
$$\text{Pump Brake Power (hp)} = P_B = \frac{(Q)(H)(\rho)}{30000\,\eta_P}$$
$$P_B = \frac{(242.6\ gpm)(100\ ft)(6.772\ lb/gal)}{30000(0.641)} = 7.76 \text{ hp}$$
$$\text{Motor Efficiency} = \eta_M = 0.80 + 0.0319(\ln P_B) - 0.00182(\ln P_B)^2$$
$$\eta_M = 0.80 + 0.0319(\ln(7.76)) - 0.00182(\ln(7.76))^2 = 0.858$$
$$\text{Power Consumption (hp)} = P_C = \frac{P_B}{\eta_C}$$
$$P_C = \frac{7.76}{0.858} = \mathbf{9.05\ hp}$$

Costing

$$C_P = F_T C_B$$
$$F_T = 1.80 \text{ for Explosion} - \text{Proof Motor}$$
$$C_B = \exp\{5.9332 + 0.16829(\ln P_C) - 0.110056(\ln P_C)^2 + 0.071416(\ln P_C)^3 - 0.0063788(\ln P_C)^4\}$$
$$C_B = \exp\{5.9332 + 0.16829(\ln(9.05)) - 0.110056(\ln(9.05))^2 + 0.071416(\ln(9.05))^3 - 0.0063788(\ln(9.05))^4\} = \$592$$
$$C_P = (1.80)(\$592) = \$1{,}065$$

To convert a CE Index of 567 to 616, the final purchase cost is:

$$C_{p,616} = \left(\frac{616}{567}\right) C_{P,567} = \left(\frac{616}{567}\right)(\$1{,}065) = \$\mathbf{1,157}$$

25.2.5. Horizontal Pressure Vessels/Tanks

Equations are taken from Seider et. al. Chapter 16, Section 5, Pages 464-467.

Horizontal Pressure Vessel Sample Calculation shown for V-201

Sizing

The tank was modeled to have a 3-hr residence time and to be half-full. Assume a length-diameter ratio of 2:1. The density of the stream entering the pump is a weighted average of the component densities.

$$V = 2\dot{V}\tau$$

$$V = 2\left(436\frac{ft^3}{hr}\right)(3\ hr) = 2619\ ft^3$$

$$D = \left(\frac{2V}{\pi}\right)^{\frac{1}{3}} = \left(\frac{2(2619)}{\pi}\right)^{1/3} = 11.86\ ft$$

$$L = 2D = 23.71\ ft$$

$$W = \pi(D + t_s)(L + 0.8D)t_S\rho$$

$$t_S = 0.625\ in, \rho = 0.284\ lb/in^3$$

$$W = \pi(142\ in + 0.625\ in)\big(285\ in + 0.8(142\ in)\big)(0.625\ in)(0.284\ lb/in^3) = 23{,}434\ lb$$

Costing

$$C_P = C_{P,tank} + C_{P,agitator}$$

$$C_{P,tank} = F_M C_V$$

$$F_M = 1.00 \text{ for Carbon Steel}$$

$$C_V = \exp\{5.6336 + 0.4599(\ln W) + 0.00582(\ln W)^2\}$$

$$C_V = \exp\{5.6336 + 0.4599(\ln(23434)) + 0.00582(\ln(23434))^2\} = \$51{,}551$$

$$C_{P,tank} = (1.00)(\$51551) = \$51{,}551$$

$$C_{P,agitator} = 4105(Hp)^{0.57}$$

$$Hp = 10 \text{ based off of } 0.5\ \text{Hp}/1000\ \text{gal}$$

$$C_{P,agitator} = 4105(10)^{0.57} = \$15{,}252$$

$$C_P = (\$51551) + (\$15252) = \$\mathbf{66,803}$$

To convert a CE Index of 567 to 616, the final purchase cost is:

$$C_{p,616} = \left(\frac{616}{567}\right) C_{P,567} = \left(\frac{616}{567}\right)(\$66{,}803) = \$\mathbf{72,576}$$

25.2.6. Solid Storage Bins
Equations are taken from Seider et. al. Chapter 16, Section 6, Page 484.

Solid Storage Bin Sample Calculation shown for B-201

Sizing
A storage capacity of 7 days-worth of LDPE product was used to design the total volume.

$$V = \dot{V} \cdot (Total\ Storage\ Time)$$
$$V = \left(1829 \frac{ft^3}{day}\right)(7\ days) = \mathbf{12,805\ ft^3}$$

A storage bin is modeled with an upper portion (cubic cross-section) and a lower hopper (one side is sloping). Assume the ratio of the height of the bin to the shorter width is 3:1 as shown in Figure 15.2.6.1. Assume to thickness is three times the top width.

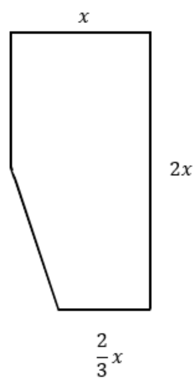


Figure 15.2.6.1. Example Storage Bin.

$$V = V_{cube} + V_{hopper}$$
$$V = 3x^3 + \frac{5}{3}x^3$$
$$x = (\frac{3}{14}V)^{1/3}$$
$$x = (\frac{3}{14}(12{,}805))^{1/3} = 14\ ft$$

Height = 28 feet, Thickness = 42 feet
Ground Cross-sectional Area = 588 ft^2, Top Cross-sectional Area = 392 ft^2

Costing

$$C_P = 646(V)^{0.46}$$
$$C_P = 646(12805)^{0.46} = \$\mathbf{50,075}$$

To convert a CE Index of 567 to 616, the final purchase cost is:

$$C_{p,616} = \left(\frac{616}{567}\right) C_{P,567} = \left(\frac{616}{567}\right)(\$50{,}075) = \$\mathbf{54,403}$$

25.2.7. Distillation Columns
Equations are taken from Seider et. al. Chapter 16, Section 5, Pages 464-469.

Distillation Column Sample Calculation shown for D-201

Sizing
Modeled with 24-in. tray spacing with 25 equilibrium stages.

$$W = \pi(D + t_s)(L + 0.8D)t_S\rho$$
$$D = 12\ ft \text{ estimated from ASPEN}$$
$$t_s = 0.625\ in \text{ to meet minimum thickness and corrosive protection}$$
$$L = (4ft) + 2(N_T - 1) + (10ft)$$
$$L = 4 + 2(24 - 1) + 10 = 60\ ft$$
$$W = \pi(144\ in + 0.625\ in)\big(720\ in + 0.8(144\ in)\big)(0.625\ in)(0.284\ lb/in^3) = 58{,}107\ lb$$

Costing
Tray Base Cost needs to be adjusted to current CE Index of 616.

$$C_P = C_{P,column} + C_{P,trays}$$
$$C_{P,column} = F_M C_{PL} + C_V$$
$$F_M = 1.00 \text{ for carbon steel}$$
$$C_{PL} = 341(D)^{0.63316}(L)^{0.80161}$$
$$C_{PL} = 341(12)^{0.63316}(60)^{0.80161} = \$43{,}796$$
$$C_V = \exp\{10.5449 - 0.4672(\ln W) + 0.05482(\ln W)^2\}$$
$$C_V = \exp\{10.5449 - 0.4672(ln(58107)) + 0.05482(ln(58107))^2\} = \$165{,}517$$
$$C_{P,column} = (1.00)(\$43796) + (\$165517) = \$209{,}313$$
$$C_{P,trays} = N_T F_{NT} F_{TT} F_{TM} C_{bt}$$
$$\text{Number Factor} = F_{NT} = 1.00 \text{ for} > 20 \text{ trays}$$
$$\text{Type Factor} = F_{TT} = 1.0 \text{ for Sieve Tray}$$
$$\text{Materials Factor} = F_{TM} = 1.00 \text{ for Carbon Steel}$$
$$\text{Tray Base Cost} = C_{bt} = 468 \exp\{0.1482(D)\} \times \left(\frac{616}{567}\right)$$
$$C_{bt} = 468 \exp\{0.1482(12)\} \times \left(\frac{616}{567}\right) = \$3{,}010$$
$$C_{P,trays} = (24)(1.00)(1.0)(1.00)(\$508) = \$72{,}244$$
$$C_P = (\$209{,}313) + (\$72{,}224) = \$281{,}557$$

To convert a CE Index of 567 to 616, the final purchase cost is:

$$C_{p,616} = \left(\frac{616}{567}\right) C_{P,567} = \left(\frac{616}{567}\right)(\$281{,}557) = \$\mathbf{305{,}889}$$

25.2.8. Rotary-Drum Vacuum Filters
Equations are taken from Seider et. al. Chapter 16, Section 6, Pages 471,484

Rotary-Drum Vacuum Filter Sample Calculation shown for F-201

Sizing

$$Total\ Filter\ Area = A = \pi DL$$
$$A = \pi(8\ ft)(10\ ft) = \mathbf{251\ ft^2}$$

Costing

$$C_P = \exp\{11.793 - 0.1905(\ln A) + 0.0554(\ln A)^2\}$$
$$C_P = \exp\{11.793 - 0.1905(\ln(251)) + 0.0554(\ln(251))^2\} = \$250{,}784$$

To convert a CE Index of 567 to 616, the final purchase cost is:

$$C_{p,616} = \left(\frac{616}{567}\right) C_{P,567} = \left(\frac{616}{567}\right)(\$250{,}784) = \$\mathbf{272,457}$$

25.2.9. Indirect-heat Steam Tube Rotary Dryers

Equations are taken from Seider et. al. Chapter 16, Section 6, Page 481 and modeled from Perry et. al. Chapter 12, Page 12-63.

Indirect-heat Steam Tube Rotary Dryer Sample Calculation shown for H-201

Sizing

Modeled from Perry et. al. Chapter 12, Page 12-63, Table 12-22.
Diameter x Length: 0.965 m x 4.572 m
Heat Transfer Area: 14 tubes (114 mm OD)
Motor Size: 2.2 hp (6 rotations/min)

$$A = N_T(\pi DL)$$
$$A = 14\big(\pi(0.114\ m)(4.572\ m)\big)\left(10.7639\frac{ft^2}{m^2}\right) = \mathbf{352\ ft^2}$$

Costing

$$C_P = 1520(A)^{0.80}$$
$$C_P = 1520(352)^{0.80} = \$165{,}791$$

To convert a CE Index of 567 to 616, the final purchase cost is:

$$C_{p,616} = \left(\frac{616}{567}\right) C_{P,567} = \left(\frac{616}{567}\right)(\$165{,}791) = \$\mathbf{180,119}$$

25.3. Tables and Figures

25.4. MSDS Sheets

Safety Data Sheet
according to 29CFR1910/1200 and GHS Rev. 3

Effective date : 01.31.2015 Page 1 of 8

Toluene, Reagent Grade

SECTION 1 : Identification of the substance/mixture and of the supplier

Product name : **Toluene, Reagent Grade**

Manufacturer/Supplier Trade name:

Manufacturer/Supplier Article number: **S25611**

Recommended uses of the product and uses restrictions on use:

Manufacturer Details:

AquaPhoenix Scientific
9 Barnhart Drive, Hanover, PA 17331

Supplier Details:

Fisher Science Education
15 Jet View Drive, Rochester, NY 14624

Emergency telephone number:

Fisher Science Education Emergency Telephone No.: 800-535-5053

SECTION 2 : Hazards identification

Classification of the substance or mixture:

Flammable
Flammable liquids, category 2

Irritant
Skin irritation, category 2
Specific target organ toxicity following single exposure, category 3

Health hazard
Reproductive toxicity, category 2
Specific target organ toxicity following repeated exposure, category 2
Aspiration hazard, category 2

Flam. Liq. 2
Skin Irrit. 2
Repr. 2
STOT SE 3, Central nervous system
STOT RE 2
Asp. Tox. 1
Aquatic Acute 2

Signal word :Danger

Hazard statements:
Highly flammable liquid and vapour
May be harmful if swallowed and enters airways
Causes skin irritation
May cause drowsiness or dizziness
Suspected of damaging fertility or the unborn child
May cause damage to organs through prolonged or repeated exposure
Toxic to aquatic life

Created by Global Safety Management, Inc. -Tel: 1-813-435-5161 - www.gsmsds.com

Precautionary statements:

If medical advice is needed, have product container or label at hand
Keep out of reach of children
Read label before use
Obtain special instructions before use
Wash skin thoroughly after handling
Use only outdoors or in a well-ventilated area
Avoid release to the environment
Wear protective gloves/protective clothing/eye protection/face protection
Do not handle until all safety precautions have been read and understood
Keep away from heat/sparks/open flames/hot surfaces. No smoking
Keep container tightly closed
Ground/bond container and receiving equipment
Use explosion-proof electrical/ventilating/light/equipment
Use only non-sparking tools
Take precautionary measures against static discharge
Do not breathe dust/fume/gas/mist/vapours/spray
IF SWALLOWED: Immediately call a POISON CENTER or doctor/physician
IF ON SKIN (or hair): Remove/Take off immediately all contaminated clothing. Rinse skin with water/shower
IF INHALED: Remove victim to fresh air and keep at rest in a position comfortable for breathing
IF exposed or concerned: Get medical advice/attention
Specific treatment (see supplemental first aid instructions on this label)
Do NOT induce vomiting
If skin irritation occurs: Get medical advice/attention
Take off contaminated clothing and wash before reuse
In case of fire: Use agents recommended in section 5 for extinction
Store in a well ventilated place. Keep container tightly closed
Store in a well ventilated place. Keep cool
Store locked up
Dispose of contents and container to an approved waste disposal plant

Other Non-GHS Classification:

WHMIS

B2


D2A


D2B


NFPA/HMIS

NFPA SCALE (0-4)

Health	2
Flammability	3
Physical Hazard	0
Personal Protection	X

HMIS RATINGS (0-4)

SECTION 3 : Composition/information on ingredients

Ingredients:
Percentages are by weight

SECTION 4 : First aid measures

Description of first aid measures

After inhalation: Move exposed to fresh air. Give artificial respiration if necessary. If breathing is difficult give oxygen.Loosen clothing and place exposed in a comfortable position.Seek immediate medical attention.

After skin contact: IMMEDIATELY flood affected skin with water while removing and isolating all contaminated clothing. Gently wash all affected skin areas thoroughly with soap and water. If symptoms such as redness or irritation develop, IMMEDIATELY call a physician and be prepared to transport the victim to a hospital for treatment.

After eye contact: Protect unexposed eye.Flush exposed eye gently using water for 15-20 minutes. Remove contact lenses while rinsing.IMMEDIATELY transport the victim after flushing eyes to a hospital even if no symptoms (such as redness or irritation) develop.

After swallowing: Rinse mouth with water.Never give anything by mouth to an unconscious person.DO NOT INDUCE VOMITING. IMMEDIATELY transport the victim to a hospital.

Most important symptoms and effects, both acute and delayed:

Irritation.Shortness of breath.Headache.Nausea.Dizziness.The substance is irritating to the eyes and respiratory tract. The substance may cause effects on the central nervous system. If this liquid is swallowed, aspiration into the lungs may result in chemical pneumonitis. Exposure at high levels could cause cardiac dysrhythmia and unconsciousness.;The substance defats the skin, which may cause dryness or cracking. The substance may have effects on the central nervous system. Exposure to the substance may increase noise-induced hearing loss. Animal tests show that this substance possibly causes toxicity to human reproduction or development.

Indication of any immediate medical attention and special treatment needed:

If seeking medical attention provide SDS document to physician. Physician should treat symptomatically.

SECTION 5 : Firefighting measures

Extinguishing media

Suitable extinguishing agents: Use foam, dry chemical, or carbon dioxide.

For safety reasons unsuitable extinguishing agents: Solid streams of water may spread fire.

Special hazards arising from the substance or mixture:

Thermal decomposition can lead to release of irritating gases and vapors.Vapors may ignited and cause explosion if in confined space. Vapors can flow across ignition source and flashback.

Advice for firefighters:

Protective equipment: Wear protective eyeware, gloves, and clothing. Refer to Section 8.

Additional information (precautions): Avoid inhaling gases, fumes, dust, mist, vapor, and aerosols. Avoid contact with skin, eyes, and clothing.Cool closed containers exposed to fire with water spray.Approach fire from upwind to avoid hazardous vapors and toxic decomposition. If material on fire or involved in fire: Do not extinguish fire unless flow can be stopped or safely confined. Use water in flooding quantities as fog. Solid streams of water may spread fire. Cool all affected containers with flooding quantities of water. Apply water from as far a distance as possible.

SECTION 6 : Accidental release measures

Personal precautions, protective equipment and emergency procedures:

Ensure adequate ventilation.Ensure that air-handling systems are operational. Beware of vapours accumulating to form explosive concentrations. Vapours can accumulate in low areas.Remove all sources of ignition.

Environmental precautions:

Should not be released into environment.Prevent from reaching drains, sewer, or waterway.

Methods and material for containment and cleaning up:

Wear protective eyeware, gloves, and clothing. Refer to Section 8.Always obey local regulations.If necessary use trained response staff or contractor. Evacuate personnel to safe areas. Containerize for disposal. Refer to Section 13.Keep in suitable closed containers for disposal.Remove all sources of ignition.Have extinguishing agent available in case of fire. Use non-sparking equipment.

Reference to other sections:

SECTION 7 : Handling and storage

Precautions for safe handling:

Avoid contact with skin, eyes, and clothing.Follow good hygiene procedures when handling chemical materials. Refer to Section 8.Follow proper disposal methods. Refer to Section 13.Do not eat, drink, smoke, or use personal products when handling chemical substances.Use explosion-proof equipment.Keep away from open flames, hot surfaces and sources of ignition.

Conditions for safe storage, including any incompatibilities:

Store in a cool location.Keep away from food and beverages.Protect from freezing and physical damage.Provide ventilation for containers. Keep container tightly sealed. Store away from incompatible materials. Store as flammable. Keep away from sources of ignition.

SECTION 8 : Exposure controls/personal protection



Control Parameters:	108-88-3 , Toluene, ACGIH TLV TWA 20 ppm 108-88-3, Toluene, OSHA PEL TWA 200 ppm
Appropriate Engineering controls:	Emergency eye wash fountains and safety showers should be available in the immediate vicinity of use or handling. Provide exhaust ventilation or other engineering controls to keep the airborne concentrations of vapor and mists below the applicable workplace exposure limits (Occupational Exposure Limits-OELs) indicated above.Use under a chemical fume hood.Use explosion-proof equipment.

Respiratory protection:	Where risk assessment shows air-purifying respirators are appropriate use a full-face particle respirator type N100 (US) or type P3 (EN 143) respirator cartridges as a backup to engineering controls.When necessary use NIOSH approved breathing equipment. Use under a chemical fume hood.
Protection of skin:	Select glove material impermeable and resistant to the substance.Select glove material based on rates of diffusion and degradation. Dispose of contaminated gloves after use in accordance with applicable laws and good laboratory practices.Use proper glove removal technique without touching outer surface. Avoid skin contact with used gloves.Wear protective clothing.
Eye protection:	Wear equipment for eye protection tested and approved under appropriate government standards such as NIOSH (US) or EN 166(EU).Safety glasses or goggles are appropriate eye protection.
General hygienic measures:	Perform routine housekeeping.Wash hands before breaks and immediately after handling the product.Avoid contact with skin, eyes, and clothing.Before rewearing wash contaminated clothing.

SECTION 9 : Physical and chemical properties

Appearance (physical state,color):	Clear, colorless liquid	**Explosion limit lower**: **Explosion limit upper**:	7 %(V) 1.2 %(V)
Odor:	Sweet, pungent, benzene-like odor.	**Vapor pressure**:	28.4 mm Hg @ 25 deg C
Odor threshold:	1.03 to 140 ug/cu m	**Vapor density**:	3.1
pH-value:	Not Determined	**Relative density**:	0.865 g/mL at 25 °C (77 °F)
Melting/Freezing point:	95°C (-139°F)	**Solubilities**:	Insoluble in water
Boiling point/Boiling range:	110 - 111 °C (230 - 232 °F)	**Partition coefficient (n-octanol/water)**:	log Kow 2.73
Flash point (closed cup):	4.0 °C (39.2 °F)	**Auto/Self-ignition temperature**:	535.0 °C (995.0 °F)
Evaporation rate:	2.4	**Decomposition temperature**:	Not Determined
Flammability (solid,gaseous):	Highly flammable	**Viscosity**:	a. Kinematic:Not determined b. Dynamic: Not Determined
Density: Not Determined			

SECTION 10 : Stability and reactivity

Reactivity: Nonreactive under normal conditions.Reacts violently with strong oxidants. This generates fire and explosion hazard.
Chemical stability: Stable under normal conditions.
Possible hazardous reactions: None under normal processing.Vapours may form explosive mixture with air.
Conditions to avoid: Incompatible materials.excess heat.Direct Sunlight
Incompatible materials: Oxidizing agents. Acids.

Toluene, Reagent Grade

Hazardous decomposition products: Carbon oxides.

SECTION 11 : Toxicological information

Acute Toxicity:		
Dermal:	108-88-3 (Toluene)	LD50 Rabbit: 12,124 mg/kg
Oral:	108-88-3 (Toluene)	LD50 Rat: 5000mg/kg
Inhalation:	108-88-3 (Toluene)	LC50 Rat: 12,500 - 28,800 mg/m3/4 h
Chronic Toxicity: No additional information.		
Corrosion Irritation:		
Dermal:	108-88-3 (Toluene)	Rabbit: Skin Irritation - 24 h
Sensitization:		No additional information.
Single Target Organ (STOT):		No additional information.
Numerical Measures:		No additional information.
Carcinogenicity:		IARC:: Group 3: Not classifiable as to its carcinogenicity to humans (Toluene)
Mutagenicity:		rat Liver DNA damage
Reproductive Toxicity:		Suspected human reproductive toxicant. rat - Inhalation Paternal Effects: Spermatogenesis (including genetic material, sperm morphology,motility, and count).rat - Oral Effects on Embryo or Fetus: Fetotoxicity (except death, e.g., stunted fetus).

SECTION 12 : Ecological information

Ecotoxicity

Fish LC50 - Oncorhynchus mykiss (rainbow trout) - 7.63 mg/l - 96 h: 108-88-3 (Toluene)

Invertebrates EC50 - Daphnia magna (Water flea) - 6 mg/l - 48 h: 108-88-3 (Toluene)

Persistence and degradability: Readily biodegradable
Bioaccumulative potential: bioconcentration in aquatic organisms is low to moderate
Mobility in soil: toluene is expected to have high to moderate mobility in soil.2.65 log Pow
Other adverse effects:

SECTION 13 : Disposal considerations

Waste disposal recommendations:

Contact a licensed professional waste disposal service to dispose of this material.Dispose of empty containers as unused product.Product or containers must not be disposed together with household garbage. It is the responsibility of the waste generator to properly characterize all waste materials according to applicable regulatory entities (US 40CFR262.11). Chemical waste generators must determine whether a discarded chemical is classified as a hazardous waste. Chemical waste generators must also consult local, regional, and national hazardous waste regulations. Ensure complete and accurate classification.

SECTION 14 : Transport information

UN-Number

1294

UN proper shipping name

Toluene

Transport hazard class(es)

Class:
3 Flammable liquids

Packing group:II
Environmental hazard:
Transport in bulk:
Special precautions for user:

SECTION 15 : Regulatory information

United States (USA)

SARA Section 311/312 (Specific toxic chemical listings):

Acute, Chronic, Fire

SARA Section 313 (Specific toxic chemical listings):

None of the ingredients is listed

RCRA (hazardous waste code):

108-88-3 Toluene - U220

TSCA (Toxic Substances Control Act):

All ingredients are listed.

CERCLA (Comprehensive Environmental Response, Compensation, and Liability Act):

108-88-3 Toluene 1000 lb

Proposition 65 (California):

Chemicals known to cause cancer:

None of the ingredients is listed

Chemicals known to cause reproductive toxicity for females:

None of the ingredients is listed

Chemicals known to cause reproductive toxicity for males:

None of the ingredients is listed

Chemicals known to cause developmental toxicity:

108-88-3 Toluene

Canada

Canadian Domestic Substances List (DSL):

All ingredients are listed.

Canadian NPRI Ingredient Disclosure list (limit 0.1%):

None of the ingredients is listed

Canadian NPRI Ingredient Disclosure list (limit 1%):

108-88-3 Toluene

SECTION 16 : Other information

This product has been classified in accordance with hazard criteria of the Controlled Products Regulations and the SDS contains all the information required by the Controlled Products Regulations. Note: . The responsibility to provide a safe workplace remains with the user. The user should consider the health hazards and safety information contained herein as a guide and should take those precautions required in an individual operation to instruct employees and develop work practice procedures for a safe work environment.The information contained herein is, to the best of our knowledge and belief, accurate. However, since the conditions of handling and use are beyond our control, we make no guarantee of results, and assume no liability for damages incurred by the use of this material. It is the responsibility of the user to comply with all applicable laws and regulations applicable to this material.

GHS Full Text Phrases:

Abbreviations and acronyms:

Effective date : 01.31.2015
Last updated : 03.19.2015

Isopropyl Alcohol (2-Propanol)

Safety Data Sheet

according to Federal Register / Vol. 77, No. 58 / Monday, March 26, 2012 / Rules and Regulations

Date of issue: 11/14/2013 Revision date: 01/26/2018 Supersedes: 09/29/2015 Version: 1.2

SECTION 1: Identification

1.1. Identification

Product form	: Substance
Substance name	: Isopropyl Alcohol (2-Propanol)
CAS-No.	: 67-63-0
Product code	: LC15750
Formula	: C3H8O
Synonyms	: 1-methylethanol / 1-methylethyl alcohol / 2-hydroxypropane / dimethyl carbinol / ethyl carbinol / hydroxypropane / IPA / i-propanol / isoethylcarbinol / propan-2-ol / sec-propanol

1.2. Recommended use and restrictions on use

Use of the substance/mixture	: Disinfectant Solvent

1.3. Supplier

LabChem Inc
Jackson's Pointe Commerce Park Building 1000, 1010 Jackson's Pointe Court
Zelienople, PA 16063 - USA
T 412-826-5230 - F 724-473-0647
info@labchem.com - www.labchem.com

1.4. Emergency telephone number

Emergency number	: CHEMTREC: 1-800-424-9300 or 011-703-527-3887

SECTION 2: Hazard(s) identification

2.1. Classification of the substance or mixture

GHS-US classification

Flammable liquids Category 2	H225	Highly flammable liquid and vapour
Serious eye damage/eye irritation Category 2A	H319	Causes serious eye irritation
Specific target organ toxicity (single exposure) Category 3	H335	May cause respiratory irritation

Full text of H statements : see section 16

2.2. GHS Label elements, including precautionary statements

GHS-US labeling

Hazard pictograms (GHS-US) :

GHS02 GHS07

Signal word (GHS-US) : Danger

Hazard statements (GHS-US) :
H225 - Highly flammable liquid and vapour
H319 - Causes serious eye irritation
H335 - May cause respiratory irritation

Precautionary statements (GHS-US) :
P210 - Keep away from heat, hot surfaces, open flames, sparks. - No smoking.
P233 - Keep container tightly closed.
P240 - Ground/bond container and receiving equipment.
P241 - Use explosion-proof electrical, lighting, ventilating equipment
P242 - Use only non-sparking tools.
P243 - Take precautionary measures against static discharge.
P261 - Avoid breathing mist, vapors, spray.
P264 - Wash exposed skin thoroughly after handling.
P271 - Use only outdoors or in a well-ventilated area.
P280 - Wear eye protection, face protection, protective clothing, protective gloves.
P303+P361+P353 - IF ON SKIN (or hair): Remove/Take off immediately all contaminated clothing. Rinse skin with water/shower.
P305+P351+P338 - If in eyes: Rinse cautiously with water for several minutes. Remove contact

lenses, if present and easy to do. Continue rinsing
P312 - Call a POISON CENTER or doctor/physician if you feel unwell.
P337+P313 - If eye irritation persists: Get medical advice/attention.
P370+P378 - In case of fire: Use dry chemical powder, alcohol-resistant foam, carbon dioxide (CO_2) to extinguish
P403+P233 - Store in a well-ventilated place. Keep container tightly closed.
P405 - Store locked up.
P501 - Dispose of contents/container to comply with local, state and federal regulations
P235 - Keep cool.
If inhaled: Remove person to fresh air and keep comfortable for breathing

2.3. Other hazards which do not result in classification

Other hazards not contributing to the classification : None.

2.4. Unknown acute toxicity (GHS US)

Not applicable

SECTION 3: Composition/Information on ingredients

3.1. Substances

Substance type : Mono-constituent

Name	Product identifier	%	GHS-US classification
Isopropyl Alcohol (2-Propanol) (Main constituent)	(CAS-No.) 67-63-0	100	Flam. Liq. 2, H225 Eye Irrit. 2A, H319 STOT SE 3, H335

Full text of hazard classes and H-statements : see section 16

3.2. Mixtures

Not applicable

SECTION 4: First-aid measures

4.1. Description of first aid measures

First-aid measures general : Check the vital functions. Unconscious: maintain adequate airway and respiration. Respiratory arrest: artificial respiration or oxygen. Cardiac arrest: perform resuscitation. Victim conscious with labored breathing: half-seated. Victim in shock: on his back with legs slightly raised. Vomiting: prevent asphyxia/aspiration pneumonia. Prevent cooling by covering the victim (no warming up). Keep watching the victim. Give psychological aid. Keep the victim calm, avoid physical strain. Depending on the victim's condition: doctor/hospital. Never give alcohol to drink.

First-aid measures after inhalation : Remove the victim into fresh air. Respiratory problems: consult a doctor/medical service.

First-aid measures after skin contact : Rinse with water. Soap may be used. Do not apply (chemical) neutralizing agents. Take victim to a doctor if irritation persists.

First-aid measures after eye contact : Rinse immediately with plenty of water. Do not apply neutralizing agents. Take victim to an ophthalmologist if irritation persists.

First-aid measures after ingestion : Rinse mouth with water. Immediately after ingestion: give lots of water to drink. Do not induce vomiting. Give activated charcoal. Call Poison Information Centre (www.big.be/antigif.htm). Consult a doctor/medical service if you feel unwell. Ingestion of large quantities: immediately to hospital. Doctor: gastric lavage.

4.2. Most important symptoms and effects (acute and delayed)

Symptoms/effects after inhalation : EXPOSURE TO HIGH CONCENTRATIONS: Coughing. Dry/sore throat. Central nervous system depression. Dizziness. Headache. Narcosis.

Symptoms/effects after skin contact : Dry skin.

Symptoms/effects after eye contact : Irritation of the eye tissue.

Symptoms/effects after ingestion : AFTER ABSORPTION OF LARGE QUANTITIES: Central nervous system depression. Headache. Dilation of the blood vessels. Low arterial pressure. Nausea. Vomiting. Abdominal pain. Disturbed motor response. Disturbances of consciousness. FOLLOWING SYMPTOMS MAY APPEAR LATER: Body temperature fall. Slowing respiration.

Chronic symptoms : ON CONTINUOUS/REPEATED EXPOSURE/CONTACT: Red skin. Dry skin. Itching. Cracking of the skin. Skin rash/inflammation. Impaired memory.

4.3. Immediate medical attention and special treatment, if necessary

No additional information available

SECTION 5: Fire-fighting measures

5.1. Suitable (and unsuitable) extinguishing media

Suitable extinguishing media : Water spray. Polyvalent foam. Alcohol-resistant foam. BC powder. Carbon dioxide.

Unsuitable extinguishing media : Solid water jet ineffective as extinguishing medium.

5.2. Specific hazards arising from the chemical

Fire hazard : DIRECT FIRE HAZARD. Highly flammable. Gas/vapor flammable with air within explosion limits. INDIRECT FIRE HAZARD. May be ignited by sparks. Gas/vapor spreads at floor level: ignition hazard.

Explosion hazard : DIRECT EXPLOSION HAZARD. Gas/vapour explosive with air within explosion limits. INDIRECT EXPLOSION HAZARD. may be ignited by sparks. Reactions with explosion hazards: see "Reactivity Hazard".

Reactivity : Upon combustion: CO and CO2 are formed. Violent to explosive reaction with (strong) oxidizers. Prolonged storage/in large quantities: may form peroxides.

5.3. Special protective equipment and precautions for fire-fighters

Firefighting instructions : Cool tanks/drums with water spray/remove them into safety. Do not move the load if exposed to heat.

Protection during firefighting : Heat/fire exposure: compressed air/oxygen apparatus.

SECTION 6: Accidental release measures

6.1. Personal precautions, protective equipment and emergency procedures

6.1.1. For non-emergency personnel

Protective equipment : Gloves. Protective goggles. Protective clothing. Large spills/in enclosed spaces: compressed air apparatus. See "Material-Handling" to select protective clothing.

Emergency procedures : Keep upwind. Mark the danger area. Consider evacuation. Seal off low-lying areas. Close doors and windows of adjacent premises. Stop engines and no smoking. No naked flames or sparks. Spark- and explosion-proof appliances and lighting equipment. Keep containers closed. Wash contaminated clothes.

6.1.2. For emergency responders

Protective equipment : Equip cleanup crew with proper protection. Do not breathe gas, fumes, vapor or spray.

Emergency procedures : Stop leak if safe to do so. Ventilate area. If a major spill occurs, all personnel should be immediately evacuated and the area ventilated.

6.2. Environmental precautions

Prevent spreading in sewers.

6.3. Methods and material for containment and cleaning up

For containment : Contain released substance, pump into suitable containers. Consult "Material-handling" to select material of containers. Plug the leak, cut off the supply. Dam up the liquid spill. Try to reduce evaporation. Measure the concentration of the explosive gas-air mixture. Dilute/disperse combustible gas/vapour with water curtain. Provide equipment/receptacles with earthing. Do not use compressed air for pumping over spills.

Methods for cleaning up : Take up liquid spill into absorbent material, e.g.: dry sand/earth/vermiculite or powdered limestone. Scoop absorbed substance into closing containers. See "Material-handling" for suitable container materials. Damaged/cooled tanks must be emptied. Do not use compressed air for pumping over spills. Carefully collect the spill/leftovers. Clean contaminated surfaces with an excess of water. Take collected spill to manufacturer/competent authority. Wash clothing and equipment after handling.

6.4. Reference to other sections

No additional information available

SECTION 7: Handling and storage

7.1. Precautions for safe handling

Precautions for safe handling : Comply with the legal requirements. Remove contaminated clothing immediately. Clean contaminated clothing. Handle uncleaned empty containers as full ones. Thoroughly clean/dry the installation before use. Do not discharge the waste into the drain. Do not use compressed air for pumping over. Use spark-/explosionproof appliances and lighting system. Take precautions against electrostatic charges. Keep away from naked flames/heat. Keep away from ignition sources/sparks. Observe normal hygiene standards. Keep container tightly closed. Measure the concentration in the air regularly. Work under local exhaust/ventilation.

Hygiene measures	: Wash hands and other exposed areas with mild soap and water before eating, drinking or smoking and when leaving work. Wash contaminated clothing before reuse.

7.2. Conditions for safe storage, including any incompatibilities

Incompatible products	: Ammonia. Strong acids. Strong oxidizers.
Incompatible materials	: Direct sunlight. Heat sources. Sources of ignition.
Heat-ignition	: KEEP SUBSTANCE AWAY FROM: heat sources. ignition sources.
Prohibitions on mixed storage	: KEEP SUBSTANCE AWAY FROM: oxidizing agents. strong acids. (strong) bases. amines. halogens.
Storage area	: Store in a cool area. Store in a dry area. Ventilation at floor level. Fireproof storeroom. Provide for an automatic sprinkler system. Provide for a tub to collect spills. Provide the tank with earthing. May be stored under nitrogen. Meet the legal requirements.
Special rules on packaging	: SPECIAL REQUIREMENTS: closing. with pressure relief valve. dry. clean. correctly labelled. meet the legal requirements. Secure fragile packagings in solid containers.
Packaging materials	: SUITABLE MATERIAL: stainless steel. monel steel. carbon steel. copper. nickel. bronze. glass. Teflon. polyethylene. polypropylene. zinc. MATERIAL TO AVOID: steel with rubber inner lining. aluminium.

SECTION 8: Exposure controls/personal protection

8.1. Control parameters

Isopropyl Alcohol (2-Propanol) (67-63-0)		
ACGIH	ACGIH TWA (ppm)	200 ppm (2-propanol; USA; Time-weighted average exposure limit 8 h; TLV - Adopted Value)
ACGIH	ACGIH STEL (ppm)	400 ppm (2-propanol; USA; Short time value; TLV - Adopted Value)
OSHA	OSHA PEL (TWA) (mg/m³)	980 mg/m³
OSHA	OSHA PEL (TWA) (ppm)	400 ppm
IDLH	US IDLH (ppm)	2000 ppm
NIOSH	NIOSH REL (TWA) (mg/m³)	980 mg/m³
NIOSH	NIOSH REL (TWA) (ppm)	400 ppm
NIOSH	NIOSH REL (STEL) (mg/m³)	1225 mg/m³
NIOSH	NIOSH REL (STEL) (ppm)	500 ppm

8.2. Appropriate engineering controls

Appropriate engineering controls	: Emergency eye wash fountains and safety showers should be available in the immediate vicinity of any potential exposure. Provide adequate general and local exhaust ventilation.

8.3. Individual protection measures/Personal protective equipment

Personal protective equipment:

Safety glasses. Gloves. Protective clothing. Face shield. High gas/vapor concentration: gas mask with filter type A.

Materials for protective clothing:

GIVE EXCELLENT RESISTANCE: butyl rubber. nitrile rubber. viton. polyethylene/ethylenevinylalcohol. GIVE GOOD RESISTANCE: neoprene. GIVE LESS RESISTANCE: PVC. neoprene/natural rubber. GIVE POOR RESISTANCE: natural rubber. polyethylene. PVA

Hand protection:

Gloves

Eye protection:

Safety glasses

Skin and body protection:

Protective clothing

Respiratory protection:

Wear gas mask with filter type A if conc. in air
> exposure limit

SECTION 9: Physical and chemical properties

9.1. Information on basic physical and chemical properties

Physical state	: Liquid
Appearance	: Liquid.
Color	: Colourless
Odor	: Alcohol odour Stuffy odour Mild odour
Odor threshold	: 3 - 610 ppm 8 - 1499 mg/m³
pH	: No data available
Melting point	: -88 °C
Freezing point	: No data available
Boiling point	: 82 °C (1013 hPa)
Critical temperature	: 235 °C
Critical pressure	: 47600 hPa
Flash point	: 12 °C
Relative evaporation rate (butyl acetate=1)	: 2.3
Relative evaporation rate (ether=1)	: 21
Flammability (solid, gas)	: No data available
Vapor pressure	: 44 hPa (20 °C)
Vapor pressure at 50 °C	: 60.2 hPa (25 °C)
Relative vapor density at 20 °C	: 2.1
Relative density	: 0.79
Relative density of saturated gas/air mixture	: 1.05
Specific gravity / density	: 785 kg/m³
Molecular mass	: 60.1 g/mol
Solubility	: Soluble in water. Soluble in ethanol. Soluble in ether. Soluble in acetone. Soluble in oils/fats. Soluble in chloroform. Water: Complete Ethanol: Complete Ether: Complete Acetone: soluble
Log Pow	: 0.05 (Weight of evidence approach; Other; 25 °C)
Auto-ignition temperature	: 399 °C
Decomposition temperature	: No data available
Viscosity, kinematic	: 2.5316 mm²/s (25 °C)
Viscosity, dynamic	: 0.002 Pa.s (25 °C)
Explosion limits	: 2 - 13 vol % 50 - 335 g/m³
Explosive properties	: No data available
Oxidizing properties	: No data available

9.2. Other information

Minimum ignition energy	: 0.65 mJ
Specific conductivity	: 5.8 µS/m
Saturation concentration	: 106 g/m³
VOC content	: 100 %
Other properties	: Gas/vapour heavier than air at 20°C. Clear. Volatile.

SECTION 10: Stability and reactivity

10.1. Reactivity

Upon combustion: CO and CO2 are formed. Violent to explosive reaction with (strong) oxidizers. Prolonged storage/in large quantities: may form peroxides.

10.2. Chemical stability

Stable under normal conditions.

10.3. Possibility of hazardous reactions

May react violently with oxidants.

10.4. Conditions to avoid

Direct sunlight. High temperature. Incompatible materials. Open flame. Sparks.

10.5. Incompatible materials

Ammonia. Strong acids. Strong oxidizers.

10.6. Hazardous decomposition products

Carbon dioxide. Carbon monoxide.

SECTION 11: Toxicological information

11.1. Information on toxicological effects

Likely routes of exposure : Inhalation; Skin and eye contact

Acute toxicity : Not classified

Isopropyl Alcohol (2-Propanol) (67-63-0)	
LD50 dermal rabbit	12870 mg/kg (Rabbit; Experimental value; Equivalent or similar to OECD 402; 16.4; Rabbit)
LC50 inhalation rat (mg/l)	73 mg/l/4h (Rat)
ATE US (oral)	5045 mg/kg body weight
ATE US (dermal)	12870 mg/kg body weight
ATE US (vapors)	73 mg/l/4h
ATE US (dust, mist)	73 mg/l/4h

Skin corrosion/irritation : Not classified

Serious eye damage/irritation : Causes serious eye irritation.

Respiratory or skin sensitization : Not classified

Germ cell mutagenicity : Not classified

Carcinogenicity : Not classified

Isopropyl Alcohol (2-Propanol) (67-63-0)	
IARC group	3 - Not classifiable

Reproductive toxicity : Not classified

Specific target organ toxicity – single exposure : May cause respiratory irritation.

Specific target organ toxicity – repeated exposure : Not classified

Aspiration hazard : Not classified

Symptoms/effects after inhalation : EXPOSURE TO HIGH CONCENTRATIONS: Coughing. Dry/sore throat. Central nervous system depression. Dizziness. Headache. Narcosis.

Symptoms/effects after skin contact : Dry skin.

Symptoms/effects after eye contact : Irritation of the eye tissue.

Symptoms/effects after ingestion : AFTER ABSORPTION OF LARGE QUANTITIES: Central nervous system depression. Headache. Dilation of the blood vessels. Low arterial pressure. Nausea. Vomiting. Abdominal pain. Disturbed motor response. Disturbances of consciousness. FOLLOWING SYMPTOMS MAY APPEAR LATER: Body temperature fall. Slowing respiration.

Chronic symptoms : ON CONTINUOUS/REPEATED EXPOSURE/CONTACT: Red skin. Dry skin. Itching. Cracking of the skin. Skin rash/inflammation. Impaired memory.

SECTION 12: Ecological information

12.1. Toxicity

Ecology - general : Not classified as dangerous for the environment according to the criteria of Directive 67/548/EEC. Not classified as dangerous for the environment according to the criteria of Regulation (EC) No 1272/2008.

Ecology - air : Not classified as dangerous for the ozone layer (Regulation (EC) No 1005/2009). Not included in the list of substances which may contribute to the greenhouse effect (Regulation (EC) No 842/2006). TA-Luft Klasse 5.2.5.

Ecology - water : Ground water pollutant. Not harmful to fishes (LC50(96h) >1000 mg/l). Not harmful to invertebrates (Daphnia). Not harmful to algae (EC50 (72h) >1000 mg/l). Inhibition of activated sludge.

Isopropyl Alcohol (2-Propanol) (67-63-0)	
LC50 fish 2	9640 mg/l (LC50; OECD 203: Fish, Acute Toxicity Test; 96 h; Pimephales promelas; Flow-through system; Fresh water; Experimental value)
EC50 Daphnia 2	13299 mg/l (EC50; Other; 48 h; Daphnia magna)
Threshold limit algae 1	> 1000 mg/l (EC50; UBA; 72 h; Scenedesmus subspicatus)

12.2. Persistence and degradability

Isopropyl Alcohol (2-Propanol) (67-63-0)	
Persistence and degradability	Readily biodegradable in water. Biodegradable in the soil. Biodegradable in the soil under anaerobic conditions. No test data on mobility of the substance available.
Biochemical oxygen demand (BOD)	1.19 g O_2/g substance
Chemical oxygen demand (COD)	2.23 g O_2/g substance
ThOD	2.4 g O_2/g substance

12.3. Bioaccumulative potential

Isopropyl Alcohol (2-Propanol) (67-63-0)	
Log Pow	0.05 (Weight of evidence approach; Other; 25 °C)
Bioaccumulative potential	Low potential for bioaccumulation (Log Kow < 4).

12.4. Mobility in soil

Isopropyl Alcohol (2-Propanol) (67-63-0)	
Surface tension	0.021 N/m (25 °C)

12.5. Other adverse effects

No additional information available

SECTION 13: Disposal considerations

13.1. Disposal methods

Waste disposal recommendations : Remove waste in accordance with local and/or national regulations. Hazardous waste shall not be mixed together with other waste. Different types of hazardous waste shall not be mixed together if this may entail a risk of pollution or create problems for the further management of the waste. Hazardous waste shall be managed responsibly. All entities that store, transport or handle hazardous waste shall take the necessary measures to prevent risks of pollution or damage to people or animals. Recycle by distillation. Remove to an authorized waste incinerator for solvents with energy recovery. Do not discharge into surface water. Obtain the consent of pollution control authorities before discharging to wastewater treatment plants.

Additional information : LWCA (the Netherlands): KGA category 03. Hazardous waste according to Directive 2008/98/EC.

SECTION 14: Transport information

Department of Transportation (DOT)

In accordance with DOT

Transport document description : UN1219 Isopropyl alcohol, 3, II

UN-No.(DOT) : UN1219

Proper Shipping Name (DOT) : Isopropyl alcohol

Transport hazard class(es) (DOT) : 3 - Class 3 - Flammable and combustible liquid 49 CFR 173.120

Packing group (DOT)	:	II - Medium Danger
Hazard labels (DOT)	:	3 - Flammable liquid

DOT Packaging Non Bulk (49 CFR 173.xxx)	:	202
DOT Packaging Bulk (49 CFR 173.xxx)	:	242
DOT Special Provisions (49 CFR 172.102)	:	IB2 - Authorized IBCs: Metal (31A, 31B and 31N); Rigid plastics (31H1 and 31H2); Composite (31HZ1). Additional Requirement: Only liquids with a vapor pressure less than or equal to 110 kPa at 50 C (1.1 bar at 122 F), or 130 kPa at 55 C (1.3 bar at 131 F) are authorized. T4 - 2.65 178.274(d)(2) Normal............. 178.275(d)(3) TP1 - The maximum degree of filling must not exceed the degree of filling determined by the following: Degree of filling = 97 / 1 + a (tr - tf) Where: tr is the maximum mean bulk temperature during transport, and tf is the temperature in degrees celsius of the liquid during filling.
DOT Packaging Exceptions (49 CFR 173.xxx)	:	4b;150
DOT Quantity Limitations Passenger aircraft/rail (49 CFR 173.27)	:	5 L
DOT Quantity Limitations Cargo aircraft only (49 CFR 175.75)	:	60 L
DOT Vessel Stowage Location	:	B - (i) The material may be stowed "on deck" or "under deck" on a cargo vessel and on a passenger vessel carrying a number of passengers limited to not more than the larger of 25 passengers, or one passenger per each 3 m of overall vessel length; and (ii) "On deck only" on passenger vessels in which the number of passengers specified in paragraph (k)(2)(i) of this section is exceeded.
Other information	:	No supplementary information available.

SECTION 15: Regulatory information

15.1. US Federal regulations

Isopropyl Alcohol (2-Propanol) (67-63-0)	
Listed on the United States TSCA (Toxic Substances Control Act) inventory Subject to reporting requirements of United States SARA Section 313	
SARA Section 311/312 Hazard Classes	Physical hazard - Flammable (gases, aerosols, liquids, or solids) Health hazard - Serious eye damage or eye irritation Health hazard - Specific target organ toxicity (single or repeated exposure)

All components of this product are listed, or excluded from listing, on the United States Environmental Protection Agency Toxic Substances Control Act (TSCA) inventory

Chemical(s) subject to the reporting requirements of Section 313 or Title III of the Superfund Amendments and Reauthorization Act (SARA) of 1986 and 40 CFR Part 372.

Isopropyl Alcohol (2-Propanol)	CAS-No. 67-63-0	100%

15.2. International regulations

CANADA

No additional information available

EU-Regulations

No additional information available

National regulations

No additional information available

15.3. US State regulations

California Proposition 65 - This product does not contain any substances known to the state of California to cause cancer, developmental and/or reproductive harm

SECTION 16: Other information

Revision date	:	01/26/2018

Full text of H-phrases: see section 16:

H225	Highly flammable liquid and vapour
H319	Causes serious eye irritation
H335	May cause respiratory irritation

NFPA health hazard : 1 - Materials that, under emergency conditions, can cause significant irritation.

NFPA fire hazard : 3 - Liquids and solids (including finely divided suspended solids) that can be ignited under almost all ambient temperature conditions.

NFPA reactivity : 0 - Material that in themselves are normally stable, even under fire conditions.

Hazard Rating

Health : 1 Slight Hazard - Irritation or minor reversible injury possible

Flammability : 3 Serious Hazard - Materials capable of ignition under almost all normal temperature conditions. Includes flammable liquids with flash points below 73 F and boiling points above 100 F. as well as liquids with flash points between 73 F and 100 F. (Classes IB & IC)

Physical : 0 Minimal Hazard - Materials that are normally stable, even under fire conditions, and will NOT react with water, polymerize, decompose, condense, or self-react. Non-Explosives.

Personal protection : H

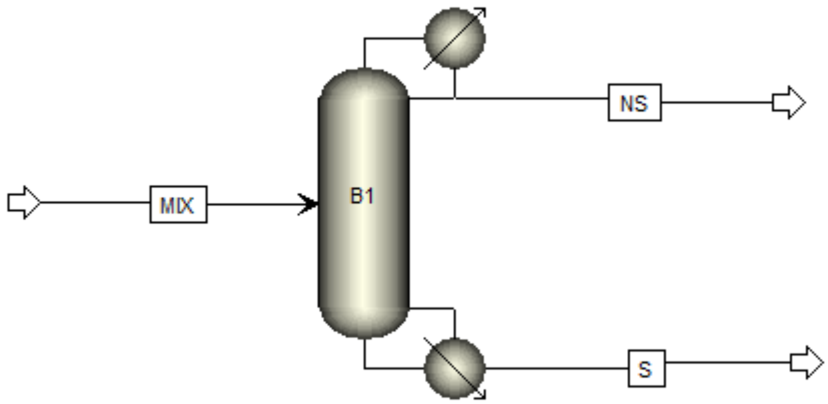
H - Splash goggles, Gloves, Synthetic apron, Vapor respirator

SDS US LabChem

25.5. Aspen Reports

25.5.1. Distillation Column Modeling

Below is the Flow Diagram for the distillation column (D-201).



This is the report. The heat duty, reflux ratio and other factors were used to determine the sizing and designing of other components in the process.

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PLATFORM: WINDOWS                                       APRIL 13, 2019
VERSION: 36.0   Build 250 Patchlevel 1                  SATURDAY
INSTALLATION:                                           1:04:00 P.M.

ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                   04/13/2019  PAGE    I


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RUN CONTROL SECTION

RUN CONTROL INFORMATION

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TYPE OF RUN: NEW

INPUT FILE NAME: _4055mgp.inm

OUTPUT PROBLEM DATA FILE NAME: _0358jec
LOCATED IN:

PDF SIZE USED FOR INPUT TRANSLATION:
NUMBER OF FILE RECORDS (PSIZE) = 0
NUMBER OF IN-CORE RECORDS = 256
PSIZE NEEDED FOR SIMULATION = 1

CALLING PROGRAM NAME: apmain
LOCATED IN: C:\Program Files (x86)\AspenTech\Aspen Plus V10.0\Engine\\xeq

SIMULATION REQUESTED FOR ENTIRE FLOWSHEET

FLOWSHEET SECTION

FLOWSHEET CONNECTIVITY BY STREAMS

STREAM	SOURCE	DEST	STREAM	SOURCE	DEST
MIX	----	B1	NS	B1	----
S	B1	----			

FLOWSHEET CONNECTIVITY BY BLOCKS

BLOCK	INLETS	OUTLETS
B1	MIX	NS S

COMPUTATIONAL SEQUENCE

```
 SEQUENCE USED WAS:
    B1

 OVERALL FLOWSHEET BALANCE
 -------------------------

                      ***  MASS AND ENERGY BALANCE  ***
                                    IN                OUT        RELATIVE DIFF.
    CONVENTIONAL COMPONENTS (KMOL/HR )
       TOLUE-01                  116.228          116.228         0.00000
       ISOPR-01                  534.609          534.609         0.00000
    TOTAL BALANCE
       MOLE(KMOL/HR )            650.837          650.837         0.00000
       MASS(KG/HR   )            42837.1          42837.1         0.00000
       ENTHALPY(CAL/SEC )      -0.106076E+08   -0.104284E+08   -0.168958E-01

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



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                          PHYSICAL PROPERTIES SECTION

 COMPONENTS
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  ID       TYPE  ALIAS          NAME
   TOLUE-01 C     C7H8           TOLUENE
   ISOPR-01 C     C3H8O-2        ISOPROPYL-ALCOHOL
```



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                              U-O-S BLOCK SECTION

 BLOCK:  B1       MODEL: DSTWU
 -----------------------------
   INLET STREAM:          MIX
   CONDENSER OUTLET:      NS
   REBOILER OUTLET:       S
   PROPERTY OPTION SET:   RK-SOAVE  STANDARD RKS EQUATION OF STATE

                      ***  MASS AND ENERGY BALANCE  ***
                                    IN                OUT        RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(KMOL/HR )            650.837          650.837         0.00000
       MASS(KG/HR   )            42837.1          42837.1         0.00000
       ENTHALPY(CAL/SEC )      -0.106076E+08   -0.104284E+08   -0.168958E-01

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

                          ***  INPUT DATA  ***
    HEAVY KEY COMPONENT                                        TOLUE-01
    RECOVERY FOR HEAVY KEY                                   0.00100000
    LIGHT KEY COMPONENT                                        ISOPR-01
    RECOVERY FOR LIGHT KEY                                   0.99990
    TOP STAGE PRESSURE (BAR     )                            2.02650
```

BOTTOM STAGE PRESSURE (BAR)	2.02650
NO. OF EQUILIBRIUM STAGES	25.0000
DISTILLATE VAPOR FRACTION	0.0

*** RESULTS ***

DISTILLATE TEMP. (C)	95.5255
BOTTOM TEMP. (C)	138.726
MINIMUM REFLUX RATIO	0.56507
ACTUAL REFLUX RATIO	0.99383
MINIMUM STAGES	14.1731
ACTUAL EQUILIBRIUM STAGES	25.0000
NUMBER OF ACTUAL STAGES ABOVE FEED	10.7619
DIST. VS FEED	0.82151
CONDENSER COOLING REQUIRED (CAL/SEC)	2,503,360.
NET CONDENSER DUTY (CAL/SEC)	-2,503,360.
REBOILER HEATING REQUIRED (CAL/SEC)	2,682,590.
NET REBOILER DUTY (CAL/SEC)	2,682,590.

STREAM SECTION

MIX NS S

STREAM ID	MIX	NS	S
FROM :	----	B1	B1
TO :	B1	----	----
SUBSTREAM: MIXED			
PHASE:	LIQUID	LIQUID	LIQUID
COMPONENTS: KMOL/HR			
TOLUE-01	116.2277	0.1162	116.1115
ISOPR-01	534.6094	534.5560	5.3461-02
TOTAL FLOW:			
KMOL/HR	650.8371	534.6722	116.1649
KG/HR	4.2837+04	3.2135+04	1.0702+04
L/MIN	958.5157	767.8194	237.8119
STATE VARIABLES:			
TEMP C	80.0000	95.5255	138.7259
PRES BAR	2.0265	2.0265	2.0265
VFRAC	0.0	0.0	0.0
LFRAC	1.0000	1.0000	1.0000
SFRAC	0.0	0.0	0.0
ENTHALPY:			
CAL/MOL	-5.8674+04	-7.1850+04	7521.0231
CAL/GM	-891.4578	-1195.4427	81.6386
CAL/SEC	-1.0608+07	-1.0671+07	2.4269+05
ENTROPY:			
CAL/MOL-K	-93.7143	-97.0811	-68.3953
CAL/GM-K	-1.4238	-1.6152	-0.7424
DENSITY:			
MOL/CC	1.1317-02	1.1606-02	8.1412-03
GM/CC	0.7449	0.6975	0.7500
AVG MW	65.8185	60.1029	92.1258

PHYSICAL PROPERTY TABLES SECTION

FLASH CURVE TABLE: BINRY-1

PROPERTIES ALONG A FLASH CURVE FOR THE MIXTURE: (KMOL/HR)
TOLUE-01 1.000 , ISOPR-01 1.000 ,

STATE SPECIFICATIONS:
VAPOR FRACTION: 0.000

VARIED VARIABLE(S): PRES MOLEFRAC

PROPERTY SET(S): $PS-TXY

3 PHASE PV FLASHES WERE PERFORMED.

PROPERTY OPTION SET: RK-SOAVE STANDARD RKS EQUATION OF STATE

PHYSICAL PROPERTY TABLES SECTION

FLASH CURVE TABLE: BINRY-1 (CONTINUED)

PRES BAR	MOLEFRAC ISOPR-01	TEMP TOTAL C	KVL TOTAL TOLUE-01	KVL TOTAL ISOPR-01	GAMMA LIQUID 1 TOLUE-01
2.0265	0.0	138.7688	1.0000	3.1361	1.0000
2.0265	2.0000-02	136.9476	0.9590	3.0113	1.0000
2.0265	4.0000-02	135.2144	0.9210	2.8957	1.0000
2.0265	6.0000-02	133.5622	0.8859	2.7882	1.0000
2.0265	8.0000-02	131.9850	0.8532	2.6880	1.0000
2.0265	0.1000	130.4772	0.8228	2.5945	1.0000
2.0265	0.1200	129.0338	0.7945	2.5071	1.0000
2.0265	0.1400	127.6503	0.7680	2.4252	1.0000
2.0265	0.1600	126.3227	0.7432	2.3482	1.0000
2.0265	0.1800	125.0473	0.7199	2.2759	1.0000
2.0265	0.2000	123.8204	0.6980	2.2078	1.0000
2.0265	0.2200	122.6393	0.6775	2.1435	1.0001
2.0265	0.2400	121.5009	0.6581	2.0828	1.0001
2.0265	0.2600	120.4027	0.6397	2.0254	1.0001
2.0265	0.2800	119.3424	0.6224	1.9710	1.0001
2.0265	0.3000	118.3178	0.6060	1.9193	1.0002
2.0265	0.3200	117.3269	0.5904	1.8703	1.0002
2.0265	0.3400	116.3678	0.5757	1.8237	1.0002
2.0265	0.3600	115.4387	0.5617	1.7793	1.0003
2.0265	0.3800	114.5382	0.5483	1.7369	1.0004
2.0265	0.4000	113.6647	0.5356	1.6966	1.0004
2.0265	0.4200	112.8169	0.5235	1.6580	1.0005
2.0265	0.4400	111.9935	0.5120	1.6212	1.0006
2.0265	0.4600	111.1934	0.5009	1.5859	1.0007
2.0265	0.4800	110.4153	0.4904	1.5521	1.0009
2.0265	0.5000	109.6583	0.4803	1.5197	1.0010
2.0265	0.5200	108.9214	0.4706	1.4887	1.0011
2.0265	0.5400	108.2037	0.4613	1.4589	1.0013
2.0265	0.5600	107.5043	0.4525	1.4302	1.0015
2.0265	0.5800	106.8225	0.4439	1.4027	1.0017
2.0265	0.6000	106.1575	0.4358	1.3762	1.0019
2.0265	0.6200	105.5086	0.4279	1.3506	1.0022
2.0265	0.6400	104.8751	0.4203	1.3261	1.0025
2.0265	0.6600	104.2564	0.4131	1.3024	1.0028
2.0265	0.6800	103.6518	0.4061	1.2795	1.0031

PHYSICAL PROPERTY TABLES SECTION

FLASH CURVE TABLE: BINRY-1 (CONTINUED)

PRES BAR	MOLEFRAC ISOPR-01	TEMP TOTAL C	KVL TOTAL TOLUE-01	KVL TOTAL ISOPR-01	GAMMA LIQUID 1 TOLUE-01
2.0265	0.7000	103.0609	0.3993	1.2574	1.0034
2.0265	0.7200	102.4831	0.3929	1.2361	1.0038
2.0265	0.7400	101.9178	0.3866	1.2155	1.0042
2.0265	0.7600	101.3646	0.3806	1.1956	1.0047
2.0265	0.7800	100.8231	0.3748	1.1764	1.0052
2.0265	0.8000	100.2927	0.3691	1.1577	1.0057
2.0265	0.8200	99.7731	0.3637	1.1397	1.0063
2.0265	0.8400	99.2639	0.3585	1.1222	1.0069
2.0265	0.8600	98.7647	0.3534	1.1053	1.0075
2.0265	0.8800	98.2751	0.3485	1.0888	1.0082
2.0265	0.9000	97.7947	0.3438	1.0729	1.0090
2.0265	0.9200	97.3233	0.3392	1.0575	1.0098
2.0265	0.9400	96.8606	0.3348	1.0425	1.0106
2.0265	0.9600	96.4061	0.3306	1.0279	1.0115
2.0265	0.9800	95.9596	0.3264	1.0137	1.0125
2.0265	1.0000	95.5208	0.3224	1.0000	1.0136

PRES BAR	MOLEFRAC ISOPR-01	GAMMA LIQUID 1 ISOPR-01	GAMMA LIQUID 2 TOLUE-01	GAMMA LIQUID 2 ISOPR-01	KVL2 TOTAL TOLUE-01
2.0265	0.0	1.0005	MISSING	MISSING	MISSING
2.0265	2.0000-02	1.0005	MISSING	MISSING	MISSING
2.0265	4.0000-02	1.0004	MISSING	MISSING	MISSING
2.0265	6.0000-02	1.0004	MISSING	MISSING	MISSING
2.0265	8.0000-02	1.0005	MISSING	MISSING	MISSING
2.0265	0.1000	1.0005	MISSING	MISSING	MISSING
2.0265	0.1200	1.0006	MISSING	MISSING	MISSING
2.0265	0.1400	1.0007	MISSING	MISSING	MISSING
2.0265	0.1600	1.0007	MISSING	MISSING	MISSING
2.0265	0.1800	1.0008	MISSING	MISSING	MISSING

PHYSICAL PROPERTY TABLES SECTION

FLASH CURVE TABLE: BINRY-1 (CONTINUED)

PRES BAR	MOLEFRAC ISOPR-01	GAMMA LIQUID 1 ISOPR-01	GAMMA LIQUID 2 TOLUE-01	GAMMA LIQUID 2 ISOPR-01	KVL2 TOTAL TOLUE-01
2.0265	0.2000	1.0009	MISSING	MISSING	MISSING
2.0265	0.2200	1.0010	MISSING	MISSING	MISSING
2.0265	0.2400	1.0010	MISSING	MISSING	MISSING
2.0265	0.2600	1.0011	MISSING	MISSING	MISSING
2.0265	0.2800	1.0012	MISSING	MISSING	MISSING
2.0265	0.3000	1.0013	MISSING	MISSING	MISSING
2.0265	0.3200	1.0013	MISSING	MISSING	MISSING
2.0265	0.3400	1.0014	MISSING	MISSING	MISSING
2.0265	0.3600	1.0014	MISSING	MISSING	MISSING
2.0265	0.3800	1.0014	MISSING	MISSING	MISSING
2.0265	0.4000	1.0015	MISSING	MISSING	MISSING
2.0265	0.4200	1.0015	MISSING	MISSING	MISSING
2.0265	0.4400	1.0015	MISSING	MISSING	MISSING
2.0265	0.4600	1.0015	MISSING	MISSING	MISSING
2.0265	0.4800	1.0015	MISSING	MISSING	MISSING
2.0265	0.5000	1.0015	MISSING	MISSING	MISSING
2.0265	0.5200	1.0014	MISSING	MISSING	MISSING
2.0265	0.5400	1.0014	MISSING	MISSING	MISSING
2.0265	0.5600	1.0014	MISSING	MISSING	MISSING
2.0265	0.5800	1.0013	MISSING	MISSING	MISSING
2.0265	0.6000	1.0013	MISSING	MISSING	MISSING
2.0265	0.6200	1.0012	MISSING	MISSING	MISSING
2.0265	0.6400	1.0011	MISSING	MISSING	MISSING
2.0265	0.6600	1.0011	MISSING	MISSING	MISSING
2.0265	0.6800	1.0010	MISSING	MISSING	MISSING
2.0265	0.7000	1.0009	MISSING	MISSING	MISSING
2.0265	0.7200	1.0008	MISSING	MISSING	MISSING
2.0265	0.7400	1.0008	MISSING	MISSING	MISSING
2.0265	0.7600	1.0007	MISSING	MISSING	MISSING
2.0265	0.7800	1.0006	MISSING	MISSING	MISSING
2.0265	0.8000	1.0005	MISSING	MISSING	MISSING
2.0265	0.8200	1.0004	MISSING	MISSING	MISSING
2.0265	0.8400	1.0004	MISSING	MISSING	MISSING
2.0265	0.8600	1.0003	MISSING	MISSING	MISSING
2.0265	0.8800	1.0002	MISSING	MISSING	MISSING

PHYSICAL PROPERTY TABLES SECTION

FLASH CURVE TABLE: BINRY-1 (CONTINUED)

PRES BAR	MOLEFRAC ISOPR-01	GAMMA LIQUID 1 ISOPR-01	GAMMA LIQUID 2 TOLUE-01	GAMMA LIQUID 2 ISOPR-01	KVL2 TOTAL TOLUE-01
2.0265	0.9000	1.0002	MISSING	MISSING	MISSING
2.0265	0.9200	1.0001	MISSING	MISSING	MISSING
2.0265	0.9400	1.0001	MISSING	MISSING	MISSING
2.0265	0.9600	1.0000	MISSING	MISSING	MISSING
2.0265	0.9800	1.0000	MISSING	MISSING	MISSING
2.0265	1.0000	1.0000	MISSING	MISSING	MISSING

PRES BAR	MOLEFRAC ISOPR-01	KVL2 TOTAL ISOPR-01	BETA TOTAL	MOLEFRAC VAPOR TOLUE-01	MOLEFRAC VAPOR ISOPR-01
2.0265	0.0	MISSING	1.0000	1.0000	0.0
2.0265	2.0000-02	MISSING	1.0000	0.9398	6.0227-02
2.0265	4.0000-02	MISSING	1.0000	0.8842	0.1158
2.0265	6.0000-02	MISSING	1.0000	0.8327	0.1673
2.0265	8.0000-02	MISSING	1.0000	0.7850	0.2150
2.0265	0.1000	MISSING	1.0000	0.7405	0.2595
2.0265	0.1200	MISSING	1.0000	0.6991	0.3009
2.0265	0.1400	MISSING	1.0000	0.6605	0.3395
2.0265	0.1600	MISSING	1.0000	0.6243	0.3757
2.0265	0.1800	MISSING	1.0000	0.5903	0.4097
2.0265	0.2000	MISSING	1.0000	0.5584	0.4416
2.0265	0.2200	MISSING	1.0000	0.5284	0.4716
2.0265	0.2400	MISSING	1.0000	0.5001	0.4999
2.0265	0.2600	MISSING	1.0000	0.4734	0.5266
2.0265	0.2800	MISSING	1.0000	0.4481	0.5519
2.0265	0.3000	MISSING	1.0000	0.4242	0.5758
2.0265	0.3200	MISSING	1.0000	0.4015	0.5985
2.0265	0.3400	MISSING	1.0000	0.3800	0.6200
2.0265	0.3600	MISSING	1.0000	0.3595	0.6405
2.0265	0.3800	MISSING	1.0000	0.3400	0.6600

FLASH CURVE TABLE: BINRY-1 (CONTINUED)

PRES BAR	MOLEFRAC ISOPR-01	KVL2 TOTAL ISOPR-01	BETA TOTAL	MOLEFRAC VAPOR TOLUE-01	MOLEFRAC VAPOR ISOPR-01
2.0265	0.4000	MISSING	1.0000	0.3214	0.6786
2.0265	0.4200	MISSING	1.0000	0.3036	0.6964
2.0265	0.4400	MISSING	1.0000	0.2867	0.7133
2.0265	0.4600	MISSING	1.0000	0.2705	0.7295
2.0265	0.4800	MISSING	1.0000	0.2550	0.7450
2.0265	0.5000	MISSING	1.0000	0.2401	0.7599
2.0265	0.5200	MISSING	1.0000	0.2259	0.7741
2.0265	0.5400	MISSING	1.0000	0.2122	0.7878
2.0265	0.5600	MISSING	1.0000	0.1991	0.8009
2.0265	0.5800	MISSING	1.0000	0.1865	0.8135
2.0265	0.6000	MISSING	1.0000	0.1743	0.8257
2.0265	0.6200	MISSING	1.0000	0.1626	0.8374
2.0265	0.6400	MISSING	1.0000	0.1513	0.8487
2.0265	0.6600	MISSING	1.0000	0.1404	0.8596
2.0265	0.6800	MISSING	1.0000	0.1299	0.8701
2.0265	0.7000	MISSING	1.0000	0.1198	0.8802
2.0265	0.7200	MISSING	1.0000	0.1100	0.8900
2.0265	0.7400	MISSING	1.0000	0.1005	0.8995
2.0265	0.7600	MISSING	1.0000	9.1337-02	0.9087
2.0265	0.7800	MISSING	1.0000	8.2445-02	0.9176
2.0265	0.8000	MISSING	1.0000	7.3827-02	0.9262
2.0265	0.8200	MISSING	1.0000	6.5469-02	0.9345
2.0265	0.8400	MISSING	1.0000	5.7357-02	0.9426
2.0265	0.8600	MISSING	1.0000	4.9479-02	0.9505
2.0265	0.8800	MISSING	1.0000	4.1824-02	0.9582
2.0265	0.9000	MISSING	1.0000	3.4381-02	0.9656
2.0265	0.9200	MISSING	1.0000	2.7140-02	0.9729
2.0265	0.9400	MISSING	1.0000	2.0090-02	0.9799
2.0265	0.9600	MISSING	1.0000	1.3222-02	0.9868
2.0265	0.9800	MISSING	1.0000	6.5286-03	0.9935
2.0265	1.0000	MISSING	1.0000	0.0	1.0000

PHYSICAL PROPERTY TABLES SECTION

FLASH CURVE TABLE: BINRY-1 (CONTINUED)

PRES BAR	MOLEFRAC ISOPR-01	MOLEFRAC LIQUID 1 TOLUE-01	MOLEFRAC LIQUID 1 ISOPR-01	MOLEFRAC LIQUID 2 TOLUE-01	MOLEFRAC LIQUID 2 ISOPR-01
2.0265	0.0	1.0000	0.0	MISSING	MISSING
2.0265	2.0000-02	0.9800	2.0000-02	MISSING	MISSING
2.0265	4.0000-02	0.9600	4.0000-02	MISSING	MISSING
2.0265	6.0000-02	0.9400	6.0000-02	MISSING	MISSING
2.0265	8.0000-02	0.9200	8.0000-02	MISSING	MISSING
2.0265	0.1000	0.9000	0.1000	MISSING	MISSING
2.0265	0.1200	0.8800	0.1200	MISSING	MISSING
2.0265	0.1400	0.8600	0.1400	MISSING	MISSING
2.0265	0.1600	0.8400	0.1600	MISSING	MISSING
2.0265	0.1800	0.8200	0.1800	MISSING	MISSING
2.0265	0.2000	0.8000	0.2000	MISSING	MISSING
2.0265	0.2200	0.7800	0.2200	MISSING	MISSING
2.0265	0.2400	0.7600	0.2400	MISSING	MISSING
2.0265	0.2600	0.7400	0.2600	MISSING	MISSING
2.0265	0.2800	0.7200	0.2800	MISSING	MISSING
2.0265	0.3000	0.7000	0.3000	MISSING	MISSING
2.0265	0.3200	0.6800	0.3200	MISSING	MISSING
2.0265	0.3400	0.6600	0.3400	MISSING	MISSING
2.0265	0.3600	0.6400	0.3600	MISSING	MISSING
2.0265	0.3800	0.6200	0.3800	MISSING	MISSING
2.0265	0.4000	0.6000	0.4000	MISSING	MISSING
2.0265	0.4200	0.5800	0.4200	MISSING	MISSING
2.0265	0.4400	0.5600	0.4400	MISSING	MISSING
2.0265	0.4600	0.5400	0.4600	MISSING	MISSING
2.0265	0.4800	0.5200	0.4800	MISSING	MISSING
2.0265	0.5000	0.5000	0.5000	MISSING	MISSING
2.0265	0.5200	0.4800	0.5200	MISSING	MISSING
2.0265	0.5400	0.4600	0.5400	MISSING	MISSING
2.0265	0.5600	0.4400	0.5600	MISSING	MISSING
2.0265	0.5800	0.4200	0.5800	MISSING	MISSING
2.0265	0.6000	0.4000	0.6000	MISSING	MISSING
2.0265	0.6200	0.3800	0.6200	MISSING	MISSING
2.0265	0.6400	0.3600	0.6400	MISSING	MISSING
2.0265	0.6600	0.3400	0.6600	MISSING	MISSING
2.0265	0.6800	0.3200	0.6800	MISSING	MISSING

PHYSICAL PROPERTY TABLES SECTION

FLASH CURVE TABLE: BINRY-1 (CONTINUED)

PRES BAR	MOLEFRAC ISOPR-01	MOLEFRAC LIQUID 1 TOLUE-01	MOLEFRAC LIQUID 1 ISOPR-01	MOLEFRAC LIQUID 2 TOLUE-01	MOLEFRAC LIQUID 2 ISOPR-01
2.0265	0.7000	0.3000	0.7000	MISSING	MISSING
2.0265	0.7200	0.2800	0.7200	MISSING	MISSING
2.0265	0.7400	0.2600	0.7400	MISSING	MISSING
2.0265	0.7600	0.2400	0.7600	MISSING	MISSING
2.0265	0.7800	0.2200	0.7800	MISSING	MISSING
2.0265	0.8000	0.2000	0.8000	MISSING	MISSING
2.0265	0.8200	0.1800	0.8200	MISSING	MISSING
2.0265	0.8400	0.1600	0.8400	MISSING	MISSING
2.0265	0.8600	0.1400	0.8600	MISSING	MISSING
2.0265	0.8800	0.1200	0.8800	MISSING	MISSING
2.0265	0.9000	0.1000	0.9000	MISSING	MISSING
2.0265	0.9200	8.0000-02	0.9200	MISSING	MISSING
2.0265	0.9400	6.0000-02	0.9400	MISSING	MISSING
2.0265	0.9600	4.0000-02	0.9600	MISSING	MISSING
2.0265	0.9800	2.0000-02	0.9800	MISSING	MISSING
2.0265	1.0000	0.0	1.0000	MISSING	MISSING

PHYSICAL PROPERTY TABLES SECTION

FLASH CURVE TABLE: BINRY-2

PROPERTIES ALONG A FLASH CURVE FOR THE MIXTURE: (KMOL/HR   )
TOLUE-01 1.000   , ISOPR-01 1.000   ,

STATE SPECIFICATIONS:
VAPOR FRACTION: 0.000

VARIED VARIABLE(S):   PRES   MOLEFRAC

PROPERTY SET(S): $PS-TXY

3 PHASE PV FLASHES WERE PERFORMED.

PROPERTY OPTION SET: RK-SOAVE STANDARD RKS EQUATION OF STATE

PHYSICAL PROPERTY TABLES SECTION

FLASH CURVE TABLE: BINRY-2 (CONTINUED)

PRES BAR	MOLEFRAC TOLUE-01	TEMP TOTAL C	KVL TOTAL TOLUE-01	KVL TOTAL ISOPR-01	GAMMA LIQUID 1 TOLUE-01
1.0133	0.0	75.8305	0.3301	1.0000	1.0295
1.0133	2.0000-02	76.2002	0.3337	1.0136	1.0275
1.0133	4.0000-02	76.5761	0.3375	1.0276	1.0256
1.0133	6.0000-02	76.9585	0.3414	1.0420	1.0237
1.0133	8.0000-02	77.3477	0.3455	1.0569	1.0220
1.0133	0.1000	77.7439	0.3497	1.0723	1.0204
1.0133	0.1200	78.1475	0.3541	1.0881	1.0189
1.0133	0.1400	78.5587	0.3587	1.1044	1.0175
1.0133	0.1600	78.9778	0.3634	1.1212	1.0162
1.0133	0.1800	79.4052	0.3684	1.1387	1.0149
1.0133	0.2000	79.8413	0.3735	1.1566	1.0137
1.0133	0.2200	80.2862	0.3788	1.1752	1.0126
1.0133	0.2400	80.7406	0.3843	1.1944	1.0116
1.0133	0.2600	81.2046	0.3900	1.2143	1.0106
1.0133	0.2800	81.6787	0.3959	1.2349	1.0097
1.0133	0.3000	82.1634	0.4021	1.2562	1.0089
1.0133	0.3200	82.6591	0.4085	1.2783	1.0081
1.0133	0.3400	83.1662	0.4152	1.3012	1.0074
1.0133	0.3600	83.6853	0.4222	1.3250	1.0067
1.0133	0.3800	84.2168	0.4294	1.3497	1.0061
1.0133	0.4000	84.7614	0.4370	1.3753	1.0055
1.0133	0.4200	85.3196	0.4449	1.4020	1.0049
1.0133	0.4400	85.8920	0.4531	1.4297	1.0044
1.0133	0.4600	86.4792	0.4617	1.4586	1.0040
1.0133	0.4800	87.0821	0.4706	1.4887	1.0035
1.0133	0.5000	87.7012	0.4800	1.5200	1.0031
1.0133	0.5200	88.3375	0.4898	1.5528	1.0028
1.0133	0.5400	88.9917	0.5000	1.5870	1.0024
1.0133	0.5600	89.6647	0.5107	1.6227	1.0021
1.0133	0.5800	90.3576	0.5220	1.6601	1.0019
1.0133	0.6000	91.0714	0.5338	1.6993	1.0016
1.0133	0.6200	91.8071	0.5462	1.7404	1.0014
1.0133	0.6400	92.5660	0.5593	1.7835	1.0012
1.0133	0.6600	93.3495	0.5730	1.8288	1.0010
1.0133	0.6800	94.1587	0.5875	1.8765	1.0008

PHYSICAL PROPERTY TABLES SECTION

FLASH CURVE TABLE: BINRY-2 (CONTINUED)

PRES BAR	MOLEFRAC TOLUE-01	TEMP TOTAL C	KVL TOTAL TOLUE-01	KVL TOTAL ISOPR-01	GAMMA LIQUID 1 TOLUE-01
1.0133	0.7000	94.9954	0.6028	1.9267	1.0007
1.0133	0.7200	95.8612	0.6190	1.9797	1.0006
1.0133	0.7400	96.7578	0.6361	2.0357	1.0005
1.0133	0.7600	97.6872	0.6542	2.0950	1.0004
1.0133	0.7800	98.6515	0.6735	2.1577	1.0003
1.0133	0.8000	99.6532	0.6939	2.2243	1.0002
1.0133	0.8200	100.6946	0.7157	2.2951	1.0002
1.0133	0.8400	101.7788	0.7389	2.3706	1.0001
1.0133	0.8600	102.9087	0.7638	2.4510	1.0001
1.0133	0.8800	104.0878	0.7904	2.5371	1.0001
1.0133	0.9000	105.3201	0.8190	2.6293	1.0000
1.0133	0.9200	106.6096	0.8497	2.7283	1.0000
1.0133	0.9400	107.9612	0.8829	2.8349	1.0000
1.0133	0.9600	109.3801	0.9187	2.9500	1.0000
1.0133	0.9800	110.8725	0.9577	3.0745	1.0000
1.0133	1.0000	112.4451	1.0000	3.2097	1.0000

PRES BAR	MOLEFRAC TOLUE-01	GAMMA LIQUID 1 ISOPR-01	GAMMA LIQUID 2 TOLUE-01	GAMMA LIQUID 2 ISOPR-01	KVL2 TOTAL TOLUE-01
1.0133	0.0	1.0000	MISSING	MISSING	MISSING
1.0133	2.0000-02	1.0000	MISSING	MISSING	MISSING
1.0133	4.0000-02	1.0001	MISSING	MISSING	MISSING
1.0133	6.0000-02	1.0001	MISSING	MISSING	MISSING
1.0133	8.0000-02	1.0002	MISSING	MISSING	MISSING
1.0133	0.1000	1.0004	MISSING	MISSING	MISSING
1.0133	0.1200	1.0005	MISSING	MISSING	MISSING
1.0133	0.1400	1.0007	MISSING	MISSING	MISSING
1.0133	0.1600	1.0008	MISSING	MISSING	MISSING
1.0133	0.1800	1.0010	MISSING	MISSING	MISSING

PHYSICAL PROPERTY TABLES SECTION

FLASH CURVE TABLE: BINRY-2 (CONTINUED)

PRES BAR	MOLEFRAC TOLUE-01	GAMMA LIQUID 1 ISOPR-01	GAMMA LIQUID 2 TOLUE-01	GAMMA LIQUID 2 ISOPR-01	KVL2 TOTAL TOLUE-01
1.0133	0.2000	1.0012	MISSING	MISSING	MISSING
1.0133	0.2200	1.0015	MISSING	MISSING	MISSING
1.0133	0.2400	1.0017	MISSING	MISSING	MISSING
1.0133	0.2600	1.0019	MISSING	MISSING	MISSING
1.0133	0.2800	1.0021	MISSING	MISSING	MISSING
1.0133	0.3000	1.0024	MISSING	MISSING	MISSING
1.0133	0.3200	1.0026	MISSING	MISSING	MISSING
1.0133	0.3400	1.0028	MISSING	MISSING	MISSING
1.0133	0.3600	1.0031	MISSING	MISSING	MISSING
1.0133	0.3800	1.0033	MISSING	MISSING	MISSING
1.0133	0.4000	1.0035	MISSING	MISSING	MISSING
1.0133	0.4200	1.0038	MISSING	MISSING	MISSING
1.0133	0.4400	1.0040	MISSING	MISSING	MISSING
1.0133	0.4600	1.0042	MISSING	MISSING	MISSING
1.0133	0.4800	1.0044	MISSING	MISSING	MISSING
1.0133	0.5000	1.0046	MISSING	MISSING	MISSING
1.0133	0.5200	1.0047	MISSING	MISSING	MISSING
1.0133	0.5400	1.0049	MISSING	MISSING	MISSING
1.0133	0.5600	1.0051	MISSING	MISSING	MISSING
1.0133	0.5800	1.0052	MISSING	MISSING	MISSING
1.0133	0.6000	1.0053	MISSING	MISSING	MISSING
1.0133	0.6200	1.0054	MISSING	MISSING	MISSING
1.0133	0.6400	1.0055	MISSING	MISSING	MISSING
1.0133	0.6600	1.0056	MISSING	MISSING	MISSING
1.0133	0.6800	1.0056	MISSING	MISSING	MISSING
1.0133	0.7000	1.0056	MISSING	MISSING	MISSING
1.0133	0.7200	1.0057	MISSING	MISSING	MISSING
1.0133	0.7400	1.0056	MISSING	MISSING	MISSING
1.0133	0.7600	1.0056	MISSING	MISSING	MISSING
1.0133	0.7800	1.0055	MISSING	MISSING	MISSING
1.0133	0.8000	1.0055	MISSING	MISSING	MISSING
1.0133	0.8200	1.0054	MISSING	MISSING	MISSING
1.0133	0.8400	1.0052	MISSING	MISSING	MISSING
1.0133	0.8600	1.0051	MISSING	MISSING	MISSING
1.0133	0.8800	1.0049	MISSING	MISSING	MISSING

PHYSICAL PROPERTY TABLES SECTION

FLASH CURVE TABLE: BINRY-2 (CONTINUED)

PRES BAR	MOLEFRAC TOLUE-01	GAMMA LIQUID 1 ISOPR-01	GAMMA LIQUID 2 TOLUE-01	GAMMA LIQUID 2 ISOPR-01	KVL2 TOTAL TOLUE-01
1.0133	0.9000	1.0047	MISSING	MISSING	MISSING
1.0133	0.9200	1.0045	MISSING	MISSING	MISSING
1.0133	0.9400	1.0042	MISSING	MISSING	MISSING
1.0133	0.9600	1.0040	MISSING	MISSING	MISSING
1.0133	0.9800	1.0037	MISSING	MISSING	MISSING
1.0133	1.0000	1.0034	MISSING	MISSING	MISSING

PRES BAR	MOLEFRAC TOLUE-01	KVL2 TOTAL ISOPR-01	BETA TOTAL	MOLEFRAC VAPOR TOLUE-01	MOLEFRAC VAPOR ISOPR-01
1.0133	0.0	MISSING	1.0000	0.0	1.0000
1.0133	2.0000-02	MISSING	1.0000	6.6741-03	0.9933
1.0133	4.0000-02	MISSING	1.0000	1.3500-02	0.9865
1.0133	6.0000-02	MISSING	1.0000	2.0486-02	0.9795
1.0133	8.0000-02	MISSING	1.0000	2.7641-02	0.9724
1.0133	0.1000	MISSING	1.0000	3.4975-02	0.9650
1.0133	0.1200	MISSING	1.0000	4.2497-02	0.9575
1.0133	0.1400	MISSING	1.0000	5.0219-02	0.9498
1.0133	0.1600	MISSING	1.0000	5.8151-02	0.9418
1.0133	0.1800	MISSING	1.0000	6.6305-02	0.9337
1.0133	0.2000	MISSING	1.0000	7.4693-02	0.9253
1.0133	0.2200	MISSING	1.0000	8.3329-02	0.9167
1.0133	0.2400	MISSING	1.0000	9.2226-02	0.9078
1.0133	0.2600	MISSING	1.0000	0.1014	0.8986
1.0133	0.2800	MISSING	1.0000	0.1109	0.8891
1.0133	0.3000	MISSING	1.0000	0.1206	0.8794
1.0133	0.3200	MISSING	1.0000	0.1307	0.8693
1.0133	0.3400	MISSING	1.0000	0.1412	0.8588
1.0133	0.3600	MISSING	1.0000	0.1520	0.8480
1.0133	0.3800	MISSING	1.0000	0.1632	0.8368

FLASH CURVE TABLE: BINRY-2 (CONTINUED)

PRES BAR	MOLEFRAC TOLUE-01	KVL2 TOTAL ISOPR-01	BETA TOTAL	MOLEFRAC VAPOR TOLUE-01	MOLEFRAC VAPOR ISOPR-01
1.0133	0.4000	MISSING	1.0000	0.1748	0.8252
1.0133	0.4200	MISSING	1.0000	0.1868	0.8132
1.0133	0.4400	MISSING	1.0000	0.1994	0.8006
1.0133	0.4600	MISSING	1.0000	0.2124	0.7876
1.0133	0.4800	MISSING	1.0000	0.2259	0.7741
1.0133	0.5000	MISSING	1.0000	0.2400	0.7600
1.0133	0.5200	MISSING	1.0000	0.2547	0.7453
1.0133	0.5400	MISSING	1.0000	0.2700	0.7300
1.0133	0.5600	MISSING	1.0000	0.2860	0.7140
1.0133	0.5800	MISSING	1.0000	0.3028	0.6972
1.0133	0.6000	MISSING	1.0000	0.3203	0.6797
1.0133	0.6200	MISSING	1.0000	0.3387	0.6613
1.0133	0.6400	MISSING	1.0000	0.3579	0.6421
1.0133	0.6600	MISSING	1.0000	0.3782	0.6218
1.0133	0.6800	MISSING	1.0000	0.3995	0.6005
1.0133	0.7000	MISSING	1.0000	0.4220	0.5780
1.0133	0.7200	MISSING	1.0000	0.4457	0.5543
1.0133	0.7400	MISSING	1.0000	0.4707	0.5293
1.0133	0.7600	MISSING	1.0000	0.4972	0.5028
1.0133	0.7800	MISSING	1.0000	0.5253	0.4747
1.0133	0.8000	MISSING	1.0000	0.5551	0.4449
1.0133	0.8200	MISSING	1.0000	0.5869	0.4131
1.0133	0.8400	MISSING	1.0000	0.6207	0.3793
1.0133	0.8600	MISSING	1.0000	0.6569	0.3431
1.0133	0.8800	MISSING	1.0000	0.6956	0.3044
1.0133	0.9000	MISSING	1.0000	0.7371	0.2629
1.0133	0.9200	MISSING	1.0000	0.7817	0.2183
1.0133	0.9400	MISSING	1.0000	0.8299	0.1701
1.0133	0.9600	MISSING	1.0000	0.8820	0.1180
1.0133	0.9800	MISSING	1.0000	0.9385	6.1490-02
1.0133	1.0000	MISSING	1.0000	1.0000	0.0

FLASH CURVE TABLE: BINRY-2 (CONTINUED)

PRES BAR	MOLEFRAC TOLUE-01	MOLEFRAC LIQUID 1 TOLUE-01	MOLEFRAC LIQUID 1 ISOPR-01	MOLEFRAC LIQUID 2 TOLUE-01	MOLEFRAC LIQUID 2 ISOPR-01
1.0133	0.0	0.0	1.0000	MISSING	MISSING
1.0133	2.0000-02	2.0000-02	0.9800	MISSING	MISSING
1.0133	4.0000-02	4.0000-02	0.9600	MISSING	MISSING
1.0133	6.0000-02	6.0000-02	0.9400	MISSING	MISSING
1.0133	8.0000-02	8.0000-02	0.9200	MISSING	MISSING
1.0133	0.1000	0.1000	0.9000	MISSING	MISSING
1.0133	0.1200	0.1200	0.8800	MISSING	MISSING
1.0133	0.1400	0.1400	0.8600	MISSING	MISSING
1.0133	0.1600	0.1600	0.8400	MISSING	MISSING
1.0133	0.1800	0.1800	0.8200	MISSING	MISSING
1.0133	0.2000	0.2000	0.8000	MISSING	MISSING
1.0133	0.2200	0.2200	0.7800	MISSING	MISSING
1.0133	0.2400	0.2400	0.7600	MISSING	MISSING
1.0133	0.2600	0.2600	0.7400	MISSING	MISSING
1.0133	0.2800	0.2800	0.7200	MISSING	MISSING
1.0133	0.3000	0.3000	0.7000	MISSING	MISSING
1.0133	0.3200	0.3200	0.6800	MISSING	MISSING
1.0133	0.3400	0.3400	0.6600	MISSING	MISSING
1.0133	0.3600	0.3600	0.6400	MISSING	MISSING
1.0133	0.3800	0.3800	0.6200	MISSING	MISSING
1.0133	0.4000	0.4000	0.6000	MISSING	MISSING
1.0133	0.4200	0.4200	0.5800	MISSING	MISSING
1.0133	0.4400	0.4400	0.5600	MISSING	MISSING
1.0133	0.4600	0.4600	0.5400	MISSING	MISSING
1.0133	0.4800	0.4800	0.5200	MISSING	MISSING
1.0133	0.5000	0.5000	0.5000	MISSING	MISSING
1.0133	0.5200	0.5200	0.4800	MISSING	MISSING
1.0133	0.5400	0.5400	0.4600	MISSING	MISSING
1.0133	0.5600	0.5600	0.4400	MISSING	MISSING
1.0133	0.5800	0.5800	0.4200	MISSING	MISSING
1.0133	0.6000	0.6000	0.4000	MISSING	MISSING
1.0133	0.6200	0.6200	0.3800	MISSING	MISSING
1.0133	0.6400	0.6400	0.3600	MISSING	MISSING
1.0133	0.6600	0.6600	0.3400	MISSING	MISSING
1.0133	0.6800	0.6800	0.3200	MISSING	MISSING

PHYSICAL PROPERTY TABLES SECTION

FLASH CURVE TABLE: BINRY-2 (CONTINUED)

PRES BAR	MOLEFRAC TOLUE-01	MOLEFRAC LIQUID 1 TOLUE-01	MOLEFRAC LIQUID 1 ISOPR-01	MOLEFRAC LIQUID 2 TOLUE-01	MOLEFRAC LIQUID 2 ISOPR-01
1.0133	0.7000	0.7000	0.3000	MISSING	MISSING
1.0133	0.7200	0.7200	0.2800	MISSING	MISSING
1.0133	0.7400	0.7400	0.2600	MISSING	MISSING
1.0133	0.7600	0.7600	0.2400	MISSING	MISSING
1.0133	0.7800	0.7800	0.2200	MISSING	MISSING
1.0133	0.8000	0.8000	0.2000	MISSING	MISSING
1.0133	0.8200	0.8200	0.1800	MISSING	MISSING
1.0133	0.8400	0.8400	0.1600	MISSING	MISSING
1.0133	0.8600	0.8600	0.1400	MISSING	MISSING
1.0133	0.8800	0.8800	0.1200	MISSING	MISSING
1.0133	0.9000	0.9000	0.1000	MISSING	MISSING
1.0133	0.9200	0.9200	8.0000-02	MISSING	MISSING
1.0133	0.9400	0.9400	6.0000-02	MISSING	MISSING
1.0133	0.9600	0.9600	4.0000-02	MISSING	MISSING
1.0133	0.9800	0.9800	2.0000-02	MISSING	MISSING
1.0133	1.0000	1.0000	0.0	MISSING	MISSING

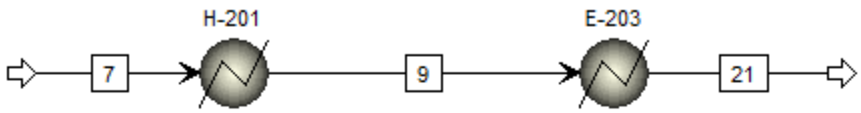
PROBLEM STATUS SECTION

BLOCK STATUS

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

25.5.2. Dryer and Heat Exchanger-3 Modeling

Below is the Flow Diagram for the dryer (H-201) and heat exchanger (E-203) for the toluene and isopropanol streams.



This is the report. These components were modeled to determine the necessary heat duties required for each component.

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+ + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + 
+ + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + 
+ +                                                                          + + 
+ +                       ASPEN PLUS CALCULATION REPORT                      + + 
+ +                                                                          + + 
+ + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + + 
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ASPEN PLUS IS A TRADEMARK OF           HOTLINE:
ASPEN TECHNOLOGY, INC.                 U.S.A. 888/996-7100
781/221-6400                           EUROPE (44) 1189-226555

PLATFORM: WINDOWS                                       APRIL 13, 2019
VERSION: 36.0   Build 250 Patchlevel 1                  SATURDAY
INSTALLATION:                                           12:50:32 P.M.

ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                   04/13/2019  PAGE    I
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RUN CONTROL SECTION

RUN CONTROL INFORMATION

THIS COPY OF ASPEN PLUS LICENSED TO UNIVERSITY OF PENNSYLVAN

TYPE OF RUN: EDIT

INPUT FILE NAME: _0118lcj.inm

INPUT PROBLEM DATA FILE NAME : _0118lcj
OUTPUT PROBLEM DATA FILE NAME: _4511uua
LOCATED IN:

PDF SIZE USED FOR INPUT TRANSLATION:
NUMBER OF FILE RECORDS (PSIZE) = 0
NUMBER OF IN-CORE RECORDS = 256
PSIZE NEEDED FOR SIMULATION = 1

CALLING PROGRAM NAME: apmain
LOCATED IN: C:\Program Files (x86)\AspenTech\Aspen Plus V10.0\Engine\\xeq

SIMULATION REQUESTED FOR ENTIRE FLOWSHEET

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FLOWSHEET SECTION

FLOWSHEET CONNECTIVITY BY STREAMS

STREAM	SOURCE	DEST	STREAM	SOURCE	DEST
7	----	H-201	9	H-201	E-203
21	E-203	----			

FLOWSHEET CONNECTIVITY BY BLOCKS

BLOCK	INLETS	OUTLETS
H-201	7	9
E-203	9	21

COMPUTATIONAL SEQUENCE

SEQUENCE USED WAS:
H-201 E-203

OVERALL FLOWSHEET BALANCE

*** MASS AND ENERGY BALANCE ***

```
                              IN              OUT        RELATIVE DIFF.
   CONVENTIONAL COMPONENTS (KMOL/HR )
      TOLUE-01             0.562188        0.562188         0.00000
      ISOPR-01              2.59946         2.59946         0.00000
   TOTAL BALANCE
      MOLE(KMOL/HR )        3.16165         3.16165         0.00000
      MASS(KG/HR   )        208.017         208.017         0.00000
      ENTHALPY(CAL/SEC )   -51768.0        -51583.3       -0.356776E-02

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

ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                 04/13/2019  PAGE 3

                         PHYSICAL PROPERTIES SECTION

COMPONENTS
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 ID       TYPE  ALIAS          NAME
  TOLUE-01 C     C7H8           TOLUENE
  ISOPR-01 C     C3H8O-2        ISOPROPYL-ALCOHOL

ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                 04/13/2019  PAGE 4

                             U-O-S BLOCK SECTION

BLOCK:  E-203    MODEL: HEATER
------------------------------
  INLET STREAM:          9
  OUTLET STREAM:         21
  PROPERTY OPTION SET:   RK-SOAVE  STANDARD RKS EQUATION OF STATE

                    ***  MASS AND ENERGY BALANCE  ***
                              IN              OUT        RELATIVE DIFF.
   TOTAL BALANCE
      MOLE(KMOL/HR )        3.16165         3.16165         0.00000
      MASS(KG/HR   )        208.017         208.017         0.00000
      ENTHALPY(CAL/SEC )   -43714.5        -51583.3        0.152546

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

                        ***  INPUT DATA  ***
  ONE    PHASE  TP  FLASH   SPECIFIED PHASE IS  LIQUID
  SPECIFIED TEMPERATURE              C                         80.0000
  SPECIFIED PRESSURE                 BAR                        1.01325
  MAXIMUM NO. ITERATIONS                                       30
  CONVERGENCE TOLERANCE                                         0.000100000


                         ***  RESULTS  ***
  OUTLET TEMPERATURE    C                                   80.000
  OUTLET PRESSURE       BAR                                 1.0132
  HEAT DUTY             CAL/SEC                            -7868.8
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BLOCK:  H-201    MODEL: HEATER
------------------------------
  INLET STREAM:          7
  OUTLET STREAM:         9
  PROPERTY OPTION SET:   RK-SOAVE  STANDARD RKS EQUATION OF STATE

ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                   04/13/2019  PAGE 5

                             U-O-S BLOCK SECTION

BLOCK:  H-201    MODEL: HEATER (CONTINUED)

                     ***  MASS AND ENERGY BALANCE  ***
                                  IN                OUT        RELATIVE DIFF.
   TOTAL BALANCE
      MOLE(KMOL/HR )           3.16165          3.16165          0.00000
      MASS(KG/HR   )           208.017          208.017          0.00000
      ENTHALPY(CAL/SEC )      -51768.0         -43714.5         -0.155570

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

                         ***  INPUT DATA  ***
  TWO    PHASE  TP  FLASH
  SPECIFIED TEMPERATURE              C                            90.0000
  SPECIFIED PRESSURE                 BAR                           0.50662
  MAXIMUM NO. ITERATIONS                                          30
  CONVERGENCE TOLERANCE                                            0.000100000



                          ***  RESULTS  ***
  OUTLET TEMPERATURE    C                                      90.000
  OUTLET PRESSURE       BAR                                   0.50662
  HEAT DUTY             CAL/SEC                                8053.5
  OUTLET VAPOR FRACTION                                        1.0000



  V-L PHASE EQUILIBRIUM :

     COMP              F(I)          X(I)          Y(I)          K(I)
     TOLUE-01        0.17781       0.40815       0.17781       1.0133
     ISOPR-01        0.82219       0.59185       0.82219       3.2310

ASPEN PLUS   PLAT: WINDOWS   VER: 36.0                   04/13/2019  PAGE 6

                                STREAM SECTION

21 7 9
------

STREAM ID                21          7           9
FROM :                   E-203       ----        H-201
TO   :                   ----        H-201       E-203

SUBSTREAM: MIXED
PHASE:                   LIQUID      LIQUID      VAPOR
COMPONENTS: KMOL/HR
  TOLUE-01                0.5622      0.5622      0.5622
  ISOPR-01                2.5995      2.5995      2.5995
TOTAL FLOW:
```

```
  KMOL/HR                3.1617     3.1617     3.1617
  KG/HR                208.0175   208.0175   208.0175
  L/MIN                  4.6552     4.6175  3100.0819
STATE VARIABLES:
  TEMP   C              80.0000    75.0000    90.0000
  PRES   BAR             1.0133     2.0265     0.5066
  VFRAC                  0.0        0.0        1.0000
  LFRAC                  1.0000     1.0000     0.0
  SFRAC                  0.0        0.0        0.0
ENTHALPY:
  CAL/MOL           -5.8735+04 -5.8945+04 -4.9775+04
  CAL/GM              -892.7131  -895.9095  -756.5333
  CAL/SEC           -5.1583+04 -5.1768+04 -4.3714+04
ENTROPY:
  CAL/MOL-K            -93.7311   -94.3380   -67.1208
  CAL/GM-K              -1.4246    -1.4338    -1.0202
DENSITY:
  MOL/CC             1.1319-02  1.1412-02  1.6998-05
  GM/CC                  0.7447     0.7508  1.1183-03
AVG MW                  65.7939    65.7939    65.7939
```


PHYSICAL PROPERTY TABLES SECTION

FLASH CURVE TABLE: BINRY-1

```
  PROPERTIES ALONG A FLASH CURVE FOR THE MIXTURE:  (KG/HR       )
      TOLUE-01  1.000     , ISOPR-01  1.000     ,

  STATE SPECIFICATIONS:
      VAPOR FRACTION:     0.000

  VARIED VARIABLE(S):    PRES      MASSFRAC

  PROPERTY SET(S):       $PS-TXY

  3 PHASE PV FLASHES WERE PERFORMED.

  PROPERTY OPTION SET:   RK-SOAVE  STANDARD RKS EQUATION OF STATE
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PHYSICAL PROPERTY TABLES SECTION

FLASH CURVE TABLE: BINRY-1 (CONTINUED)

PRES BAR	MASSFRAC TOLUE-01	TEMP TOTAL C	KVL TOTAL TOLUE-01	KVL TOTAL ISOPR-01	GAMMA LIQUID 1 TOLUE-01
0.5066	0.0	58.5691	0.3445	1.0000	1.0496
0.5066	2.0000-02	58.7749	0.3466	1.0087	1.0474
0.5066	4.0000-02	58.9859	0.3489	1.0177	1.0453
0.5066	6.0000-02	59.2021	0.3512	1.0270	1.0433
0.5066	8.0000-02	59.4239	0.3536	1.0367	1.0413
0.5066	0.1000	59.6515	0.3561	1.0467	1.0393
0.5066	0.1200	59.8852	0.3588	1.0570	1.0374
0.5066	0.1400	60.1253	0.3616	1.0678	1.0356
0.5066	0.1600	60.3720	0.3645	1.0790	1.0337

0.5066	0.1800	60.6257	0.3675	1.0906	1.0320
0.5066	0.2000	60.8868	0.3707	1.1026	1.0303
0.5066	0.2200	61.1556	0.3740	1.1152	1.0286
0.5066	0.2400	61.4324	0.3775	1.1282	1.0270
0.5066	0.2600	61.7178	0.3811	1.1418	1.0255
0.5066	0.2800	62.0122	0.3849	1.1560	1.0239
0.5066	0.3000	62.3159	0.3890	1.1708	1.0225
0.5066	0.3200	62.6296	0.3932	1.1863	1.0211
0.5066	0.3400	62.9538	0.3976	1.2024	1.0197
0.5066	0.3600	63.2891	0.4023	1.2193	1.0184
0.5066	0.3800	63.6362	0.4072	1.2370	1.0171
0.5066	0.4000	63.9956	0.4123	1.2555	1.0159
0.5066	0.4200	64.3681	0.4178	1.2750	1.0147
0.5066	0.4400	64.7546	0.4235	1.2954	1.0136
0.5066	0.4600	65.1560	0.4296	1.3169	1.0125
0.5066	0.4800	65.5730	0.4360	1.3395	1.0115
0.5066	0.5000	66.0069	0.4428	1.3634	1.0105
0.5066	0.5200	66.4586	0.4500	1.3886	1.0096
0.5066	0.5400	66.9294	0.4576	1.4153	1.0087
0.5066	0.5600	67.4207	0.4658	1.4435	1.0078
0.5066	0.5800	67.9338	0.4744	1.4734	1.0071
0.5066	0.6000	68.4705	0.4836	1.5052	1.0063
0.5066	0.6200	69.0325	0.4935	1.5390	1.0056
0.5066	0.6400	69.6217	0.5040	1.5751	1.0049
0.5066	0.6600	70.2403	0.5153	1.6137	1.0043
0.5066	0.6800	70.8908	0.5274	1.6550	1.0038

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PHYSICAL PROPERTY TABLES SECTION

FLASH CURVE TABLE: BINRY-1 (CONTINUED)

PRES BAR	MASSFRAC TOLUE-01	TEMP TOTAL C	KVL TOTAL TOLUE-01	KVL TOTAL ISOPR-01	GAMMA LIQUID 1 TOLUE-01
0.5066	0.7000	71.5759	0.5404	1.6994	1.0033
0.5066	0.7200	72.2987	0.5545	1.7471	1.0028
0.5066	0.7400	73.0625	0.5698	1.7986	1.0023
0.5066	0.7600	73.8712	0.5863	1.8544	1.0019
0.5066	0.7800	74.7293	0.6043	1.9150	1.0016
0.5066	0.8000	75.6419	0.6240	1.9810	1.0013
0.5066	0.8200	76.6146	0.6455	2.0532	1.0010
0.5066	0.8400	77.6543	0.6693	2.1325	1.0008
0.5066	0.8600	78.7687	0.6955	2.2200	1.0006
0.5066	0.8800	79.9670	0.7246	2.3170	1.0004
0.5066	0.9000	81.2599	0.7572	2.4251	1.0003
0.5066	0.9200	82.6603	0.7938	2.5464	1.0002
0.5066	0.9400	84.1836	0.8353	2.6834	1.0001
0.5066	0.9600	85.8487	0.8825	2.8392	1.0000
0.5066	0.9800	87.6786	0.9369	3.0181	1.0000
0.5066	1.0000	89.7022	1.0000	3.2255	1.0000

PRES BAR	MASSFRAC TOLUE-01	GAMMA LIQUID 1 ISOPR-01	GAMMA LIQUID 2 TOLUE-01	GAMMA LIQUID 2 ISOPR-01	KVL2 TOTAL TOLUE-01
0.5066	0.0	1.0000	MISSING	MISSING	MISSING
0.5066	2.0000-02	1.0000	MISSING	MISSING	MISSING
0.5066	4.0000-02	1.0000	MISSING	MISSING	MISSING
0.5066	6.0000-02	1.0001	MISSING	MISSING	MISSING
0.5066	8.0000-02	1.0002	MISSING	MISSING	MISSING
0.5066	0.1000	1.0003	MISSING	MISSING	MISSING
0.5066	0.1200	1.0004	MISSING	MISSING	MISSING
0.5066	0.1400	1.0006	MISSING	MISSING	MISSING
0.5066	0.1600	1.0007	MISSING	MISSING	MISSING
0.5066	0.1800	1.0009	MISSING	MISSING	MISSING

FLASH CURVE TABLE: BINRY-1 (CONTINUED)

PRES BAR	MASSFRAC TOLUE-01	GAMMA LIQUID 1 ISOPR-01	GAMMA LIQUID 2 TOLUE-01	GAMMA LIQUID 2 ISOPR-01	KVL2 TOTAL TOLUE-01
0.5066	0.2000	1.0011	MISSING	MISSING	MISSING
0.5066	0.2200	1.0014	MISSING	MISSING	MISSING
0.5066	0.2400	1.0016	MISSING	MISSING	MISSING
0.5066	0.2600	1.0019	MISSING	MISSING	MISSING
0.5066	0.2800	1.0022	MISSING	MISSING	MISSING
0.5066	0.3000	1.0025	MISSING	MISSING	MISSING
0.5066	0.3200	1.0028	MISSING	MISSING	MISSING
0.5066	0.3400	1.0032	MISSING	MISSING	MISSING
0.5066	0.3600	1.0035	MISSING	MISSING	MISSING
0.5066	0.3800	1.0039	MISSING	MISSING	MISSING
0.5066	0.4000	1.0043	MISSING	MISSING	MISSING
0.5066	0.4200	1.0047	MISSING	MISSING	MISSING
0.5066	0.4400	1.0051	MISSING	MISSING	MISSING
0.5066	0.4600	1.0056	MISSING	MISSING	MISSING
0.5066	0.4800	1.0060	MISSING	MISSING	MISSING
0.5066	0.5000	1.0064	MISSING	MISSING	MISSING
0.5066	0.5200	1.0069	MISSING	MISSING	MISSING
0.5066	0.5400	1.0073	MISSING	MISSING	MISSING
0.5066	0.5600	1.0078	MISSING	MISSING	MISSING
0.5066	0.5800	1.0083	MISSING	MISSING	MISSING
0.5066	0.6000	1.0087	MISSING	MISSING	MISSING
0.5066	0.6200	1.0092	MISSING	MISSING	MISSING
0.5066	0.6400	1.0097	MISSING	MISSING	MISSING
0.5066	0.6600	1.0101	MISSING	MISSING	MISSING
0.5066	0.6800	1.0105	MISSING	MISSING	MISSING

0.5066	0.7000	1.0110	MISSING	MISSING	MISSING
0.5066	0.7200	1.0114	MISSING	MISSING	MISSING
0.5066	0.7400	1.0117	MISSING	MISSING	MISSING
0.5066	0.7600	1.0121	MISSING	MISSING	MISSING
0.5066	0.7800	1.0124	MISSING	MISSING	MISSING
0.5066	0.8000	1.0127	MISSING	MISSING	MISSING
0.5066	0.8200	1.0129	MISSING	MISSING	MISSING
0.5066	0.8400	1.0131	MISSING	MISSING	MISSING
0.5066	0.8600	1.0133	MISSING	MISSING	MISSING
0.5066	0.8800	1.0134	MISSING	MISSING	MISSING

PHYSICAL PROPERTY TABLES SECTION

FLASH CURVE TABLE: BINRY-1 (CONTINUED)

PRES BAR	MASSFRAC TOLUE-01	GAMMA LIQUID 1 ISOPR-01	GAMMA LIQUID 2 TOLUE-01	GAMMA LIQUID 2 ISOPR-01	KVL2 TOTAL TOLUE-01
0.5066	0.9000	1.0134	MISSING	MISSING	MISSING
0.5066	0.9200	1.0133	MISSING	MISSING	MISSING
0.5066	0.9400	1.0131	MISSING	MISSING	MISSING
0.5066	0.9600	1.0129	MISSING	MISSING	MISSING
0.5066	0.9800	1.0125	MISSING	MISSING	MISSING
0.5066	1.0000	1.0120	MISSING	MISSING	MISSING

PRES BAR	MASSFRAC TOLUE-01	KVL2 TOTAL ISOPR-01	BETA TOTAL	MASSFRAC VAPOR TOLUE-01	MASSFRAC VAPOR ISOPR-01
0.5066	0.0	MISSING	1.0000	0.0	1.0000
0.5066	2.0000-02	MISSING	1.0000	6.9645-03	0.9930
0.5066	4.0000-02	MISSING	1.0000	1.4082-02	0.9859
0.5066	6.0000-02	MISSING	1.0000	2.1360-02	0.9786
0.5066	8.0000-02	MISSING	1.0000	2.8807-02	0.9712
0.5066	0.1000	MISSING	1.0000	3.6430-02	0.9636
0.5066	0.1200	MISSING	1.0000	4.4239-02	0.9558
0.5066	0.1400	MISSING	1.0000	5.2243-02	0.9478
0.5066	0.1600	MISSING	1.0000	6.0451-02	0.9395
0.5066	0.1800	MISSING	1.0000	6.8875-02	0.9311
0.5066	0.2000	MISSING	1.0000	7.7526-02	0.9225
0.5066	0.2200	MISSING	1.0000	8.6416-02	0.9136
0.5066	0.2400	MISSING	1.0000	9.5557-02	0.9044
0.5066	0.2600	MISSING	1.0000	0.1050	0.8950
0.5066	0.2800	MISSING	1.0000	0.1147	0.8853
0.5066	0.3000	MISSING	1.0000	0.1246	0.8754
0.5066	0.3200	MISSING	1.0000	0.1349	0.8651
0.5066	0.3400	MISSING	1.0000	0.1456	0.8544

0.5066	0.3600	MISSING	1.0000	0.1565	0.8435
0.5066	0.3800	MISSING	1.0000	0.1679	0.8321

PHYSICAL PROPERTY TABLES SECTION

FLASH CURVE TABLE: BINRY-1 (CONTINUED)

PRES BAR	MASSFRAC TOLUE-01	KVL2 TOTAL ISOPR-01	BETA TOTAL	MASSFRAC VAPOR TOLUE-01	MASSFRAC VAPOR ISOPR-01
0.5066	0.4000	MISSING	1.0000	0.1796	0.8204
0.5066	0.4200	MISSING	1.0000	0.1918	0.8082
0.5066	0.4400	MISSING	1.0000	0.2044	0.7956
0.5066	0.4600	MISSING	1.0000	0.2175	0.7825
0.5066	0.4800	MISSING	1.0000	0.2310	0.7690
0.5066	0.5000	MISSING	1.0000	0.2452	0.7548
0.5066	0.5200	MISSING	1.0000	0.2598	0.7402
0.5066	0.5400	MISSING	1.0000	0.2752	0.7248
0.5066	0.5600	MISSING	1.0000	0.2911	0.7089
0.5066	0.5800	MISSING	1.0000	0.3078	0.6922
0.5066	0.6000	MISSING	1.0000	0.3252	0.6748
0.5066	0.6200	MISSING	1.0000	0.3435	0.6565
0.5066	0.6400	MISSING	1.0000	0.3626	0.6374
0.5066	0.6600	MISSING	1.0000	0.3827	0.6173
0.5066	0.6800	MISSING	1.0000	0.4038	0.5962
0.5066	0.7000	MISSING	1.0000	0.4260	0.5740
0.5066	0.7200	MISSING	1.0000	0.4494	0.5506
0.5066	0.7400	MISSING	1.0000	0.4741	0.5259
0.5066	0.7600	MISSING	1.0000	0.5003	0.4997
0.5066	0.7800	MISSING	1.0000	0.5280	0.4720
0.5066	0.8000	MISSING	1.0000	0.5575	0.4425
0.5066	0.8200	MISSING	1.0000	0.5889	0.4111
0.5066	0.8400	MISSING	1.0000	0.6223	0.3777
0.5066	0.8600	MISSING	1.0000	0.6581	0.3419
0.5066	0.8800	MISSING	1.0000	0.6964	0.3036
0.5066	0.9000	MISSING	1.0000	0.7375	0.2625
0.5066	0.9200	MISSING	1.0000	0.7819	0.2181
0.5066	0.9400	MISSING	1.0000	0.8298	0.1702
0.5066	0.9600	MISSING	1.0000	0.8818	0.1182
0.5066	0.9800	MISSING	1.0000	0.9383	6.1691-02
0.5066	1.0000	MISSING	1.0000	1.0000	0.0

PHYSICAL PROPERTY TABLES SECTION

FLASH CURVE TABLE: BINRY-1 (CONTINUED)

PRES	MASSFRAC	MASSFRAC LIQUID 1	MASSFRAC LIQUID 1	MASSFRAC LIQUID 2	MASSFRAC LIQUID 2

	TOLUE-01	TOLUE-01	ISOPR-01	TOLUE-01	ISOPR-01
BAR					
0.5066	0.0	0.0	1.0000	MISSING	MISSING
0.5066	2.0000-02	2.0000-02	0.9800	MISSING	MISSING
0.5066	4.0000-02	4.0000-02	0.9600	MISSING	MISSING
0.5066	6.0000-02	6.0000-02	0.9400	MISSING	MISSING
0.5066	8.0000-02	8.0000-02	0.9200	MISSING	MISSING
0.5066	0.1000	0.1000	0.9000	MISSING	MISSING
0.5066	0.1200	0.1200	0.8800	MISSING	MISSING
0.5066	0.1400	0.1400	0.8600	MISSING	MISSING
0.5066	0.1600	0.1600	0.8400	MISSING	MISSING
0.5066	0.1800	0.1800	0.8200	MISSING	MISSING
0.5066	0.2000	0.2000	0.8000	MISSING	MISSING
0.5066	0.2200	0.2200	0.7800	MISSING	MISSING
0.5066	0.2400	0.2400	0.7600	MISSING	MISSING
0.5066	0.2600	0.2600	0.7400	MISSING	MISSING
0.5066	0.2800	0.2800	0.7200	MISSING	MISSING
0.5066	0.3000	0.3000	0.7000	MISSING	MISSING
0.5066	0.3200	0.3200	0.6800	MISSING	MISSING
0.5066	0.3400	0.3400	0.6600	MISSING	MISSING
0.5066	0.3600	0.3600	0.6400	MISSING	MISSING
0.5066	0.3800	0.3800	0.6200	MISSING	MISSING
0.5066	0.4000	0.4000	0.6000	MISSING	MISSING
0.5066	0.4200	0.4200	0.5800	MISSING	MISSING
0.5066	0.4400	0.4400	0.5600	MISSING	MISSING
0.5066	0.4600	0.4600	0.5400	MISSING	MISSING
0.5066	0.4800	0.4800	0.5200	MISSING	MISSING
0.5066	0.5000	0.5000	0.5000	MISSING	MISSING
0.5066	0.5200	0.5200	0.4800	MISSING	MISSING
0.5066	0.5400	0.5400	0.4600	MISSING	MISSING
0.5066	0.5600	0.5600	0.4400	MISSING	MISSING
0.5066	0.5800	0.5800	0.4200	MISSING	MISSING
0.5066	0.6000	0.6000	0.4000	MISSING	MISSING
0.5066	0.6200	0.6200	0.3800	MISSING	MISSING
0.5066	0.6400	0.6400	0.3600	MISSING	MISSING
0.5066	0.6600	0.6600	0.3400	MISSING	MISSING
0.5066	0.6800	0.6800	0.3200	MISSING	MISSING

FLASH CURVE TABLE: BINRY-1 (CONTINUED)

PRES	MASSFRAC	MASSFRAC LIQUID 1	MASSFRAC LIQUID 1	MASSFRAC LIQUID 2	MASSFRAC LIQUID 2
	TOLUE-01	TOLUE-01	ISOPR-01	TOLUE-01	ISOPR-01
BAR					
0.5066	0.7000	0.7000	0.3000	MISSING	MISSING
0.5066	0.7200	0.7200	0.2800	MISSING	MISSING
0.5066	0.7400	0.7400	0.2600	MISSING	MISSING
0.5066	0.7600	0.7600	0.2400	MISSING	MISSING

0.5066	0.7800	0.7800	0.2200	MISSING	MISSING
0.5066	0.8000	0.8000	0.2000	MISSING	MISSING
0.5066	0.8200	0.8200	0.1800	MISSING	MISSING
0.5066	0.8400	0.8400	0.1600	MISSING	MISSING
0.5066	0.8600	0.8600	0.1400	MISSING	MISSING
0.5066	0.8800	0.8800	0.1200	MISSING	MISSING
0.5066	0.9000	0.9000	0.1000	MISSING	MISSING
0.5066	0.9200	0.9200	8.0000-02	MISSING	MISSING
0.5066	0.9400	0.9400	6.0000-02	MISSING	MISSING
0.5066	0.9600	0.9600	4.0000-02	MISSING	MISSING
0.5066	0.9800	0.9800	2.0000-02	MISSING	MISSING
0.5066	1.0000	1.0000	0.0	MISSING	MISSING

PROBLEM STATUS SECTION

BLOCK STATUS

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

25.6. MATLAB Material Balance Script

```
%% Initial Conditions

SolventPurge = 0.001; % 0.1 percent purge
NonsolventPurge = 0.001; % 0.1 percent purge
Impurities = 0.01; % Assume 1% impurities in feed

%% Solve Overall Mass Balances

syms m1 m2 m3 m4 m5 m6 m7 m8 m9 m10 m11 m12 m13 m14 m15 m16 m17 m18 m19 m20

eq1m = m1 == 4167; % Feed
eq2m = m1 - 0.15*m3 == 0; % Assume 15% feed in solution with solvent recycle
eq3m = m3 - m2 - m1 == 0;
eq4m = m4 - Impurities*m1 == 0;
eq5m = m3 - m4 - m19 == 0;
eq6m = m5 - 3*(m2 - 99*(1-Impurities)*m1/99001) == 0; % Assume 3:1 NS to S
feeds in precipitation vessel
eq7m = m11 - 0.750175*(m8 - m10/99) == 0;
eq8m = m16 - NonsolventPurge*m11 == 0;
eq9m = m11 - m17 - m16 == 0;
eq10m = m17 - m5 + m18 == 0;
eq11m = (1 - Impurities)*m1 - (0.99001/0.99)*m10 == 0; % Based on polymer
balance (99 percent polymer M10, 0.99001 percent polymer M2, 100 percent
polymer M3)
eq12m = m13 - SolventPurge*m12 == 0;
eq13m = m12 - m13 - m14 == 0;
eq14m = m2 - m14 - m15 == 0;
eq15m = m8 - m11 - m12 == 0;
eq16m = m6 - m8 - m10 == 0;
eq17m = m10 - 0.90*m7 == 0; % Assume polymer makes up 90 percent of stream 7
eq18m = m7 - m9 - m10 == 0;
eq19m = m6 - m20 - m7 == 0;
eq20m = m6 - m5 - m19 == 0;

[A,B] = equationsToMatrix([eq1m, eq2m, eq3m, eq4m, eq5m, eq6m, ...
    eq7m, eq8m, eq9m, eq10m, eq11m, eq12m, eq13m, eq14m, eq15m, ...
    eq16m, eq17m, eq18m, eq19m, eq20m], [m1 m2 m3 m4 m5 m6 m7 ...
    m8 m9 m10 m11 m12 m13 m14 m15 m16 m17 m18 m19 m20]);

M = double(linsolve(A,B));

% Make some math changes to allow solvent and nonsolvent to balance

SolventChange = M(13) - M(15);
M(15) = M(15) + SolventChange;
M(2) = M(2) + SolventChange;
M(3) = M(3) + SolventChange;
M(19) = M(19) + SolventChange;

NonsolventChange = M(16) - M(18);
M(18) = M(18) + NonsolventChange;
M(5) = M(5) + NonsolventChange;
```

```
%% Solve Polymer Balances
syms p1 p2 p3 p4 p5 p6 p7 p8 p9 p10 p11 p12 p13 p14 p15 p16 p17 p18 p19 p20

eq1p = p1 == (1 - Impurities)*M(1);
eq2p = p4 == 0;
eq3p = p11 == 0; % Assume no polymer in distillate
eq4p = p16 == 0;
eq5p = p17 == 0;
eq6p = p18 == 0;
eq7p = p5 == 0; % No polymer in fresh nonsolvent
eq8p = p15 == 0; % No polymer in fresh solvent
eq9p = p9 == 0; % Assume all polymer in stream 7 moves to product
eq10p = p3 - p19 ==0;
eq11p = p10 - p7 == 0;
eq12p = p7 - 0.99*p6 == 0; % Assume 99 percent of polymer precipitates from
precipitation vessel
eq13p = p6 - p20 - p7 == 0;
eq14p = p8 - p20 == 0;
eq15p = p8 - p12 == 0;
eq16p = p13 - SolventPurge*p12 == 0;
eq17p = p12 - p14 - p13 == 0;
eq18p = p14 - p2 == 0;
eq19p = p3 - p2 - p1 == 0;
eq20p = p19 - p6 == 0;

[C,D] = equationsToMatrix([eq1p, eq2p, eq3p, eq4p, eq5p, eq6p, ...
    eq7p, eq8p, eq9p, eq10p, eq11p, eq12p, eq13p, eq14p, eq15p, ...
    eq16p, eq17p, eq18p, eq19p, eq20p], [p1 p2 p3 p4 p5 p6 p7 ...
    p8 p9 p10 p11 p12 p13 p14 p15 p16 p17 p18 p19 p20]);

P = double(linsolve(C,D));
%% Solve Solvent Balance

syms s1 s2 s3 s4 s5 s6 s7 s8 s9 s10 s11 s12 s13 s14 s15 s16 s17 s18 s19 s20
eq1s = s12 == 0.9997*(M(12)-P(12)); % Assume in stream 8, solvent to
nonsolvent ratio is 1:3
eq2s = s11 == 0.0003*(M(11)-P(11)); % From ASPEN
eq3s = s16 - NonsolventPurge*s11 == 0;
eq4s = s11 - s16 - s17 == 0;
eq5s = s18 == 0; % No solvent in fresh nonsolvent stream
eq6s = s5 - s18 - s17 == 0;
eq7s = s8 - s11 - s12 == 0;
eq8s = s13 - SolventPurge*s12 == 0;
eq9s = s12 - s13 - s14 == 0;
eq10s = s15 == M(15);
eq11s = s2 - s15 - s14 == 0;
eq12s = s1 == 0; % No solvent in feed stream
eq13s = s3 - s2 - s1 == 0;
eq14s = s4 == 0; % Assume no solvent removed in filter
eq15s = s3 - s4 - s19 == 0;
eq16s = s6 - s5 - s19 == 0;
eq17s = s10 == 0; % Assume no solvent in final product
eq18s = ((M(7) - P(7))/(M(6) - P(6)))*s6 - s7 == 0; % Assume solvent to
nonsolvent ratio same in stream 7 and stream 6
eq19s = s20 + s7 - s6 == 0;
```

```
eq20s = s9 - s7 == 0;

[E,F] = equationsToMatrix([eq1s, eq2s, eq3s, eq4s, eq5s, eq6s, ...
    eq7s, eq8s, eq9s, eq10s, eq11s, eq12s, eq13s, eq14s, eq15s, ...
    eq16s, eq17s, eq18s, eq19s, eq20s], [s1 s2 s3 s4 s5 s6 s7 ...
    s8 s9 s10 s11 s12 s13 s14 s15 s16 s17 s18 s19 s20]);

S = double(linsolve(E,F));

%% Solve Nonsolvent Balance

syms n1 n2 n3 n4 n5 n6 n7 n8 n9 n10 n11 n12 n13 n14 n15 n16 n17 n18 n19 n20
eq1n = n12 == 0.0003*(M(12)-P(12)); % Assume in stream 8, solvent to
nonsolvent ratio is 1:3
eq2n = n11 == 0.9997*(M(11)-P(11)); % From ASPEN
eq3n = n16 - NonsolventPurge*n11 == 0;
eq4n = n11 - n16 - n17 == 0;
eq5n = n18 == M(18);
eq6n = n5 - n18 - n17 == 0;
eq7n = n8 - n11 - n12 == 0;
eq8n = n13 - SolventPurge*n12 == 0;
eq9n = n12 - n13 - n14 == 0;
eq10n = n15 == 0; % No nonsolvent in fresh solvent feed
eq11n = n2 - n15 - n14 == 0;
eq12n = n1 == 0; % No nonsolvent in feed stream
eq13n = n3 - n2 - n1 == 0;
eq14n = n4 == 0; % Assume no nonsolvent removed in filter
eq15n = n3 - n4 - n19 == 0;
eq16n = n6 - n5 - n19 == 0;
eq17n = n10 == 0; % Assume no nonsolvent in final product
eq18n = n6 - n7 - n20 == 0;
eq19n = n9 == M(9) - S(9);
eq20n = ((M(7) - P(7))/(M(6) - P(6)))*n6 - n7 == 0; % Assume solvent to
nonsolvent ratio same in stream 7 and stream 6

[G,H] = equationsToMatrix([eq1n, eq2n, eq3n, eq4n, eq5n, eq6n, ...
    eq7n, eq8n, eq9n, eq10n, eq11n, eq12n, eq13n, eq14n, eq15n, ...
    eq16n, eq17n, eq18n, eq19n, eq20n], [n1 n2 n3 n4 n5 n6 n7 ...
    n8 n9 n10 n11 n12 n13 n14 n15 n16 n17 n18 n19 n20]);

N = double(linsolve(G,H));

%% Make Table of Total Flows and Compositions

% Within polymer, assume 99.99% LDPE and 0.0001% Impurity from dyes
P = 0.9999*P;

PComp = P./M;
NComp = N./M;
SComp = S./M;

table(P,N,S,M,PComp,NComp,SComp)
```

25.7. Energy Integration Calculations

For all the energy integration calculations, Table 25.X applies when computing the weighted average density and heat capacities.

Table 25.X. Component-specific densities and specific heat capacities.

Component	Density (g/L)	C_P (J/g·K)
LDPE	930	2.10
Toluene	867	1.70
Isopropanol	786	3.00

Dissolution Vessel

T_{VESSEL} = 85°C

Assume that there is no heat loss from conduction or convection due to good insulation.

$$Q_1 = Q_2$$

$$m_1 C_{P,1}(T_{VESSEL} - T_1) = -m_2 C_{P,2}(T_{VESSEL} - T_2)$$

$$T_2 = T_{VESSEL} + \frac{m_1 C_{P,1}}{m_2 C_{P,2}}(T_{VESSEL} - T_1)$$

$$C_{P,1} = 2.10\ \mathrm{J/g \cdot K}$$

$$C_{P,2} = \left(\frac{41.6}{23624.7}\right)(2.10) + \left(\frac{23576.0}{23624.7}\right)(1.70) + \left(\frac{7.1}{23624.7}\right)(3.00) = 1.701\ \mathrm{J/g \cdot K}$$

$$T_2 = (85) + \frac{(4167.0)(2.10)}{(23624.7)(1.701)}(85 - 25) = 98.0°\mathrm{C} = \mathbf{208.4°F}$$

Solvent Feed Tank

T_{VESSEL} = 98.0°C (from previous calculation)

Assume that there is no heat loss from conduction or convection due to good insulation.

$$Q_{15} = Q_{14}$$

$$m_{15} C_{P,15}(T_{VESSEL} - T_{15}) = -m_{14} C_{P,14}(T_{VESSEL} - T_{14})$$

$$T_{14} = T_{VESSEL} + \frac{m_{15} C_{P,15}}{m_{14} C_{P,14}}(T_{VESSEL} - T_{15})$$

$$C_{P,15} = 1.70\ \mathrm{J/g \cdot K}$$

$$C_{P,14} = \left(\frac{41.6}{23601.0}\right)(2.10) + \left(\frac{23552.4}{23601.0}\right)(1.70) + \left(\frac{7.1}{236201.0}\right)(3.00) = 1.701\ \mathrm{J/g \cdot K}$$

$$T_{14} = (98.0) + \frac{(23.6)(1.70)}{(23601.0)(1.701)}(98.0 - 25) = 98.1°\mathrm{C} = \mathbf{208.6°F}$$

Precipitation Vessel

T_{VESSEL} = 80°C

Assume that there is no heat loss from conduction or convection due to good insulation.

$$Q_{19} = Q_5$$

$$m_{19}C_{P,19}(T_{VESSEL} - T_{19}) = -m_5 C_{P,5}(T_{VESSEL} - T_5)$$
$$T_5 = T_{VESSEL} + \frac{m_{19}C_{P,19}}{m_5 C_{P,5}}(T_{VESSEL} - T_{19})$$
$$C_{P,19} = \left(\frac{4166.5}{27750.0}\right)(2.10) + \left(\frac{23576.0}{27750.0}\right)(1.70) + \left(\frac{7.1}{27750.0}\right)(3.00) = 1.745\ \mathrm{J/g\cdot K}$$
$$C_{P,5} = \left(\frac{0}{70815.0}\right)(2.10) + \left(\frac{21.2}{70815.0}\right)(1.70) + \left(\frac{70793.8}{70815.0}\right)(3.00) = 3.000\ \mathrm{J/g\cdot K}$$

$$T_5 = (80) + \frac{(27750.0)(1.745)}{(70815.0)(3.000)}(80 - 85) = 78.8°\mathrm{C} = \mathbf{173.8°F}$$

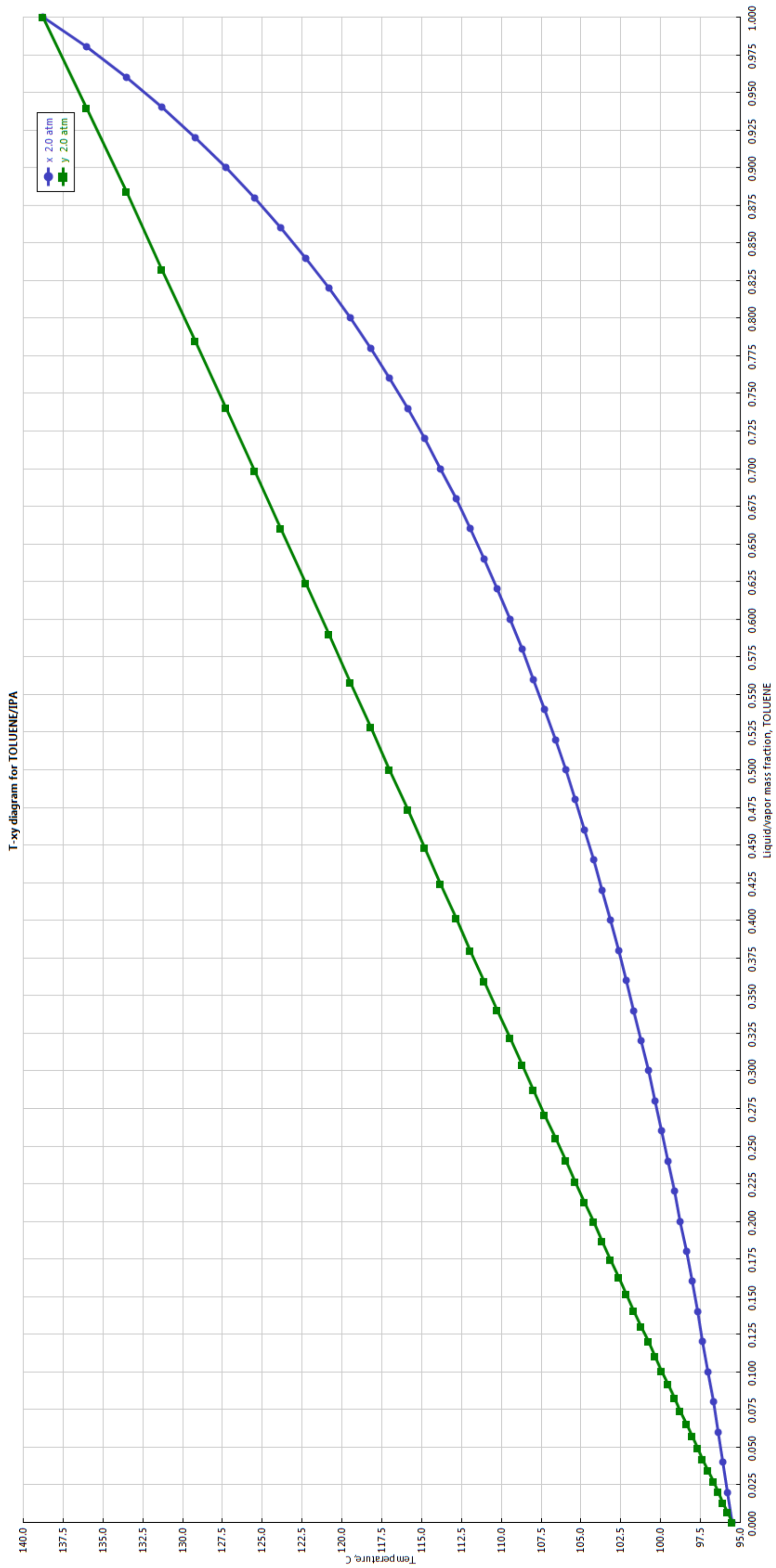
<u>Nonsolvent Feed Tank</u>
T_{VESSEL} = 78.8°C (from previous calculation)
Assume that there is no heat loss from conduction or convection due to good insulation.

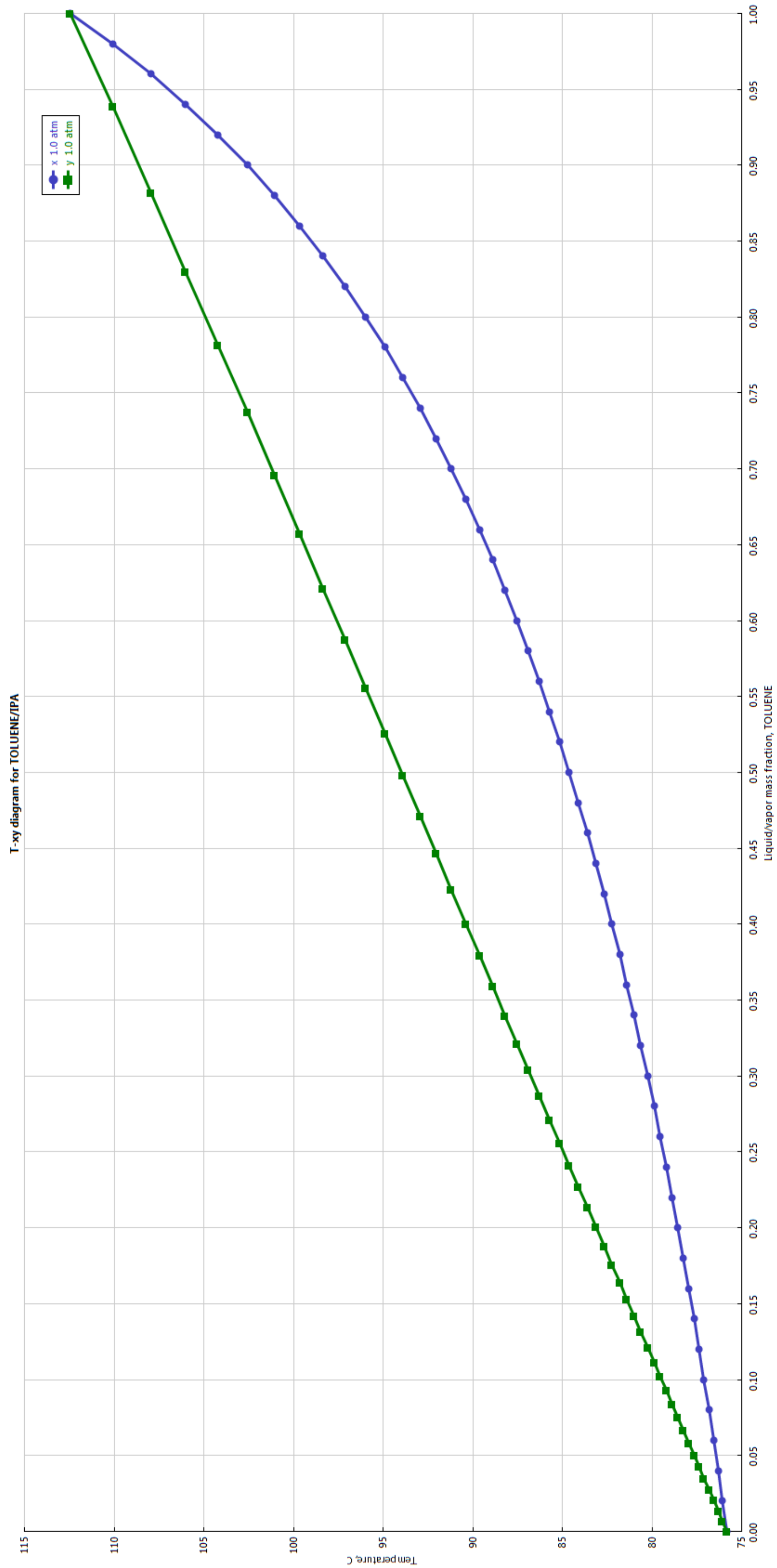
$$Q_{18} = Q_{23}$$
$$m_{18}C_{P,18}(T_{VESSEL} - T_{18}) = -m_{23}C_{P,23}(T_{VESSEL} - T_{23})$$
$$T_{23} = T_{VESSEL} + \frac{m_{18}C_{P,18}}{m_{23}C_{P,23}}(T_{VESSEL} - T_{18})$$
$$C_{P,18} = 3.00\ \mathrm{J/g\cdot K}$$
$$C_{P,23} = \left(\frac{0}{70744.2}\right)(2.10) + \left(\frac{21.2}{70744.2}\right)(1.70) + \left(\frac{70723.0}{70744.2}\right)(3.00) = 3.000\ \mathrm{J/g\cdot K}$$

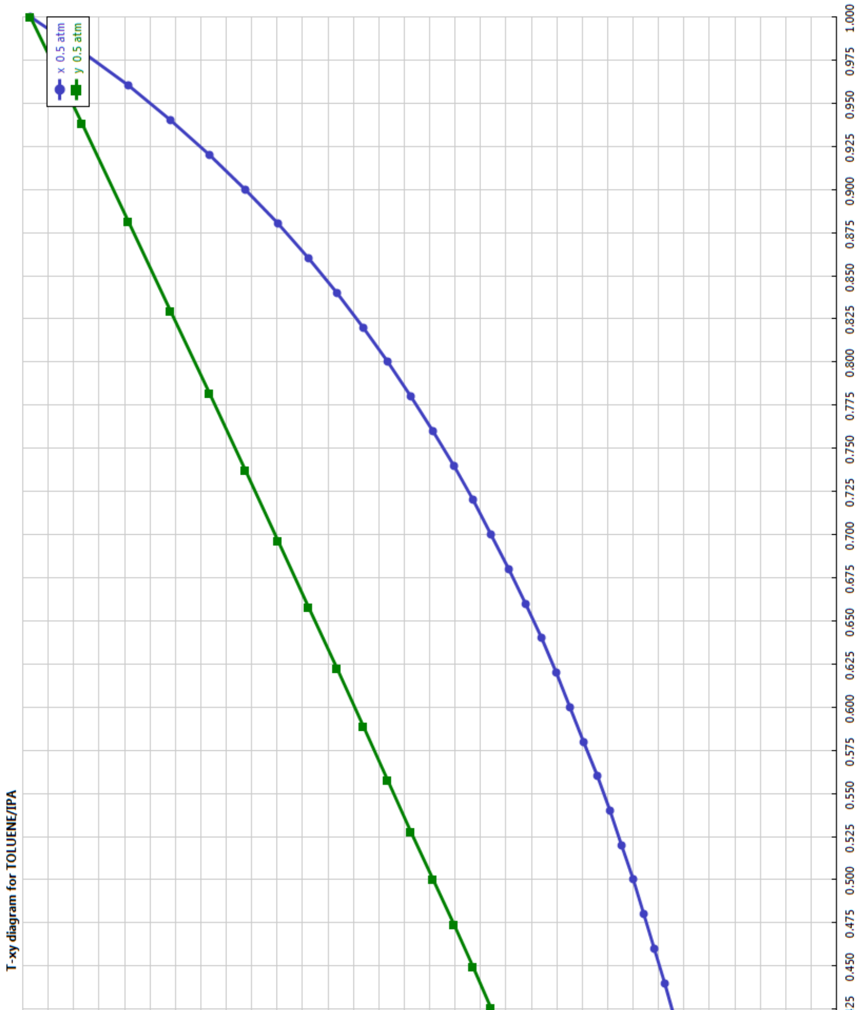
$$T_{23} = (78.8) + \frac{(27750.0)(3.000)}{(70815.0)(3.000)}(78.8 - 25) = 78.9°\mathrm{C} = \mathbf{174.0°F}$$

25.8. T-xy Diagrams for Toluene-Isopropanol Mixture

The following T-xy diagrams were produced from ASPEN to identify the boiling point of the mixture at three pressures: 2 atm, 1 atm and 0.5 atm.




T-xy diagram for TOLUENE/IPA
x 1.0 atm
y 1.0 atm
Liquid/vapor mass fraction, TOLUENE
Temperature, C


T-xy diagram for TOLUENE/IPA
x 0.5 atm
y 0.5 atm
Temperature, C