University of Pennsylvania, School of Engineering and Applied Science
Department of Chemical and Biomolecular Engineering
220 South 33rd Street
Philadelphia, PA 19104

April 17, 2018

Dear Dr. Daeyeon Lee and Mr. Bruce Vrana,

Enclosed is a proposal for the design of a waste plastics pyrolysis process based on the research of A. Karaduman. The proposed plant uses pyrolysis to recycle polystyrene and produce its monomer styrene as the main product. The process design is based on a feedstock of 100 tons per day, with the goal of producing styrene monomer at a polymer grade purity greater than 99.9%. The plant is to be located in an industrial complex on the United States Gulf Coast where a number of styrene monomer producers are situated.

Clean and sorted polystyrene is collected, densified, and brought to the facility, where the feedstock will have ample space for storage due to the large capacity required. It is then fed to a rotary kiln reactor to carry out the pyrolysis reaction. The rotating vessel attached to an auger allows for the solid residue removal. The gaseous product is cooled to produce high-pressured steam, then condensed to separate the light hydrocarbons from the desirable liquid products. The light gases are reused as fuel gas for pyrolyzer heating and any excess is sold. The liquid product mixture is separated using distillation columns to isolate styrene and other liquid products (ethylbenzene, methyl styrene and toluene) at purity levels higher than 99.9%. Seven days' supply of products is maintained in storage tanks. Energy and heat integration is optimized to reduce operating expenses.

The plant will operate for 24 hours a day, 330 days a year, with polystyrene available for \$0.30 per pound and styrene valued at \$1.00 per pound. The proposed design requires an investment of \$25.0 MM to meet the processing goal of 100 tons per day of polystyrene, and yields an investor's rate of return (IRR) of 18.5%. We recommend investing in this process while remaining wary of the market prices of polystyrene and styrene.

Sincerely,

Jade Bassil	Gabrielle Dreux	Gwendolyn Eastaugh

Chemical Recycling of Polystyrene Using Pyrolysis

Jade Bassil | Gabrielle Dreux | Gwendolyn Eastaugh

Project submitted to Dr. Daeyeon Lee and Prof. Bruce Vrana.
Project proposed by Matthew Targett.

Department of Chemical and Biomolecular Engineering
School of Engineering and Applied Science
University of Pennsylvania
April 18, 2017

Table of Contents

Section 1. Abstract

There are significant economic and environmental benefits to the recycling of waste plastics, especially that of polystyrene. Currently, much of polystyrene waste is sent to landfills due to the difficulty in separation and cleaning processes, where it accumulates indefinitely. It contributes to plastic pollution and adversely affects wildlife, oceans and humans. Pyrolysis of waste polystyrene is explored in this paper as a chemical recycling method. This reaction yields useful liquid fuel products such as styrene, ethylbenzene, toluene, and methylstyrene, which can be sold to provide project revenues. Beginning with a polystyrene feed of 100 tons per day, the suggested design achieves a liquid styrene product purity of 99.9%. The plant includes a rotary-kiln reactor to carry out the pyrolysis reaction and a distillation train to isolate the liquid products. Pumps, blowers and storage equipment are also included in the design. Heat and energy are optimally integrated using heat exchangers to reduce the cost of purchased utilities. The suggested design requires a capital investment of $25.0 MM and yields a fifteen-year net present value of $5.1 MM. The internal rate of return it achieves is equal to 18.5%. The projected cash flows of this plant suggest that it will break even by 2030 on a cumulative discounted free cash flow basis. The design is recommended based on project specifications and current price projections, though investors should exercise caution with regards to the effect of realistic market prices of styrene and polystyrene on the project's profitability measures.

Section 2. Introduction and Objective-Time Chart

i. Introduction

The growing use of plastics in modern society has created significant sustainability concerns. Plastics, although valuable for their inherent strength and durability, pose complications regarding their disposal as are non-degradable and thus accumulate in the environment indefinitely. Only ten percent of all plastics in the Unites States are recycled, with polystyrene recovery at less than one percent. Though this low figure can be partially explained by imperfect consumer recycling practices, technological constraints limit a great deal of plastics recycling.

Waste plastics are recycled by means of three major processes: closed loop, or primary, recycling; mechanical, or secondary, recycling; and chemical, or tertiary, recycling. Current recycling processes for waste polystyrene focus heavily on closed-loop recycling, which is made difficult by the presence of impurities as it requires a feed of uncontaminated, singly-used plastic. The chemical recycling of polystyrene, however, is a relatively unexploited market with significant potential for both economic and environmental benefits. From an economic perspective, the thermal degradation of polystyrene produces useful liquid products including benzene, toluene, ethylbenzene, styrene and methylstyrene, which can be sold for profit. From an environmental perspective, it provides a way of decreasing the amount of polystyrene currently accumulating in landfills and an ecological, alternative method of producing styrene.

Despite the low availability of clean feedstock material, the lack of market competition coupled with the high liquid selling prices motivate this process. Modeled after Karaduman's research, pyrolysis of waste polystyrene is explored in this report as a chemical recycling method. This reaction results in solid, liquid and gaseous products when carried out at a temperature ranging from 350˚C to 450˚C with a residence time of 60 minutes[1]. As shown in Figure 2.1 below, the highest yield of styrene monomer is obtained by running the reaction at 400˚C, and thus it is chosen as the reaction temperature for our process. At this temperature, the yield of styrene is equal to 68.1% in the liquid product and 55.1% in the total product on a mass basis. While much of the economic benefit of this process comes from the liquid products, the solid residue and the non-condensable gaseous products are optimally integrated elsewhere in the process.

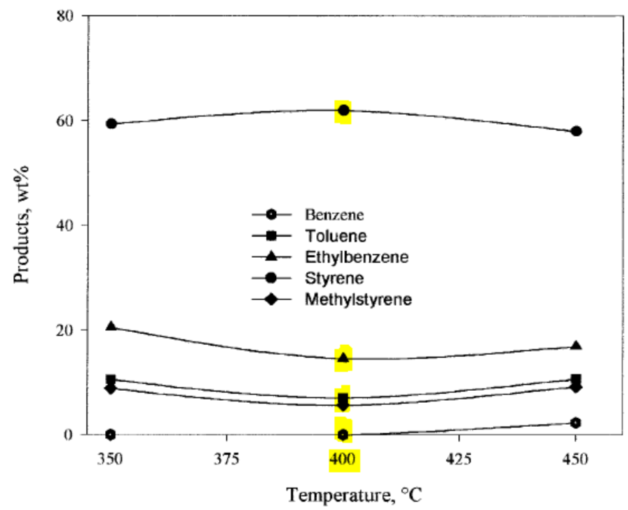

Figure 2.1. Liquid product composition of the pyrolysis of polystyrene at 350-450˚C and 60 minutes residence time. By normalizing these values, we find that at 400˚C, the reaction produces 68% of styrene, 17% of ethylbenzene, 9% of toluene and 6% of toluene in the liquid product for a residence time of 60 minutes. [Karaduman, 2002]

As environmental advantages to the chemical recycling of polystyrene are more difficult to quantify, the primary goal of this report is to analyze the potential economic profitability of the thermal pyrolytic degradation of polystyrene. The results of our analysis suggest that this process constitutes a considerable opportunity for investors, and are presented in subsequent sections.

[1] Karaduman A; Pyrolysis of Polystyrene Plastic Wastes with Some Organic Compounds for Enhancing Styrene Yield. Energy Sources, 24: 667-674, 2002

ii. *Objective-Time Chart*

Specific Goals:

- Thermal pyrolytic degradation of polystyrene only
- Temperature range of 350°C-450°C and residence time of 60 min
- Product Outputs: solid residue, liquids, gaseous products
- Liquid Product Composition: styrene, ethylbenzene, toluene, methyl styrene, and benzene

Project Scope:

- Capacity: 100 TPD PS Feed
- Liquid Products Purity, polymer grade purity of >99.9%
- Fuel Gas composition, to be determined by other references and mass balance estimations
- Solids Residue composition, assume to be a coke-type of composition
- Liquids selling prices, to be estimated by analysis of long term market trends
- Waste polymer purchase/delivery costs, to be estimated based on best practices
- Capex-Opex operation optimization based on type of pyrolyzer, temperature of pyrolyzer, heat integration, fuel gas utilization

Deliverables:

- Develop complete flowsheet illustrating the designed process with accurate mass and energy balances
- Present a reasonable reactor design for the process
- Provide block results for operating conditions of each unit
- Financial analysis with process and pricing sensitivity analysis

Process Development Timetable:

- Complete mid-semester presentation for Feb. 27th, 2018
- Complete deliverables over the course of the spring semester
- Final polished product complete by April 17th, 2017

Section 3. Innovation Map

N/A

Section 4. Market and Competitive Assessment

With less than 1% of waste polystyrene being recycled in the United States, there is a large potential market for the chemical recycling of this waste plastic[2]. There is currently a high demand for polystyrene and expanded polystyrene by both consumers and industries, but there isn't any environmentally and economically efficient means to dispose of polystyrene polymer. This process provides and financially sustainable method of recycling waste polystyrene. In addition, this process suggests an alternative, environmentally-friendly method of producing styrene. Styrene does occur naturally in small quantities in natural resources such as plants, coffee, strawberries and coal tar, but it is mostly produced industrially by the dehydrogenation of ethylbenzene. Thus, styrene is typically derived from either petroleum or natural gas, both of which are non-renewable and are depleting. These limits to the supply of styrene reveal that a considerable market opportunity exists for an alternative styrene production process. In addition, these methods of producing styrene entail higher temperatures and lower yields than are used in the proposed process[3]. From a demand perspective, styrene is highly valued for its use as a precursor in the production of polymers and copolymers. More specifically, the growing demand for polystyrene drives the global styrene market growth[4].

Current companies specializing in the pyrolytic degradation of waste plastics into fuel oils include Klean Industries, Agile Process Chemicals and Beston and all primarily handle PPE and PET or tires. These companies are located outside the United States in Europe, Canada and Asia, leaving a demand for such a plant in the U.S. Because such a small percentage of plastics are recycled in general, and even a smaller percentage of that undergoes chemical recycling,

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[2] "Styrene Market - Trends, Growth, Industry Analysis and Forecast (2018 - 2023)." *Styrene Market | Size | Trends | Analysis to 2023*, www.mordorintelligence.com/industry-reports/styrene-market.
[3] Henry, Joseph P., and Loy A. Wilkinson. *Degredation of Ethylbenzene to Styrene*. 20 June 1967.
[4] "Styrene Market - Trends, Growth, Industry Analysis and Forecast (2018 - 2023)."

securing a high enough volume feedstock at 100 tons per day is of course challenging. This difficulty is considered in Section 10.1. Overall, the open market and economic and environmental benefits are indications of the potential of this project.

Section 5. Customer Requirements

N/A

Section 6. CTQ Variables – Product Requirements

N/A

Section 7. Product Concepts

N/A

Section 8. Superior Product Concepts

N/A

Section 9. Competitive (Patent) Analysis

N/A

Section 10. Preliminary Process Synthesis

i. Polystyrene Assumptions

The availability of the feedstock is a major design challenge as less than 1% of polystyrene waste is recycled while the rest is sent to landfills[5]. In 2012, the United States generated two million tons of polystyrene waste, only recovering 0.9% of it[6]. These statistics confirm that procurement of polystyrene is an important consideration affecting the construction and operation of the proposed plant.

While there is an abundance of polystyrene going to waste, its isolation from other types of plastics and its cleaning process make recycling it more of a challenge. Polystyrene is commonly used in the food industry and most of the waste plastic contains food particles among other contaminants. If not cleaned shortly after dirtying, the cleaning process is made much more difficult and thus the recycling becomes uneconomical.

In addition, the wide density range of polystyrene makes its separation more challenging. Approximately 10% of polystyrene comes in the form of expanded polystyrene (EPS) foam, with densities ranging from 0.016-0.64 g/cm^3. Polystyrene products can vary from this low-density range to a much higher level of 1.04 g/cm^3, which complicates the sorting process.[7] Only about 50% of polystyrene is produced is in its pure form, with the remainder being blended with other materials (in the case of EPS, blown with a blowing agent, typically pentane). This diversity in polystyrene products adds to the challenge and requires steps beyond other plastic sorting processes.

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[5] Rahimi, A., & García, J. M. (2017). Chemical recycling of waste plastics for new materials production. *Nature Reviews Chemistry,1*(6), 0046. doi:10.1038/s41570-017-0046
[6] Rahimi, A., & García, J. M. (2017)
[7] Rahimi, A., & García, J. M. (2017).

Despite these challenges, there are some plants in the United States that have the capabilities for separation and cleaning. For instance, companies such as Alpine Waste and Recycling, Foam Cycle, GreenMAX IntcoRecycling, Dart Container, Plastics Recycling Inc., Northeast Recycling, Moore Recycling Associates and EPS Industry Alliance all specialize in the recycling of both polystyrene and expanded polystyrene (EPS). Four of these companies are discussed further below.

Alpine Waste & Recycling is one of the first companies in Denver to accept curbside expanded polystyrene from consumers. They are also one of the few processing facilities in the U.S. to accept foam in their single-stream. In 2016, they recycled 140 tons of EPS foam total.

Dart Container Corporation, the worlds' largest manufacturer of foam cups and containers, has partnered with several companies across the United States to convert post-consumer foam into new products.[8] Plastics Recycling Inc., based out of Indianapolis, has a large Styrofoam recycling process making polystyrene pellets, that are used by companies to make picture frames, crown moulding, and planter boxes.[9] Dart has a similar process on a smaller scale at their Leola, PA facility.

Foam Cycle created an innovative and patent-pending container recycling system that allows counties, municipalities, schools, colleges and businesses to collect, recycle, process and market EPS foam. Over two tons of EPS foam was collected and processed in its first four months[10].

INTCO manufactures and sells GREENMAX EPS Compactors/Densifiers and Recycling machines/System, purchases back compressed EPS scraps, and reuses them to make frame

[8] Dart Container: Our Recycling Partners. (n.d.). Retrieved February 5, 2018, from https://www.dartcontainer.com/environment/environpartners/
[9] Styrofoam Recycling [E-mail to C. Cassidy]. (2018, February 5).
[10] Foam Cycle. (n.d.). Retrieved February 5, 2018, from http://www.foamcycle.com/

products. In 2012, INTCO recycled 50,000 tons of waste EPS, which helped save 4,000,000 trees and reduce 100,000 tons of carbon emission[11].

The existence of such companies demonstrate that procurement of clean polystyrene is feasible in small amounts. However, the challenge arises when trying to procure a steady feed of 100 tons per day, as there simply isn't enough clean and sorted polystyrene to fulfill that requirement. To reach that desired feed rate, however, we modify the cost attributed to polystyrene in our economic model. While waste polystyrene should be free at the site of origin, the cost of cleaning, sorting, aggregating, densifying and shipping it have to be considered. These factors are extremely variable and depend on hauling distances, availability of commercial supplies versus individual consumers, densification, use of polystyrene, and more. To account for the uncertainty around these costs, a base cost of $0.30 per pound of polystyrene is assumed. A detailed sensitivity analysis is then run to determine the project's profitability as this cost varies. For process purposes, it is assumed that densified polystyrene at a density of 18.57 lb/ft^3 is available and transported daily in jumbo railcars to the facility, each with a capacity of 4,000 ft^3. Three shipments are assumed to arrive per day. The polystyrene is stored in three 11,000 ft^3 silos, designed to each hold one day's worth of polystyrene inventory to ensure continuous production. These assumptions enable us to satisfy the design criteria of processing polystyrene at a rate of 100 tons per day, or 8,333 lb/hr.

ii. Alternative Recycling Methods

Though the problem statement proposed using pyrolysis to recycle waste polystyrene, other methods were initially considered. The main alternative process considered was the

[11] GREENMAX EPS Styrofoam Recycling | Polystyrene Foam Recycling Compactor. (n.d.). Retrieved February 5, 2018, from http://www.intcorecycling.com/

dissolution of polystyrene. This process involves dissolving the polystyrene in a solvent to reduce its volume, and is a relatively cheap and efficient method for recycling without degradation of polymer chains[12]. The liquid solvent can also easily be recycled for future use, which makes this an attractive alternative to pyrolysis. However, the problems with dissolution made the use of pyrolysis the better choice for this process. The problem statement requests a feedstock capacity of 100 TPD, which would be difficult to scale. Gutiérrez et al. discusses this process using an environmentally friendly solvent such as terpene as opposed to some well-known pure organic liquids like toluene, but this requires a residence time of 24 hours for only 10 kg of polystyrene[13]. Depending on the type of solvent used in the process, the solvent toxicity and environmental impact at higher temperatures must be considered[14]. The dissolution of polystyrene can produce harmful emissions, making it a less desirable method than pyrolysis.

iii. Type of Pyrolyzer

Upon concluding that pyrolysis would be the most profitable process for polystyrene recycling, the next step was to determine the design of the pyrolysis reactor. A fluidizes bed was considered for its good temperature control, high processing rate and high liquid yields. These systems, however, present difficulties with solid removal, higher capital cost and low process durability[15]. A rotary kiln, beneficial for its solids handling capabilities, is the preferred equipment. The kiln is also preferred for its lower capital cost and because its products more resemble crude oil[16]. Due to temperature gradients in the equipment, however, the system will

[12] Gutiérrez, C., García, M.T., Gracia, I. et al. Waste Biomass Valor (2013) 4: 29. https://doi.org/10.1007/s12649-012-9131-9
[13] Gutiérrez, C. (2013)
[14] Gutiérrez, C. (2013)
[15] Behzadi, S. and Farid, M. (2006)
[16] Behzadi, S. and Farid, M. (2006)

generally have higher residence times. Though the fluidized bed proposes some benefits, it was concluded that the lower capital cost of the rotary kiln outweighs these and is thus the better choice[17].

iv. Determination of Products

The composition of the final liquid products was determined by the research of Karaduman, and the solid product is assumed to be a carbonaceous char residue. The liquid product yield, being dependent on temperature, is optimized for styrene at 400˚C. The light hydrocarbon products were qualitatively determined from Achillas' research, consisting of hydrogen, methane, ethane, ethylene, propane, propylene, butane, isobutane, and butene[18]. However, due to differences in reaction conditions, the exact fractional composition was not used, and the gas species were assumed to be produced in equal amounts. The following table summarizes the composition of the gas and solid streams produced by the pyrolysis reaction. These yields are used as inputs to our reactor model in ASPEN (see Section 15.1).

[17] Behzadi, S. and Farid, M. (2006)

[18] Achilias, D. S., Kanellopoulou, I. , Megalokonomos, P. , Antonakou, E. and Lappas, A. A. (2007), Chemical Recycling of Polystyrene by Pyrolysis: Potential Use of the Liquid Product for the Reproduction of Polymer. Macromol. Mater. Eng., 292: 923-934.

Table 10.1. Composition of product from pyrolysis of polystyrene. Styrene is the most abundant product, representing 55.1% of the product on a mass basis, followed by ethylbenzene (13.3%), toluene (7.3%), the solid char (5.5%) and methylstyrene (5.1%). The remainder of the product is composed of light hydrocarbons (13.6%).

State of Matter	Species Name	Formula	Composition (%)
Gas	Toluene	C_7H_8	7.35
Gas	Ethylbenzene	C_8H_{10}	13.32
Gas	Styrene	C_8H_8	55.11
Gas	Methylstyrene	C_9H_{10}	5.05
Solid	Solid residue	C	5.48
Gas	Hydrogen	H_2	1.52
Gas	Methane	CH_4	1.52
Gas	Ethylene	C_2H_4	1.52
Gas	Ethane	C_2H_6	1.52
Gas	Propene	C_3H_6	1.52
Gas	Propane	C_3H_8	1.52
Gas	Butene	C_4H_8	1.52
Gas	Isobutane	C_4H_{10}	1.52
Gas	n-Butane	C_4H_{10}	1.52

v. Utilization of Fuel Gas

One of the key design decision was deciding whether it would be more profitable to refine and sell the gaseous product that results from pyrolysis or to re-use it as fuel for the pyrolyzer. This decision affects our economic estimations, since it alters the amount of utilities required and byproducts formed through this reaction. Both alternatives were considered in preliminary design processes, as shown in Figure 10.1 below.

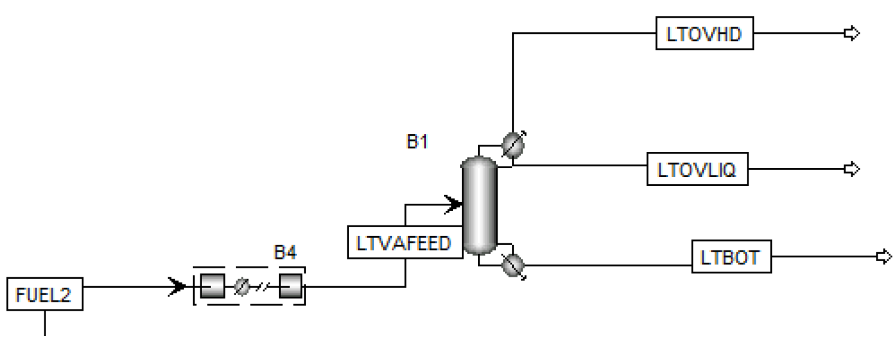


Figure 10.1. Preliminary process flow diagram. The fuel gas is compressed then separated using a tray distillation column.

It was found that the combined cost of the compressor as well as the column required to achieve the separation of the light components would be very high given the high flow rate of this stream at 1,244 lb/hr. The compressor would need to have a net work requirement of 186 hp, while the column would need to operate at the very high pressure of 330 psia, which would considerably increase its cost. Therefore, it was decided to recycle part of this stream of gases as fuel for the pyrolyzer and sell the remaining as fuel gas. The results of this energy integration strategy are presented in Section 14.1.

vi. Separation Process

One of the initial goals of this process was to obtain the liquid products at a high purity and sell them for their maximum possible value, followed by a sensitivity analysis on the distillation train comparing equipment cost with profit margins and altering the recovery accordingly. It was decided to sell the liquid products individually rather than in a mixture, so profitability could be maximized. A further separation could be done with the lighter hydrocarbons produced by the pyrolysis reaction which would require installing several more columns, or the mixed gas stream could be sold to an outside party (i.e. an olefins plant) for separation offsite. To supply heat for the rotary kiln, our process takes a portion of the light gases to be combusted in the outer shell of the kiln, and will sell the excess to an outside source.

To achieve the liquid product separation, a distillation train was designed to separate toluene, ethylbenzene, styrene, and methylstyrene into four distinct product streams with a high enough purity to be sold for profit. The design of the distillation train was looked at both in series and in parallel. In a parallel setup, the first column splits between ethylbenzene and styrene. This separation is known to be the most difficult due to the proximity in boiling points between ethylbenzene and styrene, at 381˚F and 406˚F, respectively. Upon further analysis, it was concluded that a cleaner separation resulted from arranging the distillation columns in series. Toluene, as the lightest component with a boiling point of 311˚F, is distilled out in the first column of the series at 99.5% purity. This first column was found to require 50 stages and a reflux ratio of 16 to achieve the desired separation. This is followed by the difficult separation of ethylbenzene and styrene, requiring 100 stages, but still achieving a 99.3% purity for ethylbenzene. As the styrene-methylstyrene separation column is the last in the series, it is operating under a high vacuum, and is thus designed as a packed column to avoid the pressure drop associated with trays. This column requires 40 stages, and achieves a 99.9% polymer grade purity styrene monomer in the distillate stream at a flow rate of 4,588 lb/hr, a temperature of 148˚F and a pressure of 1 psia. The columns are also designed to avoid styrene polymerization when approaching high temperatures, so a polymerization inhibitor is added to the ethylbenzene and the styrene columns, as well as the styrene storage tank.

Section 11. Assembly of Database

Compound	CAS#	Transport and Storage	Safety	Price/ton
Styrene	100-42-5	Flammable materials should be stored in a separate safety storage cabinet or room. Keep away from heat. Keep away from sources of ignition. Keep container tightly closed. Keep in a cool, well-ventilated place. Ground all equipment containing material. A refrigerated room would be preferable for materials with a flash point lower than 37.8°C (100°F).	Store in a segregated and approved area. Keep container in a cool, well-ventilated area. Keep container tightly closed and sealed until ready for use. Avoid all possible sources of ignition (spark or flame).	$2,000[19]
Ethylbenzene	100-41-4	Store in a segregated and approved area. Keep container in a cool, well-ventilated area. Keep container tightly closed and sealed until ready for use. Avoid all possible sources of ignition (spark or flame). Sensitive to light. Store in light-resistant containers.	Hazardous in case of eye contact (irritant), of ingestion, of inhalation. Slightly hazardous in case of skin contact (irritant, permeator).	$770[20]

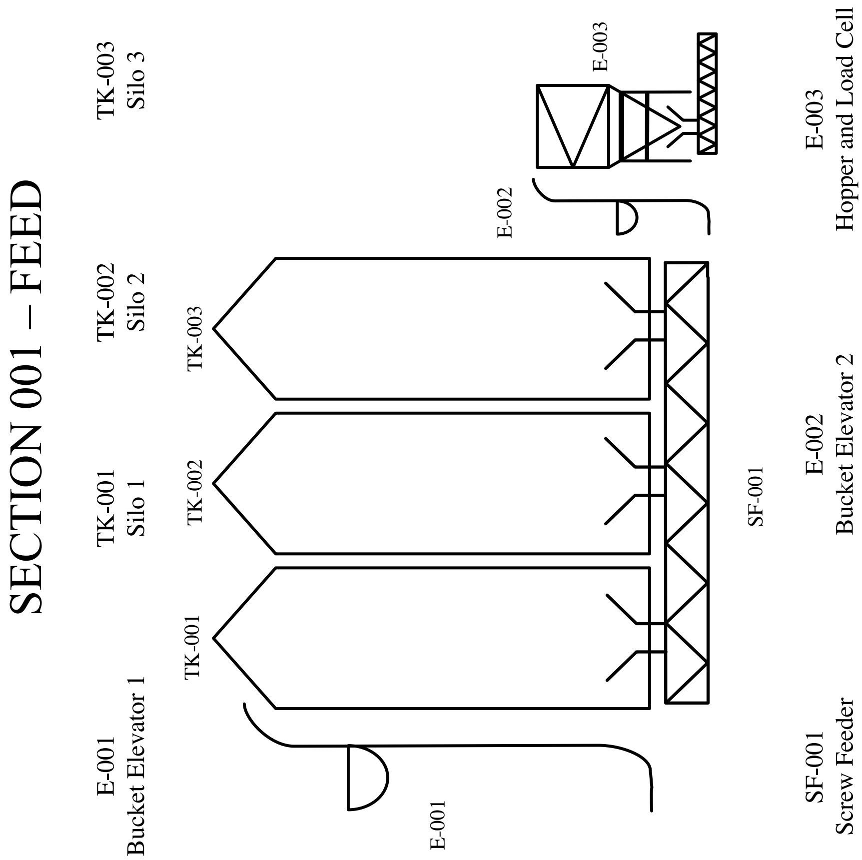
[19] "US Styrene Spot Prices Jump on Extended Outage." *Trusted Market Intelligence for the Global Chemical, Energy and Fertilizer Industries*, www.icis.com/resources/news/2017/02/17/10080426/us-styrene-spot-prices-jump-on-extended-outage/.

[20] "Ethyl Benzene | Price Assessments | Market Commentary and News." *Trusted Market Intelligence for the Global Chemical, Energy and Fertilizer Industries*, www.icis.com/chemicals/ethylbenzene/.

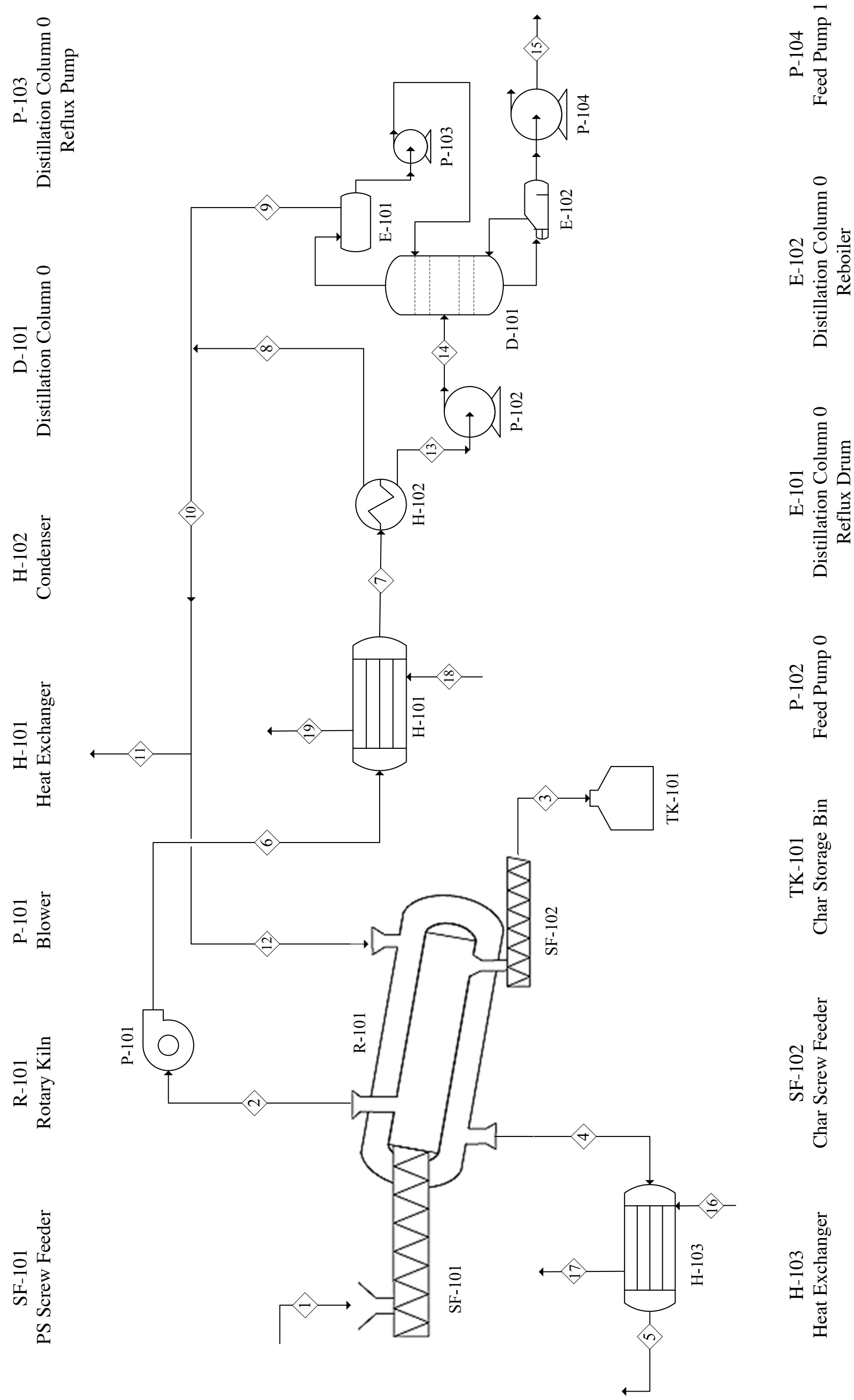
Methyl Styrene	98-83-9	Flammable materials should be stored in a separate safety storage cabinet or room. Keep away from heat. Keep away from sources of ignition. Keep container tightly closed. Keep in a cool, well-ventilated place. Ground all equipment containing material. Keep container dry. Keep in a cool place.	Very hazardous in case of eye contact (irritant), of inhalation (lung irritant). Hazardous in case of skin contact (irritant), of ingestion, . Inflammation of the eye is characterized by redness, watering, and itching.	$1,100[21]
Toluene	108-88-3	Store in a segregated and approved area. Keep container in a cool, well-ventilated area. Keep container tightly closed and sealed until ready for use. Avoid all possible sources of ignition (spark or flame).	Hazardous in case of skin contact (irritant), of eye contact (irritant), of ingestion, of inhalation. Slightly hazardous in case of skin contact (permeator).	$1,000[22]

[21] "Alpha-Methylstyrene." *Trusted Market Intelligence for the Global Chemical, Energy and Fertilizer Industries*, www.icis.com/resources/news/2000/05/22/115657/alpha-methylstyrene/.
[22] "US Spot Benzene-Toluene Spread Narrows." *Trusted Market Intelligence for the Global Chemical, Energy and Fertilizer Industries*, www.icis.com/resources/news/2016/12/12/10062118/us-spot-benzene-toluene-spread-narrows/.

Section 12. PFD and Material Balances



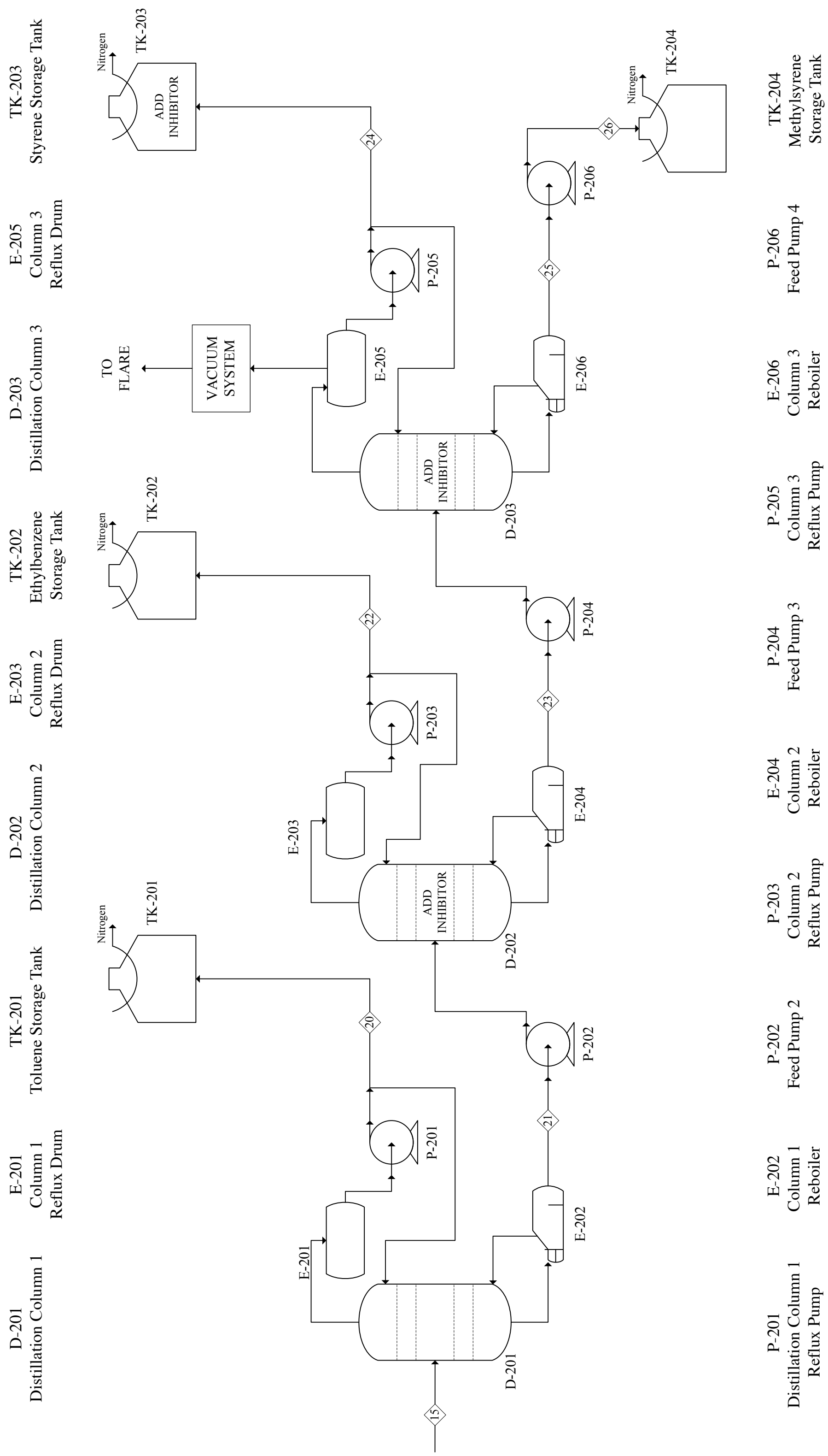
SECTION 100 – CORE PYROLYSIS PROCESS



Stream Number	1	2	3	4	5	6	7	8	9	10
Temperature	77.0	752.0	752.0	768.7	527.3	827.2	571.2	100.0	106.6	99.7
Pressure (psia)	20.0	20.0	20.0	14.7	14.7	45.0	37.0	32.0	75.0	32.0
Mass Flow (lb/hr)	8333.0	7876.3	456.7	631.9	631.9	7876.3	7876.3	1118.2	125.6	1243.8
Component Mass Flow (lb/hr)										
Polystyrene	8333.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Toluene	0.0	612.5	0.0	0.0	0.0	612.5	612.5	26.5	1.0	27.5
Ethylbenzene	0.0	1110.1	0.0	0.0	0.0	1110.1	1110.1	19.2	3.5420-02	19.2
Styrene	0.0	4592.8	0.0	0.0	0.0	4592.8	4592.8	54.7	4.1647-02	54.7
Methylstyrene	0.0	420.9	0.0	0.0	0.0	420.9	420.9	2.3	0.0	2.3
Carbon	0.0	0.0	456.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Air	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Water	0.0	0.0	0.0	43.9	43.9	0.0	0.0	0.0	0.0	0.0
Methane	0.0	126.7	0.0	0.0	0.0	126.7	126.7	126.0	0.7	126.7
Ethylene	0.0	126.7	0.0	0.0	0.0	126.7	126.7	123.9	2.7	126.7
Ethane	0.0	126.7	0.0	0.0	0.0	126.7	126.7	122.6	4.1	126.7
Propylene	0.0	126.7	0.0	0.0	0.0	126.7	126.7	115.0	11.7	126.7
Propane	0.0	126.7	0.0	0.0	0.0	126.7	126.7	113.8	12.9	126.7
Butene	0.0	126.7	0.0	0.0	0.0	126.7	126.7	95.0	31.7	126.7
Isobutane	0.0	126.7	0.0	0.0	0.0	126.7	126.7	100.9	25.8	126.7
Butane	0.0	126.7	0.0	0.0	0.0	126.7	126.7	91.6	35.1	126.7
Hydrogen	0.0	126.7	0.0	0	0	126.7	126.7	126.6	6.8772-02	126.7
O2	0.0	0.0	0.0	84.2	84.2	0.0	0.0	0.0	0.0	0.0
CO2	0.0	0.0	0.0	21.8	21.8	0.0	0.0	0.0	0.0	0.0
N2	0.0	0.0	0.0	481.9	481.9	0.0	0.0	0.0	0.0	0.0

Stream Number	11	12	13	14	15	16	17	18	19
Temperature	99.7	1172.0	100.0	101.1	424.6	90.0	297.8	90.0	478.9
Pressure (psia)	32.0	14.7	32.0	60.0	79.6	63.0	63.0	564.0	564.0
Mass Flow (lb/hr)	612.0	631.9	6758.1	6758.1	6632.5	1900.0	1900.0	1700.0	1700.0
Component Mass Flow (lb/hr)									
Polystyrene	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Toluene	13.5	14.0	586.0	586.0	585.0	0.0	0.0	0.0	0.0
Ethylbenzene	9.4	9.8	1090.9	1090.9	1090.9	0.0	0.0	0.0	0.0
Styrene	26.9	27.8	4538.1	4538.1	4538.1	0.0	0.0	0.0	0.0
Methylstyrene	1.1	1.2	418.5	418.5	418.5	0.0	0.0	0.0	0.0
Carbon	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Air	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Water	0.0	0.0	0.0	0.0	0.0	1900.0	1900.0	1700.0	1700.0
Methane	62.3	64.4	0.7	0.7	0.0	0.0	0.0	0.0	0.0
Ethylene	62.3	64.4	2.7	2.7	0.0	0.0	0.0	0.0	0.0
Ethane	62.3	64.4	4.1	4.1	0.0	0.0	0.0	0.0	0.0
Propylene	62.3	64.4	11.7	11.7	0.0	0.0	0.0	0.0	0.0
Propane	62.3	64.4	12.9	12.9	0.0	0.0	0.0	0.0	0.0
Butene	62.3	64.4	31.7	31.7	0.0	0.0	0.0	0.0	0.0
Isobutane	62.3	64.4	25.8	25.8	0.0	0.0	0.0	0.0	0.0
Butane	62.3	64.4	35.1	35.1	0.0	0.0	0.0	0.0	0.0
Hydrogen	62.3	64.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
O2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CO2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
N2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

SECTION 200 – REFINING SECTION



Stream Number	15	20	21	22	23	24	25	26
Temperature	424.6	305.9	390.1	298.3	350.3	148.6	216.1	216.1
Pressure (psia)	79.6	40.0	50.8	40.0	30.3	40.0	2.2	40.0
Mass Flow (lb/hr)	6632.5	580.8	6051.7	1092.5	4959.2	4457.8	501.4	501.4
Component Mass Flow (lb/hr)								
Polystyrene	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Toluene	585.0	578.1	6.9	6.9	0.0	0.0	0.0	0.0
Ethylbenzene	1090.9	2.4	1088.4	1085.0	3.4	3.4	0.0	0.0
Styrene	4538.1	0.3	4537.8	0.5	4537.3	4454.2	83.1	83.1
Methylstyrene	418.5	0.0	418.5	0.0	418.5	0.2	418.3	418.3
Carbon	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Air	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Water	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Methane	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ethylene	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ethane	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Propylene	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Propane	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Butene	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Isobutane	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Butane	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hydrogen	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
O2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CO2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
N2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Section 13. Process Descriptions

i. Process Overview

The process is divided into three sections: the first one is the feed section, followed by the core pyrolysis process section, and lastly the refining section. The feed section includes all the equipment necessary to take the densified polystyrene from the delivery cars to the rotary kiln reactor. The second section consists of the pyrolysis reaction in the kiln reactor, including energy and heat integration equipment. The third section serves to isolate the different liquid products that are to be sold: toluene, ethylbenzene, styrene and methylstyrene.

ii. Section 000-Feed

The collected and densified polystyrene is assumed to arrive in jumbo railcars, each with a capacity of 30,000 pounds. It is then loaded into a storage silo via a bucket elevator of 55 feet, calculated by assuming an aspect ratio equal to three (length to diameter) for the silos. Three silos of 11,000 ft^3, each hold one days' worth of feedstock at a temperature of 77˚F and atmospheric pressure. This was chosen to prevent against a complete production halt due to on site pipeline malfunctions or to increase production on days with greater demand. A screw conveyor transports the polystyrene from one silo to the next. Another bucket elevator of 20 feet height is then used to take the feedstock from the bottom of the third silo to a hopper mounted on a steel structure with load cells. It is then dropped at a constant feed rate of 8,333 lb/hr to another hopper connected to a screw conveyor that feeds it directly into the kiln reactor, at this rate.

iii. Section 100-Core Pyrolysis Process

The polystyrene is fed to the rotary kiln reactor via a screw feeder. The reactor is assumed to hold 1,255 ft^3 given the feed rate of 8,333 lb/hr (See section 15.1 for detailed calculations). As the feedstock is depolymerized in the reactor, a solid and gaseous product form.

The solid product consists of carbon char. It represents 5.5% of the total product on a mass basis and is removed at a rate of 455 lb/hr using a screw conveyor. It is then sent to a solids storage bin, estimated at a volume of 550 gallons to hold seven days' worth of product. Because this product acts as a coke, it is necessary to continuously remove it to prevent buildup in the reactor. Since char can be used as charcoal, it is assumed that it will be sold to briquette manufacturers for a cost equivalent to that of shipping it to them. Thus, it is assumed that this product is removed from the facility for a no cost/no revenue net value.

The main product from the pyrolysis reaction is a gaseous mixture containing hydrocarbons, at a flow rate of 7,876 lb/hr. The main products of the reaction are styrene (55.1% of the total product on a mass basis), ethylbenzene (13.3%), toluene (7.4%) and methylstyrene (5.1%). The other 13.6% consists of the following light hydrocarbons: hydrogen, methane, ethane, ethylene, propane, propylene, butane, isobutane and butylene. It was assumed that these light products were all produced at equal yields of 1.5% on a mass basis. A detailed explanation of the determination of these product yields is presented in Section 10.4.

This gas mixture enters a 145 hp blower to be effectively pumped through the rest of the process at a rate of 7,876 lb/hr. Its pressure increases from 20 psia to 45 psia. It is then partially cooled from 827˚F to 321˚F using a shell-and-tube, counter-current heat exchanger with 1,900 lb/hr of boiling feed water to produce high pressured steam at 63 psia, to be recycled in the process as steam for distillation columns (see Section 14.1). Its pressure also decreases from 45 psia to 37 psia. The gas mixture is further cooled to 100˚F in a shell-and-tube condenser with 265 gpm of cooling water. Its pressure decreases further to 32 psia. These subsequent operations result in a liquid stream and a non-condensable gas stream.

The liquid stream is pumped to a tray distillation column at a rate of 6758 lb/hr and a pressure of 60 psia. This separation system includes a reflux drum, reboiler and two pumps, one for the distillate and one for the bottoms. The column separates the desired liquid products (styrene, toluene, ethylbenzene and methylstyrene) from the light hydrocarbons produced by the reaction. The number of trays necessary, for feed conditions of 80 psia and 100˚F, was found to be equal to 15 with a reflux ratio of 6.

The desired product exits the bottom stream at a flow rate of 6,633 lb/hr, a temperature of 424˚F and a pressure of 80 psia and proceeds to section 200 of the process for further separation and purification.

The stream of light hydrocarbons coming out in the distillate at a flow rate of 126 lb/hr a temperature of 106˚F and a pressure of 75 psia is mixed with the non-condensable gases that exit the condenser, given that it consists of the same products. The mixture then enters a splitter where 50.8% or 632 lb/hr of gases are recycled through the process as fuel for the pyrolyzer. Indeed, only 11.7 MM BTU of the 22.9 MM BTU produced from burning the gases is required to heat the pyrolyzer (see Section 14.2). Excess gas is assumed to be sold to a nearby boiler house as fuel gas with a flow rate of 612 lb/hr.

The reactor is heated in the outer shell with the noncondensable gases while the depolymerization of the feedstock happens in the inner vessel. The steam of fuel gas coming out of the outer shell of the pyrolyzer at a flow rate of 32,367 lb/hr is subsequently cooled from 769˚F to 527˚F using a shell-and-tube, counter-current heat exchanger with 1,700 lb/hr of boiling feed water. It produces high pressured steam at 564 psia, that is recycled in the process as steam for distillation columns (see Section 14.1).

iv. Section 200-Separation

The desired product exits the bottom stream of the first distillation column in the core pyrolysis process section at a flow rate of 6,633 lb/hr, a temperature of 424˚F and a pressure of 80 psia, as mentioned above. It enters this section of the process to isolate the four liquid fuel products (toluene, styrene, methylbenzene, ethylbenzene) that are then stored in tanks to be sold for profit. Our design criteria, specifying a polymer grade purity greater than 99.9% for styrene, is closely matched with greater than 99.0% purity for the three other liquid products. Each separation system includes a column, a reflux drum and a reboiler and two pumps, one for the distillate and one for the bottoms.

The liquid mixture enters the first tray distillation column to separate the lightest compound, toluene, from the remaining three products. A startup pump is included to pump the mixture into this distillation column, even though it will not be required during normal operation. This first column was found to require 50 stages and a reflux ratio of 16 to achieve the desired separation. The separation occurs between the light key, toluene, with a boiling point of 311˚F and the heavy key, ethylbenzene, with a boiling point of 381˚F. Toluene exits the top of the column in the distillate stream at a flow rate of 580 lb/hr, a temperature of 305˚F and a pressure of 40 psia. Its purity is equal to 99.5%. It is then pumped at 60 psia to a conical storage tank with a capacity of 16,000 gal, designed to hold up to seven days' worth of product. The tank is at atmospheric temperature and pressure, which is maintained by a nitrogen control system. This control system exists for all subsequent storage tanks as well.

The remaining liquid mixture exits the column in the bottoms stream at a flow rate of 6,051 lb/hr, a temperature of 390˚F and a pressure of 50 psia. It then enters another trayed distillation column to isolate ethylbenzene from styrene and methylstyrene. A startup pump is included to pump this mixture into the second distillation column, even though it will only be required occasionally.

This separation is difficult due to the similar boiling points of the light key, ethylbenzene, with a boiling point of 381˚F, and the heavy key, styrene, with a boiling point of 406˚F. It requires 100 stages and a reflux ratio of 45. Ethylbenzene exits the top of the column in the distillate stream at a flow rate of 1,092 lb/hr, a temperature of 298˚F and a pressure of 20 psia. Its purity is equal to 99.3%. It is then pumped at 60 psia to a conical storage tank with a capacity of 29,000 gal, also designed to hold up to seven days' worth of product.

The remaining liquid mixture exits the bottom of the column in the bottoms stream at a flow rate of 4,959 lb/hr, a temperature of 350˚F and a pressure of 30 psia. It is then pumped to 60 psia before entering a packed distillation column to separate styrene from methylstyrene.

The final distillation column requires 40 stages and a reflux ratio of 15 to separate the light key, styrene, with a boiling point of 406˚F from the heavy key, methylstyrene, with a boiling point of 468˚F. Styrene, our main product, exits the top of the column in the distillate stream at a flow rate of 4,458 lb/hr, a temperature of 148˚F and a pressure of 1 psia. Its purity is equal to 99.9%. It is then pumped at 60 psia to a conical storage tank with a capacity of 104,000 gal, also designed to hold up to seven days' worth of product. Methylstyrene exits the bottom of the column in the bottoms stream at a flow rate of 501 lb/hr, a temperature of 216˚F and a pressure of 2.20 psia. Its purity is equal to 100%. It is then pumped at 60 psia to a conical storage tank with a capacity of 12,000 gal to hold up to seven days' worth of product.

Unit descriptions and specification sheets for all the equipment discussed in this section can be found in Sections 15 and 16 of this report.

Section 14. Energy Balance and Utility Requirements

i. Energy Integration Method

Given the high operating temperature of the reactor, it was decided early on to recycle the stream of non-condensable gases exiting the reactor as fuel to reduce utility costs. By modeling the reactor in ASPEN and entering the required yields (see Section 10.6), it was found that the pyrolyzer requires an input of 8.8 MM BTU/hr to process the 8,333 lb/hr of polystyrene as per the design criteria. Cooling the exit stream from the reactor then condensing it results in a gaseous stream that consists of light hydrocarbons (see Section 13, Section 100), which we will refer to as noncondensable gases, and a liquid stream that enters a subsequent distillation train.

The distillate stream from the first distillation column is composed of the same gases as the noncondensable gases stream, but that were condensed but then separated from the rest of the liquid mixture by using a tray column. This distillate stream is mixed with the noncondensable gas stream. Multiple scenarios were run on ASPEN to determine the heating value of this stream.

By using a furnace (modeled as RStoic) and inputting the combustion reactions for all components of this stream, it was found that the stream can provide up to 22.9 MM BTU/hr of heat from the heats of combustion of its individual components. This is much larger than the required 8.8 MM BTU/hr required to heat the pyrolyzer. Therefore, by using the surface area of the kiln of 508 ft^2, a heat transfer of 8.8 MM BTU/hr and a heat transfer coefficient approximated as 60 BTU/hr-ft^2-˚F, it was determined that the log-mean temperature difference (LMTD) needed was equal to 289˚F.

Thus, it was determined that the gaseous stream could be split in two streams: the first one is sent to be burned as used as fuel for the pyrolyzer, while the second one is sold as fuel gas. The split fraction required for this LMTD and for an air flow rate of 1,100 lbmol/hr was found to be equal to 0.508 on a mass basis, where 50.8% of the gas stream is sent to the pyrolyzer to be used as fuel gas. Indeed, the temperature of the stream of hot effluent gas decreases from 1722˚F to 769˚F while the polystyrene in the inner shell stays a constant temperature of 732˚F, yielding an LMTD of 289˚F. Thus, only 11.7 MM BTU of the 22.9 MM BTU produced from burning the gases is required to heat the pyrolyzer. Energy integration was therefore achieved by re-using the product gases from the pyrolysis reaction to heat the pyrolyzer. Instead of having to purchase fuel gas, we are able to sell fuel gas as a byproduct of this process.

ii. Heat Integration Method

In addition to energy integration, heat integration was achieved in our process by using the high-temperature streams to produce high-pressured steam, which was then used for the reboilers of two distillation columns.

The temperature of the reboiler was first used to determine the steam pressure required for each reboiler and the latent heat at that temperature. Then, the heat duty of the reboilers of each distillation column was determined. Finally, the latent heat value was used to obtain the pounds of steam per hour required for each reboiler. These calculations are presented in Table 14.1 below.

Table 14.1. Steam requirements for the reboiler of each distillation column.

	D-101	D-201	D-202	D-203
Reboiler Heat Duty (BTU/hr)	1,256,516.36	1,307,179.24	7,005,772.37	12,285,959.40
Reboiler Temperature (˚F)	425	390	350	216
Steam pressure required (psia)	539	380	219	38
Latent heat (BTU/lb)	747.357	786.025	835.923	934.698
Amount of steam required (lb/hr)	1,681	1,663	8,381	13,144

The stream of gases coming out of the pyrolyzer and then the blower (stream 6) is at a temperature of 827˚F and a flow rate of 7876 lb/hr. It needs to be cooled to achieve separation of its component, so a shell-and-tube, counter-current heat exchanger can be used to produce steam and achieve heat integration. It was found that cooling this stream from 827˚F to 321˚F generates 1900 pounds of steam per hour at a pressure of 63 psia, which is used to satisfy some of the steam requirements of the third distillation column (D-203). Therefore, only 11,200 pounds of 50 psig steam per hour is required as utility for the process

Similarly, the stream of gases coming out of the outer shell of the pyrolyzer (stream 4) is at a temperature of 769˚F and a flow rate of 32,367 lb/hr. It can be cooled in a shell-and-tube, counter-current heat exchanger to produce steam. It was found that cooling this stream from 769˚F to 527˚F generates 1,700 pounds of steam per hour at a pressure of 564 psia, which covers the entirety of the steam requirements for the first distillation column (D-201). Therefore, the amount of 450 psig steam required only flows from the second and third distillation columns (D-201 and D-202), and amounts to 10,000 pounds of 450 psig steam per hour.

Therefore, while the steam produced is not enough to supplement that which is needed for the columns, the steam requirements were optimized in the process to extract value from high-temperature streams. Only the net value will need to be purchased and considered in the cost analysis of utilities, as will be described in the following section.

iii. Utilities

The following table (Table 14.2) lists the energy demands for the process based on the utility and equipment, both per hour and per operating year. Cooling water is needed for the condenser, as well as for the reflux drums of distillation columns. Electricity is needed for the screw feeders, bucket elevators, pumps, and blower. For steam, only the net requirement for the reboilers of distillation columns is included (see Section 14.2). The total utility requirements are also given per pound of styrene produced (Table 14.3).

Table 14.2. Total utility requirement per piece of equipment.

Utility	**Unit Number**	**Per hour**	**Per year**
Cooling Water (lb)	H-102	265.6	
	E-101	14.67	
	E-201	69.64	
	E-203	255.93	
	E-205	364.08	
	Total	**969.92**	**8,147,328**
Electricity (kWh)	E-001	1.566	
	E-002	0.199	
	P-101	146.381	
	P-102	77.92	
	P-103	31.46	
	P-104	60	
	P-201	134.58	
	P-202	54.74	
	P-203	29.65	
	P-204	13.32	
	P-205	124.52	
	P-206	10.06	
	SF-101	0.2	
	SF-102	0.2	
	SF-103	0.2	
	Total	**684.794**	**5,752,271**
HPS 450 psig (lb)	E-202	1663	
	E-204	8381	
	Total	**10,044**	**84,369,600**
LPS 50 psig (lb)	E-204	**11244**	**94,449,600**

Table 14.3. Total utility requirement per lb of styrene produced.

Utility	**Required Ratio**	
High Pressure Steam	2.21	lb per lb of Styrene
Low Pressure Steam	2.48	lb per lb of Styrene
Cooling Water	0.21	gpm per lb of Styrene
Electricity	0.14	kWh per lb of Styrene

Section 15. Equipment List and Unit Descriptions

i. Reactor Vessel

Rotary Kiln

Unit ID: R-101	Temperature: 752 °F
Type: Reactor	Pressure: 20 psia
Material: Stainless Steel	Length: 70 ft
Heat required: 8,863,600 BTU	Diameter: 7 ft
Specification Sheet: Section 16	Design calculations: Appendix A, d)
Costing data: Table 17.1	

The rotary-kiln reactor is a core equipment unit in our process. It is the pyrolyzer that allows us to recycle the polystyrene to produce the monomer styrene and other products.

It is modeled as two concentric horizontal pressure vessels, with the assumption that the kiln is 40% full at any given time. With a specified polystyrene feed flowrate of 8,333 lb/hr and a residence time of 60 minutes, the volume of the inner vessel is calculated to be 565 ft^3. Using an aspect ratio of 10 (length to diameter), as recommended by industry consultants, this yields an inner vessel diameter of 6 feet and a length of 60 feet. To allow enough space for combustion of hot gases in the outer shell, an additional 6 inches is added to the radius of the inner vessel, giving an outer shell diameter of 7 feet. Given the uncommon use of this type of reactor, it was difficult to obtain additional sizing and costing data for the remaining pieces and equipment of the kiln.

The temperature and pressure of the kiln, as well as the residence time, were modeled after the optimal reaction conditions for highest styrene yield found in the research paper presented by Karaduman[23]. The material was chosen to be stainless steel due to the high temperature of 732˚F in the inner vessel, and 1,722˚F in the outer vessel. These temperatures exceed the 750˚F limit

[23] Karaduman (2002)

acceptable for carbon steel. The reactor is also set on an incline to allow the solid char product to exit out the bottom while the product gases circulate and flow out the top.

The reactor is modeled in Aspen as three separate blocks. An RYield block is used to model the reaction taking place, with component yields specified using the research paper by Karaduman[24] and detailed in Section 10.5. A separation block is required in ASPEN to specify that two different streams exit the reactor: the first one is the solid stream, which is disposed of by using a screw feeder, while the second one is a gaseous stream, which enters the remaining of the process. Finally, a furnace block is used to simulate the burning of fuel gases that occur in the outer shell of the kiln, and thus determine the amount of gases needed (see Section 14.1).

ii. Pumps and Blower

Blower

Unit ID: P-101	Temperature: 752 °F
Type: Centrifugal	Pressure: 45 psia
Material: Stainless Steel	Work: 144.8 hp
Specification Sheet: Section 16	Design calculations: Appendix A-g)
Costing data: Table 17.1	

The blower increases the pressure of the gaseous stream exiting the pyrolyzer at a flow rate of 7,876 lb/hr to be effectively pumped through the rest of the process. It raises the pressure of the incoming stream from 20 psia to 45 psia, and thus requires a net amount of work equal to 144.8 hp, given an efficiency of 85%. The pump is built in stainless steel since the material stream enters at a temperature of 752˚F and exits at a temperature of 827˚F, both of which exceed the maximum temperature for carbon steel.

[24] Karaduman (2004)

Feed Pump 0

Unit ID: P-102	Temperature: 100°F
Type: Pump	Pressure: 60 psia
Material: Carbon Steel	Work: 1.7 hp
Specification Sheet: Section 16	Head: 127 ft
Costing data: Table 17.1	Design calculations: Appendix A-g)

This piece of equipment is a centrifugal pump that increases the pressure of the incoming liquid stream at a flow rate of 6758 lb/hr from 32 psia to 60 psia. Using the equations shown in Appendix A-g), its head is calculated to be 127 feet. This, in turn, requires a net amount of work equal to 1.47 hp. The pump efficiency is assumed to be equal to 50%, and carbon steel is used as the material of construction since the temperature of the feed stream, 100˚F, is below the critical temperature for carbon steel, 750˚F. A spare pump is included in the equipment costs to ensure continuous production.

Feed Pump 1

Unit ID: P-104	Temperature: 425°F
Type: Pump	Pressure: 80 psia
Material: Carbon Steel	Costing data: Table 17.1

This equipment unit is used to pump the bottoms stream from the distillation column (D-101) into the second distillation column (D-201) at a flow rate of 6,632 lb/hr. However, since the pressure of that stream is equal to 80 psia during continuous operations, it is only included as a start-up pump. A bypass system exists to only use it when needed. It is possible to use carbon steel as its material of construction due to the relatively low temperature of the feed stream, at 100˚F.

Feed Pump 2

Unit ID: P-202	Temperature: 390°F
Type: Pump	Pressure: 50 psia
Material: Carbon Steel	Costing data: Table 17.1

This equipment unit is used to pump the bottoms stream from the second distillation column (D-201) into the third distillation column (D-202) at a flow rate of 6,052 lb/hr. However, since the pressure of that stream is equal to 50 psia during continuous operations, it is only included as a start-up pump. A bypass system exists to only use it when needed It is possible to use carbon steel as its material of construction due to the relatively low temperature of the feed stream, at 390˚F.

Feed Pump 3

Unit ID: P-204	Temperature: 350°F
Type: Pump	Pressure: 40 psia
Material: Carbon Steel	Work: 0.30 hp
Specification Sheet: Section 16	Head: 29.6 ft
Costing data: Table 17.1	Design calculations: Appendix A-g)

This equipment unit is used to pump the bottoms stream from the third distillation column (D-202) into the fourth distillation column (D-203) at a flow rate of 4,959 lb/hr. It increases the pressure of this stream from 30 psia to 40 psia. Using the equations shown in Appendix A-g), its head was calculated to be 29.6 feet. This, in turn, required a net amount of work equal to 0.30 hp. The pump efficiency was assumed to be equal to 50%, and carbon steel was used as the material of construction since the temperature of the feed stream, 350˚F, is below the critical temperature for carbon steel, 750˚F. A spare pump is included in the equipment costs for this pump to ensure continuous production.

Reflux Pump 0

Unit ID: P-103	Temperature: 107°F
Type: Pump	Pressure: 75 psia
Material: Carbon Steel	Costing data: Table 17.1

This equipment unit is used to pump the distillate stream from the first distillation column (D-101), which has a flow rate of 126 lb/hr. However, since the pressure of that stream is equal to 75 psia during continuous operations, it is only included as a start-up pump. A bypass system exists to only use it when needed. It is possible to use carbon steel as its material of construction due to the relatively low temperature of the feed stream, at 107˚F.

Reflux Pump 1

Unit ID: P-201	Temperature: 306°F
Type: Pump	Pressure: 40 psia
Material: Carbon Steel	Costing data: Table 17.1

This equipment unit is used to pump the distillate stream from the second distillation column (D-201), which has a flow rate of 581 lb/hr. However, since the pressure of that stream is equal to 40 psia during continuous operations, it is only included as a start-up pump. A bypass system exists to only use it when needed. It is possible to use carbon steel as its material of construction due to the relatively low temperature of the feed stream, at 306˚F.

Reflux Pump 2

Unit ID: P-203	Temperature: 298°F
Type: Pump	Pressure: 40 psia
Material: Carbon Steel	Work: 0.66 hp
Specification Sheet: Section 16	Head: 300 ft
Costing data: Table 17.1	Design calculations: Appendix A-g)

This equipment unit is used to pump the distillate stream from the third distillation column (D-202), which has a flow rate of 1,092 lb/hr. It increases the pressure of this stream from 20 psia to 40 psia. Since the flow rate was too low to use equations presented in Appendix A-g), its head was estimated at 300 feet. This number was approved by industrial consultants, and considered to be conservative. This, in turn, required a net amount of work equal to 0.66 hp. The pump efficiency was assumed to be equal to 50%. It is possible to use carbon steel as its material of construction due to the relatively low temperature of the feed stream, at 298˚F. A spare pump is included in the equipment costs for this pump to ensure continuous production.

Reflux Pump 3

Unit ID: P-205	Temperature: 148°F
Type: Pump	Pressure: 40 psia
Material: Carbon Steel	Work: 2.78 hp
Specification Sheet: Section 16	Head: 300 ft
Costing data: Table 17.1	Design calculations: Appendix A-g)

This equipment unit is used to pump the distillate stream from the fourth distillation column (D-203), which has a flow rate of 4,458 lb/hr. It increases the pressure of this stream from 1 psia to 40 psia. Since the flow rate was too low to use equations presented in Appendix A-g), its head was estimated at 300 feet. This number was approved by industrial consultants, and considered to be conservative. This, in turn, required a net amount of work equal to 2.78 hp. The pump efficiency was assumed to be equal to 50%. It is possible to use carbon steel as its material of construction due to the relatively low temperature of the feed stream, at 148˚F. A spare pump is included in the equipment costs for this pump to ensure continuous production.

Products Pump

Unit ID: P-206	Temperature: 199°F
Type: Pump	Pressure: 40 psia
Material: Carbon Steel	Work: 0.23 hp
Specification Sheet: Section 16	Head: 300 ft
Costing data: Table 17.1	Design calculations: Appendix A-g)

This equipment unit is used to pump the distillate stream from the fourth distillation column (D-203), which has a flow rate of 501 lb/hr. It increases the pressure of this stream from 2 psia to 40 psia. Since the flow rate was too low to use equations presented in Appendix A-g), its head was estimated at 300 feet. This number was approved by industrial consultants, and considered to be conservative. This, in turn, required a net amount of work equal to 0.23 hp, due to the low flow rate of this stream. The pump efficiency was assumed to be equal to 50%. It is possible to use carbon steel as its material of construction due to the relatively low temperature of the feed stream, at 199˚F. A spare pump is included in the equipment costs for this pump to ensure continuous production.

iii. Heat exchangers

Heat Exchanger 1

Unit ID: H-101	Temperature: 827 °F
Type: Counter-current heat exchanger	Pressure: 63 psia
Material: Carbon Steel	Area: 103.4 ft^2
Specification Sheet: Section 16	Heat Duty: 2,232,253 BTU/hr
Costing data: Table 17.1	Design calculations: Appendix A-f)

This unit of equipment is used to cool the exit stream from the pyrolyzer (R-101) in order to produce high-pressured steam (see Section 14.2). More specifically, it is a counter-current heat exchanger with one shell pass that cools the gaseous stream from 827˚F to 321˚F while producing 1,900 lb/hr of steam at 63 psia. The temperature of the steam increases from 90˚F to 298˚F. Using equations found in Appendix A-f), it is found that the heat transfer area is equal to 103.4 ft^2, using an LMTD of 360˚F, a heat transfer coefficient assumed to be equal to 60 BTU/hr-ft^2-˚F, and an effective heat transfer equal to 2.2 MM BTU/hr.

Heat Exchanger 2

Unit ID: H-103	Temperature: 769 °F
Type: Counter-current heat exchanger	Pressure: 564 psia
Material: Carbon Steel	Area: 96.3 ft^2
Specification Sheet: Section 16	Heat Duty: 2,071,373 BTU/hr
Costing data: Table 17.1	Design calculations: Appendix A-f)

This unit of equipment is used to cool the exit stream from the pyrolyzer in order to produce high-pressured steam (see Section 14.2). More specifically, it is a counter-current heat exchanger with one shell pass that cools the gaseous stream from 769˚F to 527˚F while producing 1,700 lb/hr of steam at 564 psia. The temperature of the steam increases from 90˚F to 479˚F. Using equations found in Appendix A-f), it is found that the heat transfer area is equal to 96.3 ft^2, using an LMTD of 359˚F, a heat transfer coefficient assumed to be equal to 60 BTU/hr-ft^2-˚F, and an effective heat transfer equal to 2.1 MM BTU/hr.

Condenser

Unit ID: H-102	Temperature: 321 °F
Type: Counter-current heat exchanger	Pressure: 37 psia
Material: Carbon Steel	Area: 412.5 ft^2
Specification Sheet: Section 16	Heat Duty: 1,859,191 BTU/hr
Costing data: Table 17.1	Design calculations: Appendix A-f)

This unit of equipment is used to condense the exit stream from the pyrolyzer, R-101, after it has been cooled using the first heat exchanger, H-101. More specifically, it is a counter-current heat exchanger with one shell pass that uses cooling water to condense the gaseous stream. The temperature of the stream decreases from 321˚F to 100˚F while that of cooling water increases from 86˚F to 100˚F, yielding an LMTD of 75.1˚F. The amount of cooling water required is equal to 132,799 lb/hr to ensure that 1.9 MM BTU/hr is extracted from the feed stream. Using these values and the equations found in Appendix A-f), and assuming a heat transfer coefficient equal to 60 BTU/hr-ft^2-˚F, it is found that the heat transfer area is equal to 412.5 ft^2.

iv. Distillation Columns

Distillation Column 0

Unit ID: D-101	Temperature:100 °F
Type: Distillation Column	Pressure: 60 psia
Material: Carbon Steel	Functional height: 26 ft
Specification Sheet: Section 16	Diameter: 1.46 ft
Costing data: Table 17.1	Design calculations: Appendix A-j)

This unit of equipment separates the desired liquid products (styrene, toluene, ethylbenzene and methylstyrene) from the light hydrocarbons produced by the pyrolysis of polystyrene. The feed stream enters at a rate of 6,758 lb/hr, a temperature of 100˚F, and a pressure of 60 psia.

It was found that the number of trays necessary for these feed conditions is equal to 15 with a reflux ratio of 6, a feed stage of 5, and a distillate ratio of 2.5 lbmol/hr. This yields a diameter of 1.47 feet and a functional height of 26 feet, with 14 trays spaced two feet apart. A skirt length of 15 feet is included to the section height, yielding a total height of 41 feet. It is possible to use carbon steel as its material of construction due to the relatively low temperature of the feed stream, at 100˚F.

The kettle reboiler, E-102, is modeled as a heat exchanger, with a heat duty of 1,256,530 BTU/hr generated by Aspen and an assumed heat transfer coefficient of 60 BTU/hr-ft^2-˚F. This results in a steam requirement of 1,681 lb/hr to be supplied by the high-pressured steam produced in the second heat exchanger, H-103, as explained in Section 14.2.

Finally, a residence time of 20 minutes and an L/D aspect ratio of 2, the reflux accumulator is sized as a horizontal pressure vessel using the equations found in Appendix A to be 0.44 feet in diameter and 0.88 feet in length.

Distillation Column 1

Unit ID: D-201	Temperature: 425 °F
Type: Distillation Column	Pressure: 80 psia
Material: Carbon Steel	Functional height: 96 ft
Specification Sheet: Section 16	Diameter: 1.54 ft
Costing data: Table 17.1	Design calculations: Appendix A-j)

This unit of equipment separates separate the lightest compound, toluene, from the remaining three products. The feed stream enters at a rate of 6,633 lb/hr, a temperature of 425˚F, and a pressure of 80 psia. It was found that the number of stages necessary for these feed conditions is equal to 50 with a reflux ratio of 16, a feed stage of 17, and a distillate ratio of 6.3 lbmol/hr. This yields a diameter of 1.54 feet and a functional height of 96 feet, with 49 trays spaced two feet apart. A skirt length of 15 feet is included to the section height, yielding a total height of 111 feet. It is possible to use carbon steel as its material of construction due to the relatively low temperature of the feed stream, at 425˚F. This column allows us to achieve a 99.5% purity of toluene.

The kettle reboiler, E-202, is modeled as a heat exchanger, with a heat duty of 1,307,180 BTU/hr generated by Aspen and an assumed heat transfer coefficient of 60 BTU/hr-ft^2-˚F. This results in a 450 psig steam requirement of 1,663 lb/hr, as presented in Section 14.2.

Finally, assuming a residence time of 20 minutes and an L/D aspect ratio of 2, the reflux accumulator is sized as a horizontal pressure vessel using the equations found in Appendix A to be 2.8 feet in diameter and 5.6 feet in length.

Distillation Column 2

Unit ID: D-202	Temperature: 390 °F
Type: Distillation Column	Pressure: 50 psia
Material: Carbon Steel	Functional height: 196 ft
Specification Sheet: Section 16	Diameter: 3.85 ft
Costing data: Table 17.1	Design calculations: Appendix A-j)

This unit of equipment separates separate ethylbenzene from styrene and methylstyrene. The feed stream enters at a rate of 6,051 lb/hr, a temperature of 390˚F, and a pressure of 50 psia. It was found that the number of stages necessary for these feed conditions is equal to 100 with a reflux ratio of 45, a feed stage of 41, and a distillate ratio of 10.3 lbmol/hr. This yields a diameter of 3.85 feet and a functional height of 196 feet, with 99 trays spaced two feet apart. A skirt length of 15 feet is included to the section height, yielding a total height of 211 feet. It is possible to use carbon steel as its material of construction due to the relatively low temperature of the feed stream, at 390˚F.

This separation is difficult due to the similar boiling points of the light key, ethylbenzene, with a boiling point of 381˚F, and the heavy key, styrene, with a boiling point of 406˚F. In addition, it is necessary to add inhibitors to this column to prevent polymerization of styrene. This column allows us to achieve a 99.3% purity of ethylbenzene.

The kettle reboiler, E-204, is modeled as a heat exchanger, with a heat duty of 7,005,770 BTU/hr generated by Aspen and an assumed heat transfer coefficient of 60 BTU/hr-ft^2-˚F. This results in a 450 psig steam requirement of 8,381 lb/hr, as presented in Section 14.2.

Finally, assuming a residence time of 20 minutes and an L/D aspect ratio of 2, the reflux accumulator is sized as a horizontal pressure vessel using the equations found in Appendix A to be 4.4 feet in diameter and 8.8 feet in length.

Distillation Column 3

Unit ID: D-203	Temperature: 350 °F
Type: Distillation Column	Pressure: 40 psia
Material: Carbon Steel	Functional height: 22.5 ft
Specification Sheet: Section 16	Diameter: 11.02 ft
Costing data: Table 17.1	Design calculations: Appendix A-j)

This unit of equipment separates separate styrene from methylstyrene. The feed stream enters at a rate of 4,959 lb/hr, a temperature of 350˚F, and a pressure of 40 psia. It was found that the number of stages necessary for these feed conditions is equal to 20 with a reflux ratio of 16, a feed stage of 13, and a distillate ratio of 42.8 lbmol/hr. This yields a diameter of 11.02 feet and a functional height of 22.5 feet, with 19 trays spaced two feet apart. A skirt length of 15 feet is included to the section height, yielding a total height of 37.5 feet. It is possible to use carbon steel as its material of construction due to the relatively low temperature of the feed stream, at 350˚F. This column allows us to achieve a 99.9% purity of styrene and thus meet the design criteria for our project. In addition, it is necessary to add inhibitors to this column to prevent polymerization of styrene.

The kettle reboiler, E-206, is modeled as a heat exchanger, with a heat duty of 12,701,300BTU/hr generated by Aspen and an assumed heat transfer coefficient of 60 BTU/hr-ft^2-˚F. This results in a 50 psig steam requirement of 13,144 lb/hr, as presented in Section 14.2.

Finally, assuming a residence time of 20 minutes and an L/D aspect ratio of 2, the reflux accumulator is sized as a horizontal pressure vessel using the equations found in Appendix A to be 5.25 feet in diameter and 10.5 feet in length.

v. Storage Tanks

Toluene Storage Tank

Unit ID: TK-201	Temperature: 77°F
Type: Storage Tank	Pressure: 14.7 psia
Material: Carbon Steel	Height: 30 ft
Specification Sheet: Section 16	Diameter: 10 ft
Costing data: Table 17.1	Design calculations: Appendix A-i)

The liquid product storage tanks were designed to hold seven days' worth of product. Given the toluene flow rate of 581 lb/hr, or 95 gal/hr, a total storage volume of 16,000 gallons is needed. Assuming an aspect ratio of three (length over diameter), this yields a height of 30 feet and diameter of 10 feet. The tank is modeled as a conical roof storage vessel. A nitrogen blanket is used to maintain safe oxygen concentrations within the tank headspace.

Ethylbenzene Storage Tank

Unit ID: TK-202	Temperature: 77°F
Type: Storage Tank	Pressure: 14.7 psia
Material: Carbon Steel	Height: 36 ft
Specification Sheet: Section 16	Diameter: 12 ft
Costing data: Table 17.1	Design calculations: Appendix A-i)

Given the ethylbenzene flow rate of 1,092 lb/hr, or 175 gal/hr, a total storage volume of 29,000 gallons is needed. Assuming an aspect ratio of three (length over diameter), this yields a height of 36 feet and diameter of 12 feet. The tank is modeled as a conical roof storage vessel. A nitrogen blanket is used to maintain safe oxygen concentrations within the tank headspace.

Styrene Storage Tank

Unit ID: TK-203	Temperature: 77°F
Type: Storage Tank	Pressure: 14.7 psia
Material: Carbon Steel	Height: 54 ft
Specification Sheet: Section 16	Diameter: 18 ft
Costing data: Table 17.1	Design calculations: Appendix A-i)

Given the styrene flow rate of 4,458 lb/hr, or 618 gal/hr, a total storage volume of 104,000 gallons is needed. Assuming an aspect ratio of three (length over diameter), this yields a height of 54 feet and diameter of 18 feet. The tank is modeled as a conical roof storage vessel. A nitrogen blanket is used to maintain safe oxygen concentrations within the tank headspace.

Methylstyrene Storage Tank

Unit ID: TK-204	Temperature: 77°F
Type: Storage Tank	Pressure: 14.7 psia
Material: Carbon Steel	Height: 27 ft
Specification Sheet: Section 16	Diameter: 9 ft
Costing data: Table 17.1	Design calculations: Appendix A-i)

Given the methylstyrene flow rate of 501 lb/hr, or 71 gal/hr, a total storage volume of 12,000 gallons is needed. Assuming an aspect ratio of three (length over diameter), this yields a height of 27 feet and diameter of 9 feet. The tank is modeled as a conical roof storage vessel. A nitrogen blanket is used to maintain safe oxygen concentrations within the tank headspace.

Section 16. Specification Sheets

ROTARY KILN

Identification:	Item	*Rotary Kiln*			Date: *9 April 2018*
	Item No.	*R-101*			
	No. Required	1			By: *JGG*
Function:	Combust fuel gas in outer shell to carry out pyrolysis of polystyrene in the inner vessel				
Operation:	Continuous				
Materials Handled:	Feed	Product	Char	Shell Gas (in)	Shell Gas (out)
Stream ID	1	2	3	12	4
Temperature (°F)	77	752	752	1722	768.7
Pressure (psia)	20	20	20	14.7	14.7
Mass Flow (lb/hr)	8333	7876.28	456.69	632	632
Component Mass Flow (lb/hr)					
Polystyrene	8333	-	-	-	-
Toluene	-	612.54	-	14.0	-
Ethylbenzene	-	1110.07	-	9.8	-
Styrene	-	4592.78	-	27.8	-
Methylstyrene	-	420.86	-	1.2	-
Carbon	-	-	456.69	0.0	-
Methane	-	126.67	-	0.0	-
Ethylene	-	126.67	-	0.0	-
Ethane	-	126.67	-	64.4	-
Propylene	-	126.67	-	64.4	-
Propane	-	126.67	-	64.4	-
Butene	-	126.67	-	64.4	-
Butane	-	126.67	-	64.4	-
Isobutane	-	126.67	-	64.4	-
Hydrogen	-	126.67	-	64.4	-
Oxygen	-	-	-	-	3.02
Carbon dioxide	-	-	-	-	0.78
Nitrogen	-	-	-	-	17.3
Water	-	-	-	-	1.58
Design Data:	Material of Construction: Stainless steel Length: 70 ft Diameter: 7 ft Temperature: 752 F Pressure: 20 psia Residence time: 60 min				
Utilities:	Electricity at 0.40 kWh				
Comments:	See Section 12 Process Flow Diagram 100				

BLOWER

Identification:	Item	*Blower*		Date: *9 April 2018*
	Item No.	*P-101*		
	No. Required	1		By: *JGG*
Function:	Compress gaseous products from rotary kiln			
Operation:	Continuous			
Materials Handled:			Feed	Discharge
Stream ID			2	6
Temperature (°F)			752	827.23
Pressure (psia)			20	45
Mass Flow (lb/hr)			7876.28	7876.28
Component Mass Flow (lb/hr)				
Polystyrene			-	-
Toluene			612.54	612.54
Ethylbenzene			1110.07	1110.07
Styrene			4592.78	4592.78
Methylstyrene			420.86	420.86
Carbon			-	-
Methane			126.67	126.67
Ethylene			126.67	126.67
Ethane			126.67	126.67
Propylene			126.67	126.67
Propane			126.67	126.67
Butene			126.67	126.67
Butane			126.67	126.67
Isobutane			126.67	126.67
Hydrogen			126.67	126.67
Oxygen			-	-
Carbon dioxide			-	-
Nitrogen			-	-
Water			-	-
Design Data:	Material of Construction: Stainless Steel No. Stages: 1 Type: Centifugal Orientation: Horizontal		Volumetric Flowrate: 47,965 cuft/hr Efficiency: 0.85 Net Work: 144.8 hp	
Utilities:	Electricity at 146.38 kWh			
Comments:	See Section 12 Process Flow Diagram Section 100			

FEED PUMP

Identification:	Item	*Feed Pump 1*	Date: *9 April 2018*
	Item No.	*P-102*	
	No. Required	1	By: *JGG*
Function:	Pressurize liquid product to send to distillation column		
Operation:	Continuous		

Materials Handled:	Feed	Discharge
Stream ID	13	14
Temperature (°F)	100	100
Pressure (psia)	32	60
Mass Flow (lb/hr)	6758.13	6758.13
Component Mass Flow (lb/hr)		
Polystyrene	-	-
Toluene	585.99	585.99
Ethylbenzene	1090.90	1090.90
Styrene	4538.12	4538.12
Methylstyrene	418.54	418.54
Carbon	-	-
Methane	0.667	0.667
Ethylene	2.74	2.74
Ethane	4.05	4.05
Propylene	11.67	11.67
Propane	12.89	12.89
Butene	31.66	31.66
Butane	25.77	25.77
Isobutane	35.07	35.07
Hydrogen	0.0068	0.0068
Oxygen	-	-
Carbon dioxide	-	-
Nitrogen	-	-
Water	-	-

Design Data:	Material of construction: Carbon steel Net Work: 1.47 hp No. Stages: 1 Type: Centrifugal Flowrate: 124.63 cuft/hr Head: 127.47 ft Efficiency: 0.50
Utilities:	Electricity at 77.92 kWh
Comments:	See Section 12 Process Flow Diagram Section 100

HEAT EXCHANGER 1

Identification:	Item	*Heat Exchanger 1*		Date: *9 April 2018*	
	Item No.	*H-101*			
	No. Required	1		By: *JGG*	
Function:	Cool down gaseous products from reactor while creating high pressure steam.				
Operation:	Continuous				
Materials Handled:		Cold In	Cold Out	Hot In	Hot Out
Stream ID		16	17	6	7
Temperature (°F)		90	297.8	827.23	321.23
Pressure (psia)		63	63	45	37
Mass Flow (lb/hr)		1900	1900	7876.28	7876.28
Component Mass Flow (lb/hr)					
Polystyrene		-	-	-	-
Toluene		-	-	612.54	612.54
Ethylbenzene		-	-	1110.07	1110.07
Styrene		-	-	4592.78	4592.78
Methylstyrene		-	-	420.86	420.86
Carbon		-	-	-	-
Methane		-	-	126.67	126.67
Ethylene		-	-	126.67	126.67
Ethane		-	-	126.67	126.67
Propylene		-	-	126.67	126.67
Propane		-	-	126.67	126.67
Butene		-	-	126.67	126.67
Butane		-	-	126.67	126.67
Isobutane		-	-	126.67	126.67
Hydrogen		-	-	126.67	126.67
Oxygen		-	-	-	-
Carbon dioxide		-	-	-	-
Nitrogen		-	-	-	-
Water		1900	1900	-	-
Design Data:	Material of Construction: Carbon Steel Type: Countercurrent No. of shells: 1 Effective Surface Area: 103.4 sqft		LMTD: 360 F Heat Exchanged: 2.2 MM BTU/hr Heat transfer coefficient: 60 BTU/hr.sqft.F Material of Construction: Carbon Steel		
Utilities:					
Comments:	See Section 12 Process Flow Diagram Section 100				

HEAT EXCHANGER 2

Identification:	Item	*Heat Exchanger 2*		Date: *9 April 2018*	
	Item No.	*H-103*			
	No. Required	1		By: *JGG*	
Function:	Use hot combusted fuel from rotary kiln to produce high pressure steam.				
Operation:	Continuous				
Materials Handled:		Cold In	Cold Out	Hot In	Hot Out
Stream ID		18	19	4	5
Temperature (°F)		90	478.9	768.7	527.3
Pressure (psia)		564	564	14.7	14.7
Mass Flow (lb/hr)		1700	1700	632	632
Component Mass Flow (lb/hr)					
Polystyrene		-	-	-	-
Toluene		-	-	-	-
Ethylbenzene		-	-	-	-
Styrene		-	-	-	-
Methylstyrene		-	-	-	-
Carbon		-	-	-	-
Methane		-	-	-	-
Ethylene		-	-	-	-
Ethane		-	-	-	-
Propylene		-	-	-	-
Propane		-	-	-	-
Butene		-	-	-	-
Butane		-	-	-	-
Isobutane		-	-	-	-
Hydrogen		-	-	-	-
Oxygen		-	-	3.02	3.02
Carbon dioxide		-	-	0.78	0.78
Nitrogen		-	-	17.3	17.3
Water		1700	1700	1.58	1.58
Design Data:	Material of Construction: Carbon Steel Type: Countercurrent No. of shells: 1 Effective Surface Area: 96.3 sqft LMTD: 359 F Heat Exchanged: 2.1 MM BTU/hr Heat transfer coefficient: 60 BTU/hr.sqft.F				
Utilities:					
Comments:	See Section 12 Process Flow Diagram 100				

CONDENSER

Identification:	Item	*Condenser*		Date: *9 April 2018*
	Item No.	*H-102*		
	No. Required	1		By: *JGG*
Function:	Separate most of the light hydrocarbons out from the condensable liquid products			
Operation:	Continuous			
Materials Handled:		Feed	Liquid Product	Vapor Product
Stream ID		7	13	8
Temperature (°F)		321.23	100	100
Pressure (psia)		37	32	32
Mass Flow (lb/hr)		7876.28	6758.13	1118.18
Component Mass Flow (lb/hr)				
Polystyrene		0	0	0
Toluene		612.54	585.99	26.55
Ethylbenzene		1110.07	1090.90	19.16
Styrene		4592.78	4538.12	54.66
Methylstyrene		420.86	418.54	2.32
Carbon		0	0	0
Methane		126.67	0.667	126.01
Ethylene		126.67	2.74	123.93
Ethane		126.67	4.05	122.62
Propylene		126.67	11.67	115.00
Propane		126.67	12.89	113.79
Butene		126.67	31.66	95.01
Butane		126.67	25.77	100.91
Isobutane		126.67	35.07	91.61
Hydrogen		126.67	0.0068	126.61
Oxygen		-	-	-
Carbon dioxide		-	-	-
Nitrogen		-	-	-
Water		-	-	-
Design Data:	Material of Construction: Carbon Steel Vapor fraction: 0.577 Heat transfer area: 412.5 sqft Cooling water flow rate: 132,799 lb/hr LMTD: 75.1 F Heat exchanged: 1.9 MM BTU/hr			
Utilities:	Electricity at 265.6 kWh			
Comments:	See Section 12 Process Flow Diagram Section 100			

DISTILLATION COLUMN 0

Identification:	Item	*Tray Column*		Date: *9 April 2018*
	Item No.	*D-101*		
	No. Required	1		By: *JGG*
Function:	Separate the rest of the light hydrocarbons from the valuable liquid products.			
Operation:	Continuous			
Materials Handled:		Feed	Distillate	Bottoms
Stream ID		14	9	15
Temperature (°F)		100	106.64	424.55
Pressure (psia)		80	75	79.56
Mass Flow (lb/hr)		6758.13	125.63	6632.49
Component Mass Flow (lb/hr)				
Polystyrene		-	-	-
Toluene		585.99	0.974	585.02
Ethylbenzene		1090.90	0.0035	1090.87
Styrene		4538.12	0.0041	4538.07
Methylstyrene		418.54	-	418.54
Carbon		-	-	-
Methane		0.667	0.667	-
Ethylene		2.74	2.74	-
Ethane		4.05	4.05	-
Propylene		11.67	11.67	-
Propane		12.89	12.89	-
Butene		31.66	31.66	-
Butane		25.77	25.77	-
Isobutane		35.07	35.07	-
Hydrogen		0.0068	0.0068	-
Oxygen		-	-	-
Carbon dioxide		-	-	-
Nitrogen		-	-	-
Water		-	-	-
Design Data:	Number of trays: 14 Number of passes: 1 Tray type: FLEXI Pressure: 75 psia Functional height: 26 ft Material of construction: Carbon Steel	Inside diameter: 1.47 ft Feed stage: 5 Molar reflux ratio: 6 Molar distillate rate: 2.5 lbmol/hr Skirt height: 15 ft Tray spacing: 2 ft		
Utilities:	Cooling water at 14.67 lb/hr			
Comments:	See Section 12 Process Flow Diagram Section 100			

DISTILLATION COLUMN 1

Identification:	Item	*Tray Column*		Date: *9 April 2018*
	Item No.	*D-201*		
	No. Required	1		By: *JGG*
Function:	Separate toluene out from other liquid products.			
Operation:	Continuous			

Materials Handled:	Feed	Distillate	Bottoms
Stream ID	15	20	21
Temperature (°F)	424.55	305.86	390.10
Pressure (psia)	79.56	40	50.76
Mass Flow (lb/hr)	6632.49	580.84	6051.66
Component Mass Flow (lb/hr)			
Polystyrene	-	-	-
Toluene	585.02	578.12	6.89
Ethylbenzene	1090.87	2.43	1088.44
Styrene	4538.07	0.29	4537.78
Methylstyrene	418.54	-	418.54
Carbon	-	-	-
Methane	-	-	-
Ethylene	-	-	-
Ethane	-	-	-
Propylene	-	-	-
Propane	-	-	-
Butene	-	-	-
Butane	-	-	-
Isobutane	-	-	-
Hydrogen	-	-	-
Oxygen	-	-	-
Carbon dioxide	-	-	-
Nitrogen	-	-	-
Water	-	-	-

Design Data:	Number of trays: 49	Material of construction: Carbon Steel
	Feed stage: 17	Inside diameter: 1.54 ft
	Number of passes: 1	Mass reflux ratio: 16
	Tray type: FLEXI	Molar distillate rate: 6.3 lbmol/hr
	Pressure: 40 psia	Skirt height: 15 ft
	Section pressure drop: 35.16 psi	Tray spacing: 2 ft
	Functional height: 96 ft	
Utilities:	Cooling water at 69.64 lb/hr	
	High pressure steam 450 psig at 1663 lb/hr	
Comments:	See Section 12 Process Flow Diagram Section 200	

DISTILLATION COLUMN 2

Identification:	Item	*Tray Column*	Date: *9 April 2018*
	Item No.	*D-202*	
	No. Required	1	By: *JGG*
Function:	Separate ethylbenzene out from other liquid products.		
Operation:	Continuous		

Materials Handled:	Feed	Distillate	Bottoms
Stream ID	21	22	23
Temperature (°F)	390.10	298.28	350.32
Pressure (psia)	50.76	20	30.3
Mass Flow (lb/hr)	6051.66	1092.46	4959.19
Component Mass Flow (lb/hr)			
Polystyrene	-	-	-
Toluene	6.89	6.89	-
Ethylbenzene	1088.44	1085.04	3.396
Styrene	4537.78	0.527	4537.257
Methylstyrene	418.54	-	418.54
Carbon	-	-	-
Methane	-	-	-
Ethylene	-	-	-
Ethane	-	-	-
Propylene	-	-	-
Propane	-	-	-
Butene	-	-	-
Butane	-	-	-
Isobutane	-	-	-
Hydrogen	-	-	-
Oxygen	-	-	
Carbon dioxide	-	-	-
Nitrogen	-	-	-
Water	-	-	-

Design Data:	Number of trays: 99	Inside diameter: 3.85 ft
	Number of passes: 1	Feed stage: 41
	Tray type: FLEXI	Mass reflux ratio: 45
	Pressure: 20 psia	Molar distillate rate: 10.3 lbmol/hr
	Section pressure drop: 65.25 psi	Skirt height: 15 ft
	Functional height: 196 ft	Tray spacing: 2 ft
	Material of construction: Carbon Steel	
Utilities:	Cooling water at 255.93 lb/hr	
	High pressure steam (450 psig) at 8381 lb/hr	
Comments:	Inhibitor added to prevent styrene polymerization	

DISTILLATION COLUMN 3

Identification:	Item	*Packed Column*		Date: *9 April 2018*
	Item No.	*D-203*		
	No. Required	1		By: *JGG*
Function:	Separate styrene from methylstyrene			
Operation:	Continuous			
Materials Handled:		Feed	Distillate	Bottoms
Stream ID		23	24	25
Temperature (°F)		350.32	148.64	216.12
Pressure (psia)		30.3	0.97	2.2
Mass Flow (lb/hr)		4959.19	4588.398	370.79
Component Mass Flow (lb/hr)				
Polystyrene		-	-	-
Toluene		-	-	-
Ethylbenzene		3.396	3.396	-
Styrene		4537.26	4537.26	-
Methylstyrene		418.54	47.75	370.79
Carbon		-	-	-
Methane		-	-	-
Ethylene		-	-	-
Ethane		-	-	-
Propylene		-	-	-
Propane		-	-	-
Butene		-	-	-
Butane		-	-	-
Isobutane		-	-	-
Hydrogen		-	-	-
Oxygen		-	-	-
Carbon dioxide		-	-	-
Nitrogen		-	-	-
Water		-	-	-
Design Data:	Number of stages: 40		Surface area: 100.89 sqft/cuft	
	Packing type: FlexiRing		Material of construction: Carbon Steel	
	Height: 47.5 ft		Inside diameter: 10.58 ft	
	HETP: 1.25 ft		Feed stage: 6	
	No. of passes: 1		Molar reflux ratio: 6	
	Pressure: 75 psia		Molar distillate rate: 2.5 lbmol/hr	
	Section pressure drop: 1.59 psi			
Utilities:	Cooling water at 364.08 lb/hr			
	Low pressure steam (50 psig) at 11244 lb/hr			
Comments:	Inhibitor added to prevent styrene polymerization			
	See Section 12 Process Flow Diagram Section 200			

TOLUENE STORAGE TANK

Identification:	Item	*Tank*	Date: *9 April 2018*
	Item No.	*TK-201*	
	No. Required	1	By: *JGG*
Function:	Store liquid toluene product.		
Operation:	Continuous		
Materials Handled:			Feed
Stream ID			20
Temperature (°F)			305.86
Pressure (psia)			40
Mass Flow (lb/hr)			580.84
Component Mass Flow (lb/hr)			
Polystyrene			-
Toluene			578.12
Ethylbenzene			2.43
Styrene			0.29
Methylstyrene			-
Carbon			-
Methane			-
Ethylene			-
Ethane			-
Propylene			-
Propane			-
Butene			-
Butane			-
Isobutane			-
Hydrogen			-
Oxygen			-
Carbon dioxide			-
Nitrogen			-
Water			-
Design Data:	Amount stored(time): 7 days Inside diameter: 10 ft Functional height: 30 ft Material of construction: Carbon Steel Roof design: Conical Pressure: 14.7 psig Total storage volume: 16,000 gal		
Utilities:			
Comments:	See Section 12 Process Flow Diagram Section 200		

ETHYLBENZENE STORAGE TANK

Identification:	Item	*Tank*	Date: *9 April 2018*
	Item No.	*TK-202*	
	No. Required	1	By: *JGG*
Function:	Store ethylbenzene liquid product.		
Operation:	Continuous		
Materials Handled:			Feed
Stream ID			22
Temperature (°F)			298.28
Pressure (psia)			40
Mass Flow (lb/hr)			1092.46
Component Mass Flow (lb/hr)			
Polystyrene			-
Toluene			6.9
Ethylbenzene			1085.04
Styrene			0.527
Methylstyrene			-
Carbon			-
Methane			-
Ethylene			-
Ethane			-
Propylene			-
Propane			-
Butene			-
Butane			-
Isobutane			-
Hydrogen			-
Oxygen			-
Carbon dioxide			-
Nitrogen			-
Water			-
Design Data:	Amount stored(time): 7 days Inside diameter: 12 ft Functional height: 36 ft Material of construction: Carbon steel Roof design: Conical Pressure: 14.7 psig Total storage volume: 29,000 gal		
Utilities:			
Comments:	See Section 12 Process Flow Diagram Section 200		

STYRENE STORAGE TANK

Identification:	Item	*Tank*	Date: *9 April 2018*
	Item No.	*TK-203*	
	No. Required	1	By: *JGG*
Function:	Store styrene liquid product.		
Operation:	Continuous		
Materials Handled:			Feed
Stream ID			24
Temperature (°F)			148.64
Pressure (psia)			40
Mass Flow (lb/hr)			4457.8
Component Mass Flow (lb/hr)			
Polystyrene			-
Toluene			-
Ethylbenzene			3.396
Styrene			4454.16
Methylstyrene			0.22
Carbon			-
Methane			-
Ethylene			-
Ethane			-
Propylene			-
Propane			-
Butene			-
Butane			-
Isobutane			-
Hydrogen			-
Oxygen			-
Carbon dioxide			-
Nitrogen			-
Water			-
Design Data:	Amount stored(time): 7 days Inside diameter: 18 ft Functional height: 54 ft Pressure: 14.7 psig Total storage volume: 104,000 gal	Material of construction: Carbon steel Roof design: Conical	
Utilities:			
Comments:	Inhibitor added to prevent styrene polymerization See Section 12 Process Flow Diagram Section 200		

METHYLSTYRENE STORAGE TANK			
Identification:	Item	*Tank*	Date: *9 April 2018*
	Item No.	*TK-204*	
	No. Required	1	By: *JGG*
Function:	Store methylstyrene liquid product.		
Operation:	Continuous		
Materials Handled:			Feed
Stream ID			26
Temperature (°F)			216.12
Pressure (psia)			40
Mass Flow (lb/hr)			501.42
Component Mass Flow (lb/hr)			
Polystyrene			-
Toluene			-
Ethylbenzene			-
Styrene			83.10
Methylstyrene			418.32
Carbon			-
Methane			-
Ethylene			-
Ethane			-
Propylene			-
Propane			-
Butene			-
Butane			-
Isobutane			-
Hydrogen			-
Oxygen			-
Nitrogen			-
Carbon dioxide			-
Water			-
Design Data:	Amount stored(time): 7 days Inside diameter: 9 ft Functional height: 27 ft Pressure: 14.7 psig Total storage volume: 12,000 gal	Material of construction: Carbon Steel Roof design: Conical	
Utilities:			
Comments:	See Section 12 Process Flow Diagram Section 200		

Section 17. Equipment Cost Summary

The following table details the purchase cost and bare module cost based on the equipment in the process model. The design specifications were calculated based on information obtained from ASPEN. The costs were calculated using the equations presented in Chapter 16 of *Seider et al.* Sample calculations for equipment costs can be found in Appendix A. The total equipment cost amounts to $16.7MM.

Table 17.1. Summary table for all process units including purchase cost, bare-module factor and bare-module cost

Equipment Description	Type	Purchase Cost	Bare Module Factor	Bare Module Cost
D-101	Fabricated Equipment	$43,000	4.16	$179,000
D-201	Fabricated Equipment	$160,000	4.16	$666,000
D-202	Fabricated Equipment	$558,000	4.16	$2,321,000
D-203	Fabricated Equipment	$186,000	4.16	$774,000
H-101	Fabricated Equipment	$12,000	3.17	$38,000
H-102	Fabricated Equipment	$15,000	3.17	$48,000
H-103	Fabricated Equipment	$14,000	3.17	$44,000
R-101	Fabricated Equipment	$2,398,000	3.05	$7,314,000
P-101	Process Machinery	$190,000	2.15	$409,000
P-102	Process Machinery	$34,000	3.30	$112,000
P-103	Process Machinery	$12,000	3.30	$40,000
P-104	Process Machinery	$14,000	3.30	$46,000
P-201	Process Machinery	$15,000	3.30	$50,000
P-202	Process Machinery	$12,000	3.30	$40,000
P-203	Process Machinery	$15,000	3.30	$50,000
P-204	Process Machinery	$12,000	3.30	$40,000
P-205	Process Machinery	$12,000	3.30	$40,000
P-206	Process Machinery	$50,000	3.30	$165,000
E-001	Fabricated Equipment	$247,000	3.21	$793,000
E-002	Fabricated Equipment	$135,000	3.21	$433,000
E-003	Fabricated Equipment	$10,000	3.21	$32,000
E-101	Fabricated Equipment	$3,000	3.05	$9,000
E-102	Fabricated Equipment	$58,000	3.17	$184,000
E-201	Fabricated Equipment	$11,000	3.05	$34,000
E-202	Fabricated Equipment	$36,000	3.17	$114,000
E-203	Fabricated Equipment	$18,000	3.05	$55,000
E-204	Fabricated Equipment	$52,000	3.15	$164,000
E-205	Fabricated Equipment	$21,000	3.05	$64,000
E-206	Fabricated Equipment	$44,000	3.17	$139,000
E-207	Fabricated Equipment	$17,000	3.21	$55,000
TK-001	Storage	$47,000	3.21	$151,000
TK-002	Storage	$47,000	3.21	$151,000
TK-003	Storage	$47,000	3.21	$151,000
TK-101	Storage	$12,000	3.21	$39,000
TK-201	Storage	$38,000	3.21	$122,000

TK-202	Storage	$52,000	3.21	$167,000
TK-203	Storage	$101,000		$324,000
TK-204	Storage	$28,000		$90,000
SF-001	Fabricated Equipment	$9,000		$29,000
SF-101	Fabricated Equipment	$4,000		$13,000
SF-102	Fabricated Equipment	$2,000		$6,000
P-102S	Spares	$34,000		$109,000
P-201S	Spares	$15,000		$48,000
P-203S	Spares	$15,000		$48,000
P-204S	Spares	$12,000		$39,000
P-205S	Spares	$12,000		$39,000
P-206S	Spares	$50,000		$161,000
Total				***16,139,000***

A breakdown of costs is presented in the figure below:

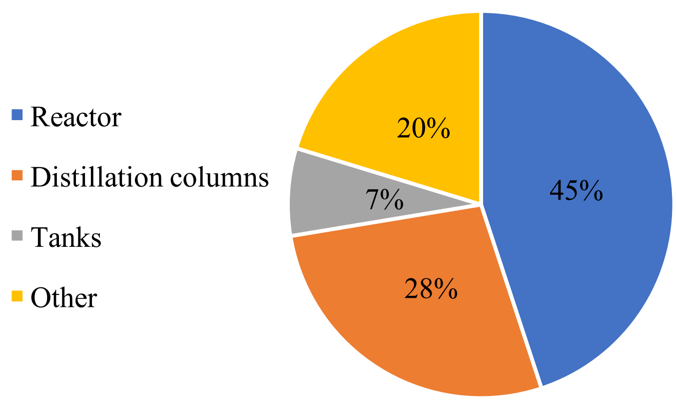


Figure 17.1. Breakdown of total equipment costs required for plant construction. The reactor constitutes a large portion of the fixed capital investment due to its size and complexity. Columns represent an important cost as well due to the difficult separation of ethylbenzene from styrene. Tanks costs are relatively large due to their abundance in the process, though their average cost is not as high as the reactor and the distillation columns.

The rotary kiln reactor, central to our process, accounts for 45% of this total amount. This equipment is at the core of the pyrolysis process. As explained in Section 15.1, it is a complex structure composed of an interior as well as an exterior vessel, a motor, a vacuum pump and more. Due to its complexity and to the lack of available information, sizing and costing considerations were challenging. However, our estimation of its bare-module cost of $7.3 MM was deemed reasonable by several practitioners in the industry. A sensitivity analysis is run to evaluate the impact of this cost on the profitability of the suggested design (see Section 20.2.3).

The next most expensive type of equipment is the distillation columns, which accounts for 28% of the total cost. More specifically, the third distillation column in the process, D-202, is the most expensive one at $2.7MM. It achieves the most difficult separation between the light key, ethylbenzene, with a boiling point of 381˚F, and the heavy key, styrene, with a boiling point of 406˚F. It requires 100 stages and a reflux ratio of 45. This column has been optimized to yield a purity of ethylbenzene equal to 99.3%. Finally, the tanks represent 7% of the total equipment cost. This is due to their abundance in the process, as there are eight of them. Three silos of 11,000 $ft^3$are each designed to hold one day's worth of polystyrene inventory. Five conical storage tanks varying in size are designed to hold seven days' worth of liquid product inventory each. Therefore, tanks represent an important cost for this process.

Section 18. Fixed Capital Investment Summary

The total capital investment for this project was determined to be equal to $25.7MM. It was calculated by following the method presented in Chapter 16 of *Seider et al,* starting with the bare-module costs for equipment. The sequence of operations followed is presented in the table below.

Table 18.1. Relationship between total capital investment, total permanent investment, 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 softwares	C_{comp}					
Total bare-module investment, TBM		C_{TBM}				
Cost of site preparation		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}

Specifically, the factors used to determine the required costs for site preparation, service facilities, contingencies and contractor fees as well as plant start-up are shown in the table below. These calculations formed the basis for calculating the total capital investment amount.

Table 18.2. Correlations between total capital investment and required fees for the proposed plant.

Cost of Site Preparations:	5.00%	of Total Bare Module Costs
Cost of Service Facilities:	5.00%	of Total Bare Module Costs
Cost of Contingencies and Contractor Fees:	18.00%	of Direct Permanent Investment
Cost of Land:	2.00%	of Total Depreciable Capital
Cost of Plant Start-Up:	10.00%	of Total Depreciable Capital

A breakdown of the specific costs obtained for our project are presented in the table below.

Table 18.3. Calculations of the total capital investment required from estimated bare-module costs.

Investment Summary			
Total Bare Module Costs:			
	Fabricated Equipment	$13508000	
	Process Machinery	$992,000	
	Spares	$444,000	
	Storage	$1,195,000	
	Other Equipment	$-	
	Catalysts	$-	
	Computers, Software, Etc.	$-	
	Total Bare Module Costs:		**$16,139,000**
Direct Permanent Investment			
	Cost of Site Preparations:	$806,950	
	Cost of Service Facilities:	$806,950	
	Allocated Costs for utility plants and related facilities:	$-	
	Direct Permanent Investment		**$17,752,900**
Total Depreciable Capital			
	Cost of Contingencies & Contractor Fees	$3,195,522	
	Total Depreciable Capital		**$20,948,422**
Total Permanent Investment			
	Cost of Land:	$418,968	
	Cost of Royalties:	$-	
	Cost of Plant Start-Up:	$2,094,842	
	Total Permanent Investment - Unadjusted		$23,462,233
	Site Factor		1.00
	Total Permanent Investment		**$24,462,233**

Working Capital	**2020**	**2021**	**2022**
Accounts Receivable	$1,329,030	$664,515	$664,515
Cash Reserves	$345,329	$172,665	$172,665
Accounts Payable	$(788,931)	$(394,466)	$(394,466)
Styrene Inventory	$177,204	$88,602	$88,602
Raw Materials	$48,820	$24,410	$24,410
Total	**$1,111,453**	**$555,726**	**$555,726**
Present Value at 15%	*$840,418*	*$365,399*	*$317,738*
Total Capital Investment	**$24,985,788**		

Section 19. Operating Cost – Cost Of Manufacture

i. Variable costs

Variable operating costs amount to $17.2MM per year. This includes the cost of raw materials, utilities, as well as general expenses, net of the revenue generated by byproducts. The table below summarizes the variable costs for this process.

Table 19.1. Summary of variable costs estimated for the project on an annual basis.

Variable Cost Summary				
General Expenses				
Selling / Transfer Expenses:	$1,077,991			
Direct Research:	$1,724,786			
Allocated Research:	$179,665			
Administrative Expense:	$718,661			
Management Incentive Compensation:	$449,163			
Total General Expenses			$4,150,266	
Raw Materials	$0.551003	per lb of Styrene		$19,799,208
Byproducts	$0.229100	per lb of Styrene		($8,232,269)
Utilities	$0.042611	per lb of Styrene		$1,531,149
Total Variable Costs				**$17,248,354**

The only raw material required for this process is polystyrene, with a feed rate of 100 TPD, or 8,333 lb/hr. Since it was challenging to determine a cost at which we would be able to obtain polystyrene (Section 10.1), a sensitivity analysis was performed that determines the IRR as a function of the price of polystyrene (see Section 20.2.2).

High pressure steam at 450 psig is required for the distillation columns D-201 and D-202, while low pressure steam at 50 psig is required for the last distillation column D-203, which operates at a pressure of 63 psia. In addition, cooling water is needed for the condenser H-102 as well as the reflux drums of all distillation columns. Finally, electricity is required to operate the various pumps, as well as the blower, the bucket elevators and screw feeders. The specific amounts required for each are presented in Section 14.1, Table 14.1. A summary of the amounts required is presented in the table below.

Table 19.2. Utility cost estimates per pound of styrene.

Utility	Unit	Required Ratio		Utility Cost	
High Pressure Steam	lb	2.21	lb per lb of styrene	$0.008	per lb
Low Pressure Steam	lb	2.48	lb per lb of styrene	$0.006	per lb
Cooling Water	gpm	0.21	gpm per lb of styrene	$0.0001	per gpm
Electricity	kWh	0.151	kWh per lb of styrene	$0.070	per kWh

In addition, general expense data required for plant operations are used as recommended in *Seider et al*. The factors used are presented in the table below.

Table 19.3. Annual general expense 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

ii. Fixed costs

Fixed costs were found to be equal to $7.8MM per year. This includes the cost for operations, maintenance, and operating overhead as well as property taxes and insurance. These values were found assuming that we would need five operating daily shifts. We assumed that we would need four operators per shift, with three operators working on the field and one on the control board. Moreover, the tax rate was determined to be equal to 24%. The resulting table for fixed costs is presented below.

Table 19.4. Summary of fixed costs estimated for the project on an annual basis.

Fixed Cost Summary	
Operations	
Direct Wages and Benefits	$1,664,000
Direct Salaries and Benefits	$249,600
Operating Supplies and Services	$99,840
Technical Assistance to Manufacturing	$1,200,000
Control Laboratory	$1,300,000
Total Operations	**$4,513,440**
Maintenance	
Wages and Benefits	$942,679
Salaries and Benefits	$235,670
Materials and Services	$942,679
Maintenance Overhead	$47,134
Total Maintenance	**$2,168,162**
Operating Overhead	
General Plant Overhead:	$219,528
Mechanical Department Services:	$74,207
Employee Relations Department:	$182,425
Business Services:	$228,804
Total Operating Overhead	**$704,964**
Property Taxes and Insurance	
Property Taxes and Insurance:	$418,968
Other Annual Expenses	
Rental Fees (Office and Laboratory Space):	$-
Licensing Fees:	$-
Miscellaneous:	$-
Total Other Annual Expenses	**$-**
Total Fixed Costs	**$7,805,534**

Section 20. Profitability Analysis

i. Profitability Measures

Chemical recycling of polystyrene by pyrolysis displays great potential as a profitable venture in the petrochemical industry. Our project was determined to yield an 18.54% internal rate of return (IRR), with a net present value (NPV) of $5.1MM in 2018 when using a nominal interest rate of 15% over fifteen years. In addition, its return on investment (ROI) was found to be equal to 21.11% after the third production year, when the plant begins operating at full capacity. The table below displays an overview of these profitability metrics.

Table 20.1. Summary of profitability measures for the proposed process using base case pricing an 15% nominal interest rate.

Profitability Measures	
The Internal Rate of Return (IRR) for this project is	18.54%
The Net Present Value (NPV) of this project in 2018 is	$5,155,000
ROI Analysis (Third Production Year)	
Annual Sales	**32,339,736**
Annual Costs	**(23,329,053)**
Depreciation	**(1,876,979)**
Income Tax	**(1,712,089)**
Net Earnings	**5,421,615**
Total Capital Investment	**25,685,138**
ROI	**21.11%**

Since our project displays an IRR that exceeds the cost of capital of 15%, and an NPV of greater than zero, we can say that it is value creating. These compelling financials suggest that there is a profitable and realistic process design capable of recycling polystyrene using pyrolysis. While any new technological undertaking is associated with risk, the large payoff from this process warrants attention from investors.

The project will require the remainder of the current calendar year for detailed process design, followed by two years of plant construction before any styrene can be produced. Our team estimated the value of this project over a fifteen-year lifespan. The first two years of plant operation will be carried out at 50% of the 100 tons per day polystyrene processing capacity, and the remaining thirteen years at 90% production capacity.

Table 20.2. Chronology of the project. The remainder of this year will be used to complete the design of the plant, followed by two years of construction. The plant will then operate for fifteen years. The total permanent investment will be used on the first year of construction in its entirety.

Chronology

Year	Action	Distribution of Permanent Investment	Production Capacity	Depreciation 5 year MACRS	Product Price
2018	Design		0.0%		
2019	Construction	100%	0.0%		
2020	Construction	0%	0.0%		
2021	Production	0%	45.0%	20.00%	$1.00
2022	Production	0%	67.5%	32.00%	$1.00
2023	Production		90.0%	19.20%	$1.00
2024	Production		90.0%	11.52%	$1.00
2025	Production		90.0%	11.52%	$1.00
2026	Production		90.0%	5.76%	$1.00
2027	Production		90.0%		$1.00
2028	Production		90.0%		$1.00
2029	Production		90.0%		$1.00
2030	Production		90.0%		$1.00
2031	Production		90.0%		$1.00
2032	Production		90.0%		$1.00
2033	Production		90.0%		$1.00
2034	Production		90.0%		$1.00
2035	Production		90.0%		$1.00

Cash Flow Summary

Year	Percentage of Design Capacity	Product Unit Price	Sales	Capital Costs	Working Capital	Var Costs	Fixed Costs	Depreciation	Taxible Income	Taxes	Net Earnings	Cash Flow	Cumulative Net Present Value at 15%
2018	0%		-	-	-	-	-	-	-	-	-	-	-
2019	0%		-	(23,462,200)	-	-	-	-	-	-	-	(23,462,233)	(20,401,900)
2020	0%		-	-	(1,111,500)	-	-	-	-	-	-	(1,111,453)	(21,242,400)
2021	45%	$1.00	16,169,900	-	(555,700)	(7,761,800)	(7,805,500)	(4,189,700)	(3,587,100)	860,900	(2,726,200)	907,754	(20,645,500)
2022	68%	$1.00	24,254,800	-	(555,700)	(11,642,600)	(7,805,500)	(6,703,500)	(1,896,900)	455,200	(1,441,600)	4,706,150	(17,954,700)
2023	90%	$1.00	32,339,700	-	-	(15,523,500)	(7,805,500)	(4,022,100)	4,988,600	(1,197,300)	3,791,300	7,813,422	(14,070,100)
2024	90%	$1.00	32,339,700	-	-	(15,523,500)	(7,805,500)	(2,413,300)	6,597,400	(1,583,400)	5,014,000	7,427,301	(10,859,100)
2025	90%	$1.00	32,339,700	-	-	(15,523,500)	(7,805,500)	(2,413,300)	6,597,400	(1,583,400)	5,014,000	7,427,301	(8,066,900)
2026	90%	$1.00	32,339,700	-	-	(15,523,500)	(7,805,500)	(1,206,600)	7,804,100	(1,873,000)	5,931,100	7,137,710	(5,733,500)
2027	90%	$1.00	32,339,700	-	-	(15,523,500)	(7,805,500)	-	9,010,700	(2,162,600)	6,848,100	6,848,119	(3,786,900)
2028	90%	$1.00	32,339,700	-	-	(15,523,500)	(7,805,500)	-	9,010,700	(2,162,600)	6,848,100	6,848,119	(2,094,100)
2029	90%	$1.00	32,339,700	-	-	(15,523,500)	(7,805,500)	-	9,010,700	(2,162,600)	6,848,100	6,848,119	(622,200)
2030	90%	$1.00	32,339,700	-	-	(15,523,500)	(7,805,500)	-	9,010,700	(2,162,600)	6,848,100	6,848,119	657,800
2031	90%	$1.00	32,339,700	-	-	(15,523,500)	(7,805,500)	-	9,010,700	(2,162,600)	6,848,100	6,848,119	1,770,800
2032	90%	$1.00	32,339,700	-	-	(15,523,500)	(7,805,500)	-	9,010,700	(2,162,600)	6,848,100	6,848,119	2,738,600
2033	90%	$1.00	32,339,700	-	-	(15,523,500)	(7,805,500)	-	9,010,700	(2,162,600)	6,848,100	6,848,119	3,580,200
2034	90%	$1.00	32,339,700	-	-	(15,523,500)	(7,805,500)	-	9,010,700	(2,162,600)	6,848,100	6,848,119	4,312,100
2035	90%	$1.00	32,339,700	-	2,222,900	(15,523,500)	(7,805,500)	-	9,010,700	(2,162,600)	6,848,100	9,071,024	**5,155,000**

Table 20.3. Summary of cash flows for the life of the project, including sales, capital, fixed and variable costs, depreciation and taxes.

The NPV of the base case for this process over fifteen years was estimated to be $5.1 MM. This project assumes that all styrene produced is sold at $1.00 per pound, while the polystyrene is purchased at a price of $0.30 per pound. A graph of the cumulative free cash flow for this process over time is shown below.

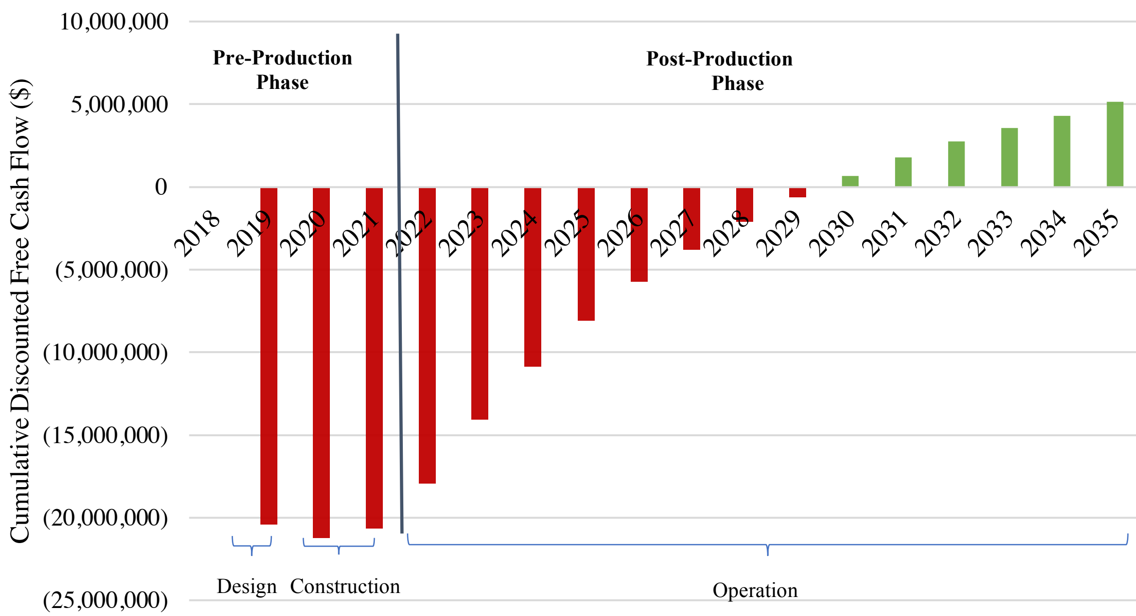


Figure 20.1. Cumulative discounted free cash flow for the process (in dollars) over a fifteen-year lifespan assuming a polystyrene cost of $0.30 per pound and a styrene selling price of $1.00 per pound. The process is shown to break-even in 2030.

The cumulative free cash flow graph illustrates the value of the polystyrene recycling process in 2018 dollars over time. In the first few years, the process nets negative discounted cash flows due to site construction and plant development concurrent with an absence of styrene production and sales. Styrene sales begin in 2021 with maximum production capacity achieved in 2023. The process breaks even in Q1 2030 and displays sustained growth in the following years.

Funding this project requires capital outlays in four phases. In the first year, substantial investment, amounting to $23.5 MM is required to build the plant and facilities. This is the Total Permanent Investment (TPI) presented in Section 18. Table 18.3 presents the detailed calculations that lead us to this value. The TPI includes the bare-module costs, the cost of site preparations and service facilities, the cost of contingencies and contractor fees as well as the cost of land and plant start-up. Over the course of the next three years, incremental capital outlays of $1.1 MM, $0.56 MM and $0.56 MM are required to fund this project's working capital requirements. Working capital represents the resources required to run the business on a day-to-day basis. Specifically, working capital in this context represents the investment required to build up the plant's inventory of raw materials and ensure that sufficient funds are available to satisfy upcoming operational expenses through accounts payable. The quick ratio, calculated by taking the ratio of current assets to current liabilities, provides insight into a project's liquidity, or its ability to meet its obligations in the short-term. Our project displays a quick ratio of 2.41 for the years 2019, 2020 and 2021, indicating that current assets (accounts receivables, cash reserves, styrene inventory and polystyrene inventory) exceed current liabilities (accounts payables). This metric demonstrates strong liquidity for the venture, ensuring that the project will be able to cover expenses and repay stakeholders in the short-run. As investments in working capital currently constitute 12% of the total capital investment, improving accounts receivable days and accounts payable days provides another opportunity for upside. Presently, accounts receivable days and account payable days are both assumed to be equal to thirty. Working to increase the former (by more quickly collecting payments from customers) and decrease the latter (by negotiating more lenient payment terms with suppliers) can help reduce the working capital requirements of this venture and contribute to even higher returns.

ii. Sensitivity Analyses

The profitability metrics discussed above are a direct function of the project's expected cash flows over the fifteen-year project lifespan. The IRR, NPV and ROI are calculated by discounting the project cash flows. Therefore, to understand more accurately these metrics, sensitivity analyses can be performed on the different components of the projected cash flows. The cash flow formula is as follows:

Cash flow = Sales – Variable Costs – Fixed Costs – Taxes – Capital costs – Working Capital

In this section, we analyze the effect of varying the different terms of this equation on the project's profitability.

a. Fixed and Variable Costs

Aside from the small-scale work performed by Karaduman, additional research has yet to be carried out to determine the accuracy of the pyrolysis yields and products. Testing at a proper pilot plant must be performed to properly assess the viability of each assumption presented in this report. It is highly likely that industrial scale data collection from this process will elucidate problems with the current design that warrant increased funding. Although the previous economic analyses only presented the base case, the following figure presents a sensitivity for the impact of increased variable and capital costs on project value.

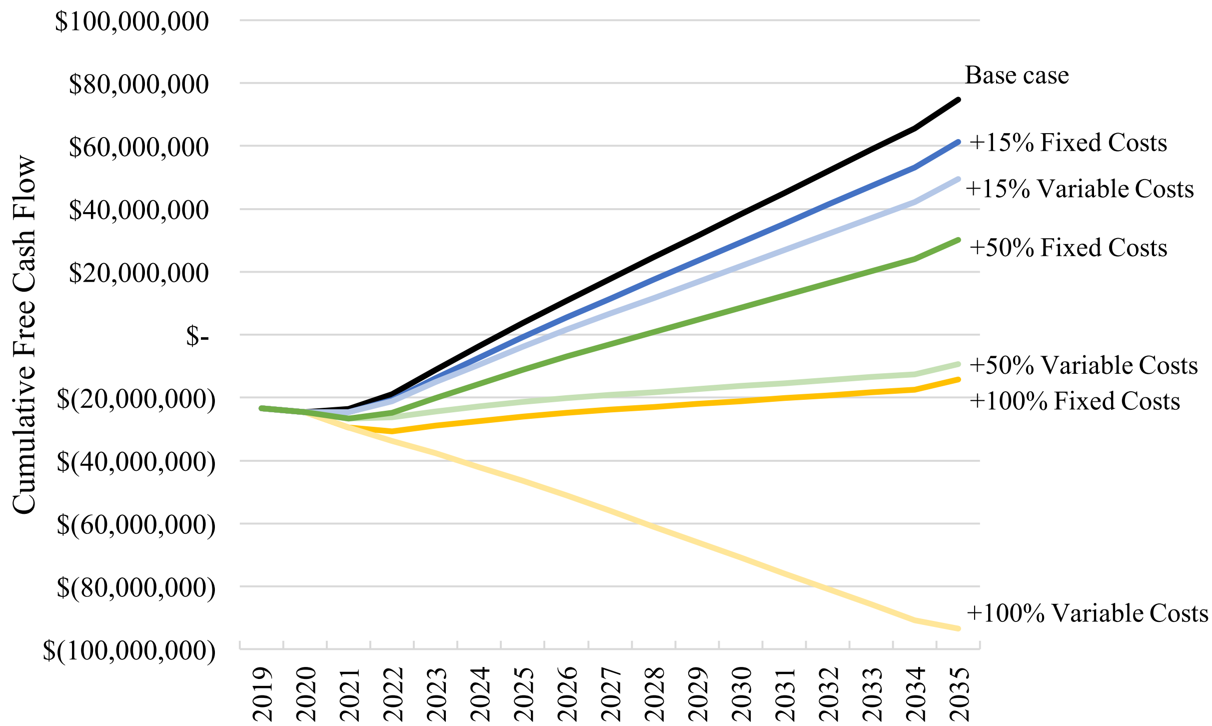


Figure 20.2. Cumulative discounted free cash flow in dollars for the project with sensitivities for 100%, 50% and 15% increases in both fixed and variable costs compared to the base case. The effect of increasing variable costs is twice as important as that of increasing fixed cost for all scenarios.

This graph displays the comparative impact of a 15%, 50% and 100% increase in fixed costs and variable costs on cumulative NPV. It can be observed that for any given increase, the impact on cash flow is twice as large for an increase in fixed costs than for an increase in variable costs. This is consistent with the fact that variable costs account for 67% of total costs while fixed costs only account for 33%, or half of this amount. These percentages are based on yearly values of these costs, which can be found in Table 20.3. Moreover, Table 19.4 details the calculations of fixed costs, while Table 19.1 details the calculations of variable costs.

Given that this venture's cost structure leans more heavily towards variable than fixed, we can say that the project relatively well-insulated from macroeconomic shocks. In the event of a recession, for instance, the plant's profitability will not suffer as much as a plant that has a higher fixed cost structure. Variable costs can be cut down by adjusting production, but fixed costs cannot. Though a subtle benefit, this venture's cost structure may help to improve its risk profile.

Moreover, the graph presented above reveals that project value hinges more on changes in variable costs than on fixed costs. Thus, profitability measures will not be as affected by inaccurate estimations for operations, maintenance, operating overhead and taxes as they will by inaccurate estimations for raw material, byproducts and utilities costs. The graph below displays a breakdown of the variable costs associated with our project.

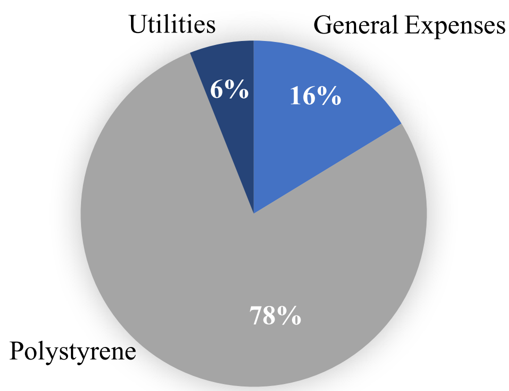


Figure 20.3. Annual variable cost distribution for the process. Polystyrene poses a serious threat to project value because it composes 78% of all project variable costs.

Polystyrene feedstock constitutes 78% of the annual variable cost associated with this process, primarily due to the large design production capacity. Its cost amounts to $19.8 MM per year. This is consistent with the fact that heat and energy integration was optimized for the process, thus reducing the cost of utilities to $1.5 MM per year (see Section 14). To better understand the impact of the cost of polystyrene on the project's profitability, a sensitivity analysis was performed to determine the maximum cost of polystyrene for which this project would still be profitable, given a cost of capital of 15%.

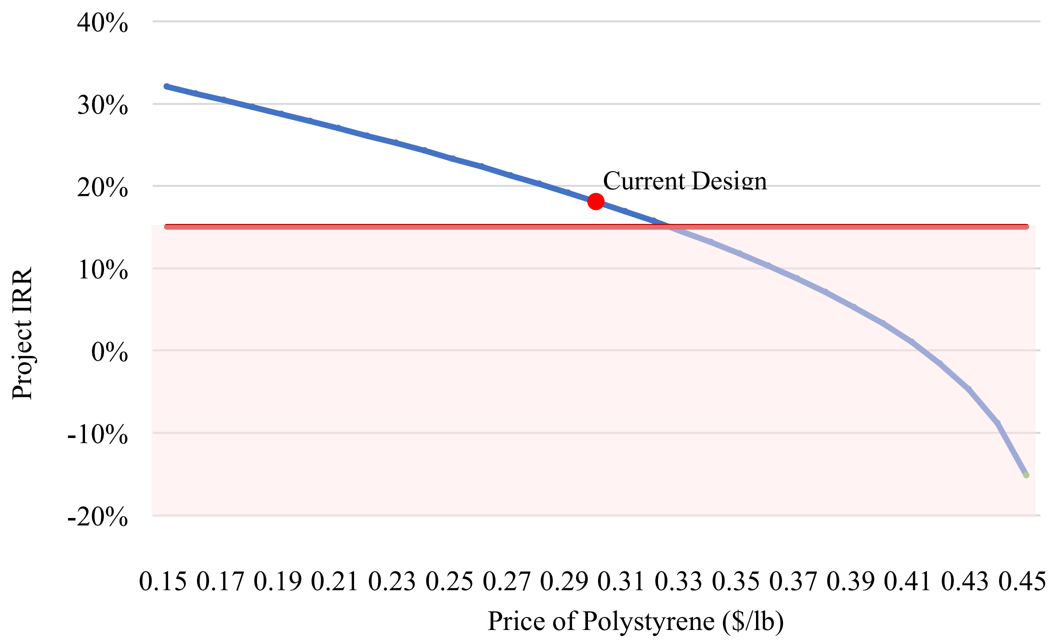


Figure 20.4. Effect of price of polystyrene on IRR of the project. The shaded region represents costs of polystyrene for which the IRR is less than the cost of capital. With the current price of $0.30 per pound of polystyrene, the process yields an 18.54% IRR. However, the process ceases to become profitable for polystyrene costs greater than $0.32 per pound. The project IRR becomes less than the project's cost of capital.

As expected, it is found that the project is highly dependent on the cost of polystyrene. If the cost of polystyrene increases by $0.02 to $0.32 per pound, the project achieves an IRR equal to its cost of capital and breaks-even. This analysis reveals that while our project is profitable when using base-case pricing assumptions, it quickly becomes unprofitable should the cost of polystyrene increase. A 40% increase in the estimated cost of polystyrene to $0.42 per pound yields a negative IRR. Therefore, the profitability metrics presented should be read with caution.

At this stage, it is important to be reminded of earlier assumptions made in the report. As explained in Section 10.1, while polystyrene should be collected for free given that it is disposed of, procurement of polystyrene is difficult at the desired feed rate of 100 tons per day. Therefore, a base cost of $0.30 per pound of polystyrene was estimated to account for the price of cleaning, sorting, aggregating, densifying and shipping the polystyrene. However, these prices are heavily dependent on the availability of polystyrene. If more companies such as Moore Recycling Associates, DART, EPS Alliance, and others emerge, these costs might decrease considerably. In contrast, if the polystyrene aggregation landscape stays as it is now, these prices might stay high or even increase to values above $0.32 per pound, rendering this project unprofitable. In subsequent design steps, a more detailed analysis of the polystyrene market and its players needs to be completed to confirm the financial viability of the proposed project.

b. Sales

A main factor in determining the profitability of the project is the amount of revenues, or sales, generated by the sale of styrene. In this section, we evaluate the impact of varying the selling price of styrene on the attractiveness of this project.

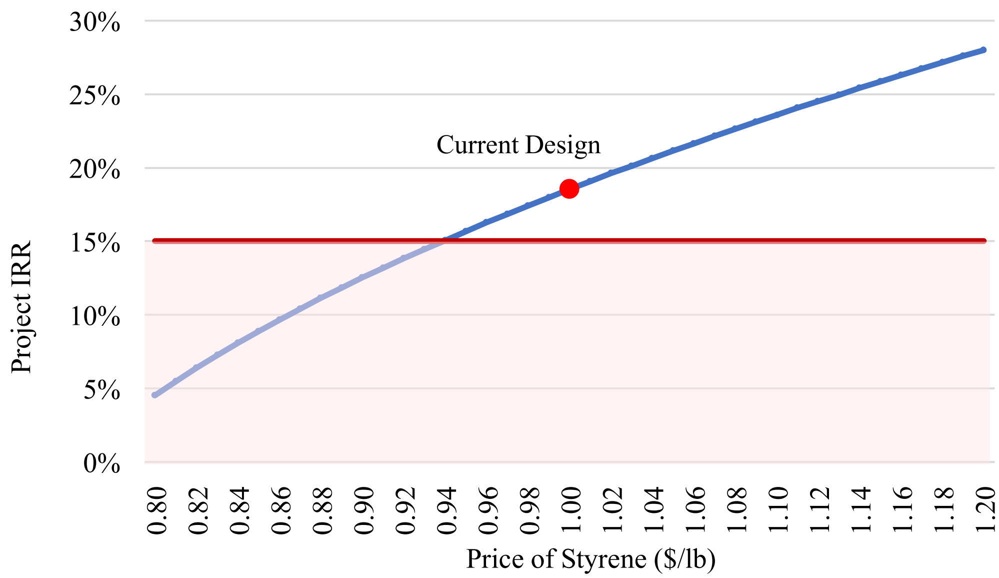


Figure 20.5. Effect of price of styrene on IRR of the project. The shaded region represents prices of styrene for which the IRR is less than the cost of capital. With the current price of $1.00 per pound of polystyrene, the process yields an 18.54% IRR. However, the process ceases to become profitable for styrene prices lower than $0.94 per pound. The project IRR becomes less than the project's cost of capital.

It is found that the project is highly dependent on the selling price of styrene. If the price of styrene decreases by $0.07 to $0.93 per pound, the project achieves an IRR lower than its cost of capital and becomes unprofitable. However, for an equivalent increase of the price of styrene, the project yields an IRR of 22.14%. While styrene prices predictions were challenging to obtain, we observed a high correlation between the price of styrene and the price of crude oil. Thus, by looking at expected oil prices, it is possible to determine the general direction in which styrene prices are expected to grow in the next two decades.

The correlation between styrene prices and oil prices can be traced back to the industrial production process of styrene. Styrene is typically produced from the alkylation of benzene with ethylene to produce ethylbenzene, followed by dehydrogenation of ethylbenzene to styrene. Thus, prices of styrene are highly dependent on prices of benzene, the raw material required for its production process. However, benzene prices are dependent on those of crude oil, since benzene itself is produced by using naphta, derived from crude oil by fractional distillation. As such, we found the correlation between the prices of styrene and crude oil to be extremely, characterized by a factor (R^2) of 0.81[25].

Crude oil prices are expected to steadily rise over the next three decades. By 2025, the average price of a barrel of crude oil is expected to rise to $85.70, up 19% from its price of $71.98 today. By 2030, world demand is expected to further drive oil prices up to $92.82 per barrel, and to $106.08 per barrel by 2040[26]. These dollar amounts are in current dollars to account for inflation. If styrene prices stay correlated to crude oil prices, it is reasonable to expect a steady increase of the price of styrene during the lifetime of the project. Therefore, while polystyrene prices represent the potential for increased production costs, steadily increasing styrene prices mitigate this risk by providing the potential for higher than anticipated revenues.

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[25] Seddon, Duncan. "The Impact of Oil Price on Styrene Price." *Duncan Seddon & Associates*, www.duncanseddon.com/c8-the-impact-of-oil-price-on-styrene-price/.

[26] Amadeo, Kimberly. "How High Will Oil Prices Rise in 2018 and 2050?" *The Balance*, 11 Apr. 2018, www.thebalance.com/oil-price-forecast-3306219.

The previous analyses indicate the effect of varying the cost of polystyrene and the price of styrene individually. However, this analysis ignores the simultaneous effect of varying the prices of styrene and polystyrene. Table 20.4 displays the IRR of the project based on different pricing scenarios.

Table 20.4. IRR as a function of both the price of polystyrene ($ per pound) and the price of styrene ($ per pound). The shaded region represents the price variations for which the IRR becomes less than the cost of capital. The current pricing at $0.30/lb of polystyrene and $1.00/lb of styrene yields an IRR of 19%. Higher returns can be achieved by increasing the selling price of styrene and decreasing the cost of polystyrene.

Styrene Price ($/lb) \ Polystyrene Price ($/lb)	$0.05	$0.10	$0.15	$0.20	$0.25	$0.30	$0.35	$0.40	$0.45	$0.50	$0.55
$0.40	14%	6%	-8%	-	-	-	-	-	-	-	-
$0.60	25%	20%	13%	5%	-10%	-	-	-	-	-	-
$0.80	33%	29%	24%	19%	13%	5%	-12%	-	-	-	-
$1.00	40%	36%	33%	28%	24%	19%	12%	4%	-14%	-	-
$1.20	46%	43%	40%	36%	32%	28%	23%	18%	12%	3%	-17%
$1.40	52%	49%	46%	43%	39%	36%	32%	28%	23%	18%	11%
$1.60	57%	54%	52%	49%	46%	42%	39%	35%	31%	27%	22%
$1.80	62%	59%	57%	54%	51%	48%	45%	42%	39%	35%	31%
$2.00	66%	64%	62%	59%	56%	54%	51%	48%	45%	42%	38%

This table confirms that as the cost of polystyrene increases, the price of styrene needs to increase as well to maintain an IRR above 15%. The current pricing scenario yields a 19% IRR for our project. However, as per the analysis above, the most likely future outcome of prices is situated in the lower right corner of the table: polystyrene costs are expected to be high due to the limited feedstock availability, and styrene prices are expected to increase as well due to the increase in crude oil prices. The table then indicates the possible combinations of polystyrene and styrene prices for which the project is still profitable. For instance, if the cost of polystyrene increases to $0.40 per pound, the price of styrene needs to increase to at least $1.20 per pound to maintain an IRR greater than 15%. In subsequent analysis, predictions for prices of polystyrene and styrene should be made over the life of the project and compared to this table to determine the financial sustainability of this design.

c. Capital costs

Another important challenge during the design of this process was determining equipment costs for our process. While correlations were available for most equipment units, they were not applicable to other units and estimations were made. In this section, we analyze the sensitivity of the project to the total permanent investment.

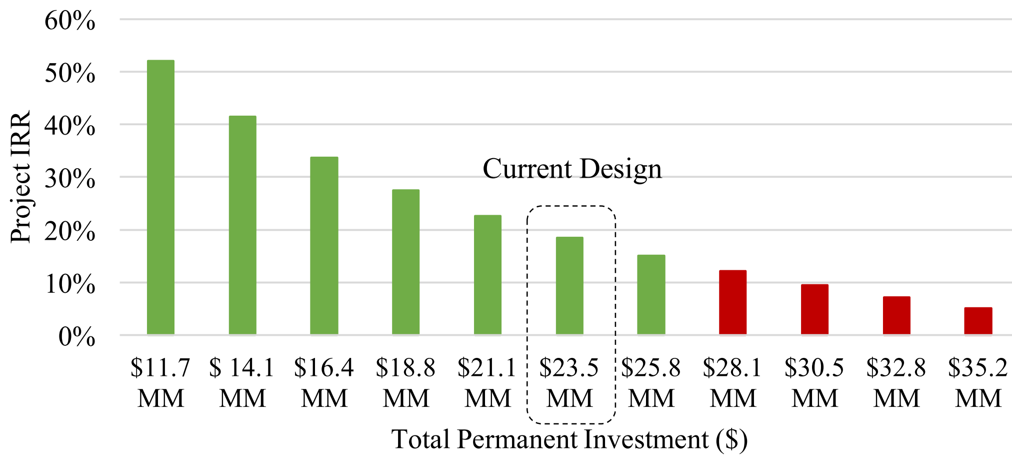

Figure 20.5. Project IRR as a function of the total permanent investment for the project in dollars. The TPI is varied in each direction in increments of 10%. The project is still profitable if the TPI increase by 10% ($25.8 MM). However, it becomes unprofitable if it increases by 20% ($28.1 MM).

Figure 20.5 presents the project IRR for different values of the TPI. The TPI is varied in each direction in increments of 10%. The project displays a high sensitivity to the TPI. If the TPI increases by 20% to $28.1 MM, the project IRR becomes lower than the cost of capital for the project. The TPI, as explained in Section 18, is based on the bare-module costs. Other factors included in its calculations are expressed as a percentage of the bare-module cost. Detailed calculations can be found in Table 18.3.

These results indicate that the project is highly dependent on the accuracy of our equipment cost. As shown in Figure 17.1, the cost of the rotary kiln reactor accounts for most of our equipment cost. It represents 45% of our total bare-module cost. In addition, as discussed in Section 15.1, determining its size constituted a major challenge given the complexity of this reactor and the limited information available about it. Therefore, a sensitivity analysis was performed to evaluate the impact of varying kiln prices on our project IRR.

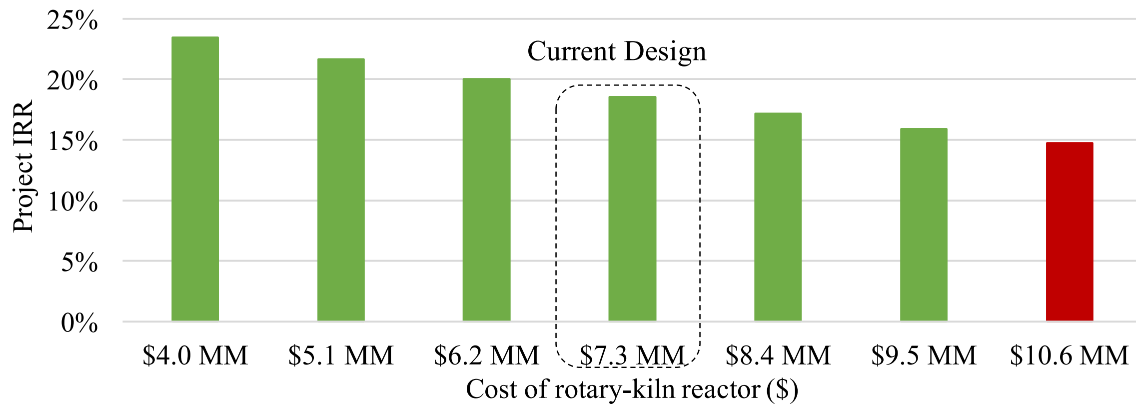

Figure 20.6. Project IRR as a function of the cost of the rotary-kiln reactor (R-101). The reactor costs are varied at increments of 15% on each side. The project is profitable for an increase in the price of the kiln up to 30%. However, for an increase of 45% in the price of the reactor, the project becomes unprofitable.

Figure 20.6 presents the project IRR for different values of the rotary-kiln reactor. The Cost of the kiln is varied in each direction in increments of 15%. The project displays a relatively high sensitivity to the cost of the kiln. If the cost of the reactor increases by 45% to $10.6 MM, the project IRR becomes lower than the cost of capital for the project, and the project becomes unprofitable. Limited data was available for our team to calculate and size the pyrolyzer with more accuracy. However, subsequent design studies should focus on determining the characteristics of the reactor more accurately to ensure the economic sustainability of the process.

Therefore, while our profitability measures seem positive based on the suggested design, further studies are needed to ensure the financial viability of the process. These studies should focus on determining the cost of polystyrene feedstock, predicting the selling price of styrene, and accurately sizing and costing the rotary-kiln pyrolyzer.

Section 21. Other Important Considerations

i. *Safety and Health Considerations*

Because of the flammability of the liquid fuel gases produced, it is important that the storage tanks are not exposed to air. A continuous flow of nitrogen is included in all tanks to maintain safe oxygen concentrations within the tank headspace. The tanks are also designed to accommodate high temperatures, which if not considered could have an impact on the on the safety of the humans, animals and environment of the surrounding area. The safety considerations for the storage of each of the products is available in Section 14 and in the MSDS in Appendix C.

ii. *Environmental Impact*

As stated in Section 2.1, most waste plastics like polystyrene end up in landfills or are incinerated. Chemically recycling the polymer will reduce the amount of non-biodegradable plastics in landfills and littered in the ocean. As for the incineration of plastics, there are high efficiency and electricity to heat ratios associated, suggesting there are benefits to such a process[27]. The production of fuel from recycling was also shown to have a 14% reduction in greenhouse gas emissions, 58% lower water consumption and 96% lower fossil fuel consumption when comparing diesel from non-recycled plastic to that from petroleum[28]. The environmental impact of recycling polystyrene is an important consideration in the overall benefits in proposing such a process.

[27] "Life-Cycle Analysis of Fuels from Post-Use Non-Recycled Plastics." *Fuel*, Elsevier, 27 Apr. 2017, www.sciencedirect.com/science/article/pii/S0016236117304775.
[28] "Life-Cycle Analysis of Fuels from Post-Use Non-Recycled Plastics."

iii. Startup

The facility will ideally be located in Texas, near a styrene monomer plant. This would allow us to benefit from the existing distribution system to sell the liquid products to potential customers. In addition, the plant will need to be near a railway system for the transportation of the feedstock by the large railcars. It is assumed that a nearby boiler house will purchase the excess fuel gas. The procurement of polystyrene for the feedstock is part of the profitability analysis and considered for the plant startup costs. Startup costs and cost analysis can be found in Section 22 and Section 24 respectively.

Section 22. Conclusions and Recommendations

Thorough analysis of the proposed design indicates that pyrolysis of waste polystyrene to produce styrene and other valuable products warrants further investigation. In accordance with the project objective, 100 tons per day of polystyrene are processed to produce styrene at a polymer grade purity greater than 99.9%. Ethylbenzene, methylstyrene and styrene are also produced at purity levels greater than 99%. The gaseous products that result from the pyrolysis are optimally integrated to provide fuel for reactor heating.

Economic analysis estimates an NPV of $5.1 MM with an IRR of 18.5%. The financial viability of the proposed design was found to depend heavily on market prices of styrene and polystyrene. Sensitivity analyses revealed that a minimum requirement for profitability of this project under the current design is a cost polystyrene equal or less than $0.32 per pound. Prior to further development of the process, additional studies should be undertaken to confirm the results presented in this project. One should estimate the selling prices of styrene and other liquid products, and determine the cost of collecting polystyrene feedstock given the existing challenges. One should also confirm the accuracy of design calculations, or revisit the assumptions made. Specifically, the characteristics of the rotary kiln reactor significantly affects the profitability of the project. Thus, accurate estimates for its cost and size should be obtained and the project re-evaluated.

Section 23. Acknowledgments

Our team would like to thank Dr. Lee and Prof. Vrana for their guidance during this design project. We would also like to thank Dr. Targett for his considerable professional knowledge and his willingness to provide us with the necessary resources to fully understand the proposed problem statement. Finally, we would like to especially thank Prof. Fabiano for his guidance with regards to ASPEN and to the overall process design. His constant support and expertise allowed us to successfully design the project, despite numerous setbacks with ASPEN. Thank you to all the professors and consultants who helped us complete this project.

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Section 25. Appendix

A. Calculations

a) Bucket Elevators

Sizing

The height of the bucket elevators was determined by adding five feet to the height of the equipment and the elevator reaches. For instance, for the first bucket elevator transporting the polystyrene from the railroad cars to the silos, the height was found to be equal to be 55 feet based on the silo height, estimated at 50 feet.

Costing

$$C_P = 692W^{0.5}L^{0.57}$$
$$C_P = 692(35\ in)^{0.5}(55\ ft)^{0.57}$$
$$C_P = \$164{,}612$$

b) Silos

Sizing

$$V = 10^2\ ft \times \pi \times 30\ ft = 11523\ ft3$$
$$V = \frac{8333\frac{lb}{hr}}{18.72\frac{lb}{ft3}} = 10700\frac{ft}{day}$$
$$V = S = 11000\ ft3$$

Costing

$$C_P = 646S^{0.46}$$
$$C_P = 646(11000\ ft3)^{0.46}$$
$$C_P = \$46{,}695$$

c) Screw Feeders

Sizing

The sizing of screw feeders is based on volumetric flow of char from pyrolyzer.

$$V = S = 500\ ft3/hr$$

Costing

(Assumed x1.5 for electric costs)

$$C_P = 1.094 \times 1.5 \times S^{0.22}$$
$$C_P = 1.094 \times 1.5 \times (300\frac{ft3}{hr})^{0.22}$$
$$C_P = \$4{,}293$$

d) Kiln

Sizing

$$100\,TPD = 14.21\frac{m3}{hr}$$
$$14.21\frac{m3}{hr} \times 1\,hr\ residence\ time = V = 14.21\,m3$$
Assuming internal volume 40% occupied by PS
$$aspect\ ratio = \frac{L}{D} = 10$$
$$V = 20r^3 \times \pi$$
$$r = 0.8268\,m = 32.55\,in$$
add 4 inches of external shell thickness for total radius
$$D = 6\,ft$$
$$Surface\ Area = 47.16\,m^2 = 508\,ft^2$$

Costing

$$C_P = F_M C_V + C_{PL}$$
$$F_M = 1.7$$
$$C_P = 1.7 \times 45993 + 3311$$
$$C_P = \$81{,}499$$

$$C_v = \exp\left[5.6336 + 0.4599\ln(W) + 0.00582(\ln(W))^2\right]$$
$$C_v = \exp\left[5.6336 + 0.4599\ln(19223\,lb) + 0.00582(\ln(19223\,lb))^2\right]$$
$$C_v = \$45{,}993$$

$$C_{PL} = 2275D^{0.2094}$$
$$C_{PL} = 2275(6\,ft)^{0.2094}$$
$$C_{PL} = \$3{,}311$$

e) Blower

Sizing

$$P_B = 0.00436\left(\frac{k}{k-1}\right) \times \frac{Q_1 P_1}{\eta_B}\left[\left(\frac{P_0}{P_1}\right)^{\frac{k-1}{k}} - 1\right]$$

$$P_B = 0.00436\left(\frac{1.4}{1.4-1}\right)\times\frac{(1695\ ft3/min\ )(20\frac{lbf}{in2})}{0.75}[\left(\frac{45\ lbf/in2}{20\ lbf/in2}\right)^{\frac{1.4-1}{1.4}} - 1]$$
$$P_B = 179.88\ hp$$

$$P_C = \frac{P_B}{\eta_m}$$
$$P_C = \frac{179.88\ hp}{0.9166} = 196.3\ hp$$

$$\eta_m = 0.80 + 0.0319\ln(P_B) - 0.00182(\ln(P_B))^2$$
$$\eta_m = 0.80 + 0.0319\ln(179.88\ hp) - 0.00182(\ln(179.88\ hp))^2$$
$$\eta_m = 0.9166$$

Costing

$$C_P = F_M C_B$$

$F_M = 2.5$ for stainless steel

$$C_P = 2.5\times72363$$
$$C_P = \$180{,}907$$

$$C_B = \exp[7.0187 + 0.7900\ln(P_C)]$$
$$C_B = \exp[7.0187 + 0.7900\ln(196.3\ hp)]$$
$$C_B = \$72{,}363$$

f) Heat Exchangers

Sizing

The surface area for heat exchangers is found by using the equation Q = U A ΔT. The details of that calculation are explained in the text (see Section 15.3)

Costing

$$C_P = F_P F_M F_L C_B$$
$$C_P = 0.99455092\times1\times1.12\times10507$$
$$C_P = \$11{,}703$$

$$C_B = \exp[11.4185 - 0.9228\ln(A) + 0.09861(\ln(A))^2]$$
$$C_B = \exp[11.4185 - 0.9228\ln(103.2\ ft2) + 0.09861(\ln(103.2\ ft2))^2]$$
$$C_B = \$10{,}507$$

$$F_M = a + \left(\frac{A}{100}\right)^b$$

$F_M = 1$ for carbon steel/carbon steel

$F_L = 1.12$ for 12 ft tube

$$F_P = 0.9803 + \frac{0.018P}{100} + 0.0017\left(\frac{P}{100}\right)^2$$
$$F_P = 0.9803 + \frac{0.018(74\ hp)}{100} + 0.0017\left(\frac{74\ hp}{100}\right)^2$$
$$F_P = 0.99455092$$

g) Pumps

Sizing

$$S = Q(H)^{0.5}$$
$$S = (0.885\frac{gal}{\min})(104.17)^{0.5}$$

$$H = \frac{\Delta P}{\rho_l}$$

$$H\ value\ for\ most\ pumps\ assumed\ based\ on\ consultant\ suggestion$$

Costing

$$C_P = F_T F_M C_B$$

$F_M = 2$ for stainless steel

$$F_T = 1$$
$$C_P = 1\times2\times23479$$
$$C_P = \$46{,}957$$

$C_B = \exp\left[12.1656 - 1.144\ln(S) + 0.0862(\ln(S))^2\right]$
$C_B = \exp\left[12.1656 - 1.144\ln(9\ gpm * ft\text{^}.5) + 0.0862(\ln(9\ gpm * ft\text{^}.5))^2\right]$

$$C_B = \$23{,}479$$

h) Electric Motors

Sizing

$$P_C = \frac{P_B}{\eta_m} = \frac{QH\rho}{33000\eta_P\eta_m}$$
$$P_C = \frac{\left(15.5\frac{gal}{\min}\right)(74.36\ ft)\left(7.25\frac{lb}{gal}\right)}{33000(0.25)(0.80)}$$
$$P_C = 1.26\ hp$$

$$\eta_m = 0.80 + 0.0319\ln(P_B) - 0.00182(\ln(P_B))^2$$
$$\eta_m = 0.80 + 0.0319\ln(1.00\ hp) - 0.00182(\ln(1.00\ hp))^2$$
$$\eta_m = 0.80$$

$$\eta_P = -0.316 + 0.24015\ln(Q) - 0.01199(\ln(Q))^2$$
$$\eta_P = -0.316 + 0.24015\ln(15.5\ gal/min) - 0.01199(\ln(15.5\ gal/min))^2$$
$$\eta_P = 0.25$$

Costing

$$C_P = F_T C_B$$
$$F_T = 1$$
$$C_P = \$390$$

$$C_B = \exp[5.9332 + 0.16829\ln(P_c) + 0.110056(\ln(P_c))^2 + 0.071413(\ln(P_c))^3 - 0.0063788(\ln(P_c))^4]$$
$$C_B = \exp[5.9332 + 0.16829\ln(1.26\ hp) + 0.110056(\ln(1.26\ hp))^2 + 0.071413(\ln(1.26\ hp))^3 - 0.0063788(\ln(1.26\ hp))^4]$$
$$C_B = \exp[5.9332 + 0.16829\ln(P_c) + 0.110056(\ln(P_c))^2 + 0.071413(\ln(P_c))^3 - 0.0063788(\ln(P_c))^4]$$
$$C_B = \$390$$

i) Storage Tanks

Sizing

Explained in text (see Section 15.5).

Costing

$$C_P = 263V^{0.513}$$
$$C_P = 263(15914)^{0.513}$$
$$C_P = \$37{,}911$$

$$V = v * 7\ days * 24\frac{hours}{day}$$
$$V = 94.73\frac{gal}{hour} * 7\ days * 24\frac{hours}{day}$$

j) Distillation Columns

Costing

$$C_P = F_M C_V + C_{PL}$$
$$F_M = 1$$
$$C_P = 22355 + 5947$$
$$C_P = \$28{,}302$$

$$C_V = \exp\{10.5449 - 0.4672[\ln(W)] + 0.05482\,[\ln(W)]^2\}$$
$$C_V = \exp\{10.5449 - 0.4672[\ln(1306\ lb)] + 0.05482\,[\ln(1306\ lb)]^2\}$$
$$C_V = \$22{,}355$$

$$C_{PL} = 341\,(D)^{0.63316}\,(L)^{0.80161}$$
$$C_{PL} = 341\,(1.47\ ft)^{0.63316}\,(26\ ft)^{0.80161}$$
$$C_{PL} = \$5{,}947$$

$$W = \pi(D_i + t_s)(L + 0.8D_i)t_s\rho$$
$$W = \pi(1.48\ ft + 0.22\ in)(26\ ft + 0.8\text{x}1.48\ ft)(0.22\ \text{in})(490\ \text{lb/ft3})$$
$$W=1306$$

$$P_d = \exp\{0.60608 + 0.91615[\ln(P_o)] + 0.0015655[\ln(P)]^2\}$$
$$P_d = \exp\{0.60608 + 0.91615[\ln(5.477\ psig)] + 0.0015655[\ln(5.477\ psig)]^2\}$$

$$C_T = N_T F_{NT} F_{TT} F_{TM} C_{BT}$$
$$F_{NT} = 1.28$$
$$F_{TT} = 1.18$$
$$F_{NT} = 1$$
$$N_T = 14$$
$$C_T = \$12{,}271$$

$$C_{BT} = 468\ \exp(0.1482\ D_i)$$
$$C_{BT} = 468\ \exp(0.1482\ \text{x}\ 1.48\ ft)$$
$$C_{BT} = \$583$$

$$C_{tot} = C_T + C_P$$

B. Tables and Figures

C. MSDS Sheets

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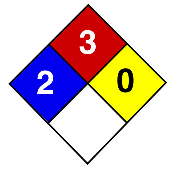

Health	2
Fire	3
Reactivity	0
Personal Protection	H

Material Safety Data Sheet
Ethylbenzene MSDS

Section 1: Chemical Product and Company Identification

Product Name: Ethylbenzene

Catalog Codes: SLE2044

CAS#: 100-41-4

RTECS: DA0700000

TSCA: TSCA 8(b) inventory: Ethylbenzene

CI#: Not available.

Synonym: Ethyl Benzene; Ethylbenzol; Phenylethane

Chemical Name: Ethylbenzene

Chemical Formula: C8H10

Contact Information:

Sciencelab.com, Inc.
14025 Smith Rd.
Houston, Texas 77396

US Sales: **1-800-901-7247**
International Sales: **1-281-441-4400**

Order Online: ScienceLab.com

CHEMTREC (24HR Emergency Telephone), call:
1-800-424-9300

International CHEMTREC, call: 1-703-527-3887

For non-emergency assistance, call: 1-281-441-4400

Section 2: Composition and Information on Ingredients

Composition:

Name	CAS #	% by Weight
Ethylbenzene	100-41-4	100

Toxicological Data on Ingredients: Ethylbenzene: ORAL (LD50): Acute: 3500 mg/kg [Rat].

Section 3: Hazards Identification

Potential Acute Health Effects:
Hazardous in case of eye contact (irritant), of ingestion, of inhalation. Slightly hazardous in case of skin contact (irritant, permeator).

Potential Chronic Health Effects:
Slightly hazardous in case of skin contact (irritant, sensitizer). CARCINOGENIC EFFECTS: Classified 2B (Possible for human.) by IARC. MUTAGENIC EFFECTS: Mutagenic for mammalian somatic cells. Mutagenic for bacteria and/or yeast. TERATOGENIC EFFECTS: Not available. DEVELOPMENTAL TOXICITY: Not available. The substance may be toxic to central nervous system (CNS). Repeated or prolonged exposure to the substance can produce target organs damage.

Section 4: First Aid Measures

Eye Contact:

p. 1

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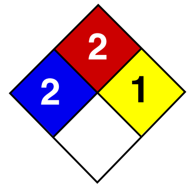

Health	2
Fire	2
Reactivity	1
Personal Protection	H

Material Safety Data Sheet
alpha-Methylstyrene MSDS

Section 1: Chemical Product and Company Identification

Product Name: alpha-Methylstyrene

Catalog Codes: SLM2257

CAS#: 98-83-9

RTECS: WL5075300

TSCA: TSCA 8(b) inventory: alpha-Methylstyrene

CI#: Not available.

Synonym:

Chemical Formula: C9H10

Contact Information:

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14025 Smith Rd.
Houston, Texas 77396

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1-800-424-9300

International CHEMTREC, call: 1-703-527-3887

For non-emergency assistance, call: 1-281-441-4400

Section 2: Composition and Information on Ingredients

Composition:

Name	CAS #	% by Weight
{alpha-}Methylstyrene	98-83-9	100

Toxicological Data on Ingredients: alpha-Methylstyrene: ORAL (LD50): Acute: 4500 mg/kg [Mouse]. 4900 mg/kg [Rat].

Section 3: Hazards Identification

Potential Acute Health Effects:
Very hazardous in case of eye contact (irritant), of inhalation (lung irritant). Hazardous in case of skin contact (irritant), of ingestion, . Inflammation of the eye is characterized by redness, watering, and itching.

Potential Chronic Health Effects:
CARCINOGENIC EFFECTS: Not available. MUTAGENIC EFFECTS: Not available. TERATOGENIC EFFECTS: Not available. DEVELOPMENTAL TOXICITY: Not available. Repeated or prolonged exposure is not known to aggravate medical condition.

Section 4: First Aid Measures

Eye Contact:
Check for and remove any contact lenses. Immediately flush eyes with running water for at least 15 minutes, keeping eyelids open. Cold water may be used. Do not use an eye ointment. Seek medical attention.

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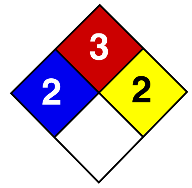

Health	2
Fire	3
Reactivity	0
Personal Protection	H

Material Safety Data Sheet
Styrene (monomer) MSDS

Section 1: Chemical Product and Company Identification

Product Name: Styrene (monomer)

Catalog Codes: SLS2512, SLU1027

CAS#: 100-42-5

RTECS: WL3675000

TSCA: TSCA 8(b) inventory: Styrene (monomer)

CI#: Not available.

Synonym: Vinylbenzene

Chemical Formula: C8H8

Contact Information:

Sciencelab.com, Inc.
14025 Smith Rd.
Houston, Texas 77396

US Sales: **1-800-901-7247**
International Sales: **1-281-441-4400**

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1-800-424-9300

International CHEMTREC, call: 1-703-527-3887

For non-emergency assistance, call: 1-281-441-4400

Section 2: Composition and Information on Ingredients

Composition:

Name	CAS #	% by Weight
Styrene (monomer)	100-42-5	100

Toxicological Data on Ingredients: Styrene (monomer): ORAL (LD50): Acute: 2650 mg/kg [Rat]. 316 mg/kg [Mouse]. VAPOR (LC50): Acute: 12000 ppm 4 hour(s) [Rat]. 9500 ppm 4 hour(s) [Mouse].

Section 3: Hazards Identification

Potential Acute Health Effects:
Very hazardous in case of eye contact (irritant). Hazardous in case of skin contact (irritant, permeator), of ingestion, of inhalation. Inflammation of the eye is characterized by redness, watering, and itching.

Potential Chronic Health Effects:
CARCINOGENIC EFFECTS: Classified + (PROVEN) by OSHA. Classified 2B (Possible for human.) by IARC. A4 (Not classifiable for human or animal.) by ACGIH. MUTAGENIC EFFECTS: Not available. TERATOGENIC EFFECTS: Not available. DEVELOPMENTAL TOXICITY: Not available. The substance is toxic to the nervous system, upper respiratory tract. Repeated or prolonged exposure to the substance can produce target organs damage.

Section 4: First Aid Measures

Eye Contact:

Safety Data Sheet

Expanded Polystyrene

Section 1 - CHEMICAL PRODUCT/COMPANY IDENTIFICATION

Material Identification

CAS Number: 9003-53-6
CAS Name: Polystyrene
Product Use: Foamed polystyrene. Packaging, thermal insulation.
Synonyms: EPS, Expanded Polystyrene, R-pad, R-pac

Company Identification

MANUFACTURER
Styrene Products, Inc.
5320 Fuller Street
Schofield, WI 54476
www.styreneproducts.com

PHONE NUMBER
(715) 359-6600

Section 2 - HAZARDS IDENTIFICATION

Hazard Classification	None.
Label Elements	None.
Signal Word	None.
Hazard Statement(s)	None.
Other Hazards	Low toxicity under normal conditions of handling and use.

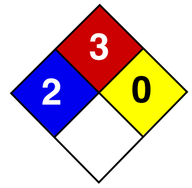
Section 3 - COMPOSITION/INFORMATION ON INGREDIENTS

Components

Material	CAS Number	Percent
Polystyrene	9003-53-6	95 – 100
Pentane* (n-pentane, isopentane, cyclopentane)	109-66-0 78-78-7/287-92-3	<2.0

Ingredients not precisely identified are proprietary or nonhazardous.

*Flammable blowing agent that off-gases from product. Most of the pentane off-gases prior to shipment.



Health	2
Fire	3
Reactivity	0
Personal Protection	H

Material Safety Data Sheet
Toluene MSDS

Section 1: Chemical Product and Company Identification

Product Name: Toluene

Catalog Codes: SLT2857, SLT3277

CAS#: 108-88-3

RTECS: XS5250000

TSCA: TSCA 8(b) inventory: Toluene

CI#: Not available.

Synonym: Toluol, Tolu-Sol; Methylbenzene; Methacide; Phenylmethane; Methylbenzol

Chemical Name: Toluene

Chemical Formula: C6-H5-CH3 or C7-H8

Contact Information:

Sciencelab.com, Inc.
14025 Smith Rd.
Houston, Texas 77396

US Sales: **1-800-901-7247**
International Sales: **1-281-441-4400**

Order Online: ScienceLab.com

CHEMTREC (24HR Emergency Telephone), call:
1-800-424-9300

International CHEMTREC, call: 1-703-527-3887

For non-emergency assistance, call: 1-281-441-4400

Section 2: Composition and Information on Ingredients

Composition:

Name	CAS #	% by Weight
Toluene	108-88-3	100

Toxicological Data on Ingredients: Toluene: ORAL (LD50): Acute: 636 mg/kg [Rat]. DERMAL (LD50): Acute: 14100 mg/kg [Rabbit]. VAPOR (LC50): Acute: 49000 mg/m 4 hours [Rat]. 440 ppm 24 hours [Mouse].

Section 3: Hazards Identification

Potential Acute Health Effects:
Hazardous in case of skin contact (irritant), of eye contact (irritant), of ingestion, of inhalation. Slightly hazardous in case of skin contact (permeator).

Potential Chronic Health Effects:
CARCINOGENIC EFFECTS: A4 (Not classifiable for human or animal.) by ACGIH, 3 (Not classifiable for human.) by IARC. MUTAGENIC EFFECTS: Not available. TERATOGENIC EFFECTS: Not available. DEVELOPMENTAL TOXICITY: Not available. The substance may be toxic to blood, kidneys, the nervous system, liver, brain, central nervous system (CNS). Repeated or prolonged exposure to the substance can produce target organs damage.

Section 4: First Aid Measures

D. Aspen Report

a) Block Report

```
BLOCK:  B1      MODEL: COMPR
-----------------------------
 INLET STREAM:         S1
 OUTLET STREAM:        CYCLVAP
 PROPERTY OPTION SET:   PENG-ROB  STANDARD PR EQUATION OF STATE

              ***  MASS AND ENERGY BALANCE  ***
                        IN            OUT       RELATIVE DIFF.
  TOTAL BALANCE
    MOLE(LBMOL/HR)          156.724        156.724        0.00000
    MASS(LB/HR   )        7876.31        7876.31        0.00000
    ENTHALPY(BTU/HR  )      0.523804E+07    0.560648E+07   -0.657162E-01

              ***  CO2 EQUIVALENT SUMMARY ***
  FEED STREAMS CO2E            3166.86      LB/HR
  PRODUCT STREAMS CO2E         3166.86      LB/HR
  NET STREAMS CO2E PRODUCTION   0.00000      LB/HR
  UTILITIES CO2E PRODUCTION     0.00000      LB/HR
  TOTAL CO2E PRODUCTION         0.00000      LB/HR

                ***  INPUT DATA  ***

 ISENTROPIC CENTRIFUGAL COMPRESSOR
  OUTLET PRESSURE  PSIA                       45.0000
  ISENTROPIC EFFICIENCY                       0.85000
  MECHANICAL EFFICIENCY                          1.00000

                ***  RESULTS  ***

  INDICATED  HORSEPOWER REQUIREMENT  HP               144.801
  BRAKE      HORSEPOWER REQUIREMENT  HP             144.801
  NET WORK REQUIRED                HP              144.801
  POWER LOSSES                  HP                0.0
  ISENTROPIC HORSEPOWER REQUIREMENT  HP               123.081
  CALCULATED OUTLET TEMP  F                        827.233
  ISENTROPIC TEMPERATURE  F                        816.209
  EFFICIENCY (POLYTR/ISENTR) USED                       0.85000
  OUTLET VAPOR FRACTION                            1.00000
  HEAD DEVELOPED,       FT-LBF/LB                 30,940.9
  MECHANICAL EFFICIENCY USED                           1.00000
  INLET HEAT CAPACITY RATIO                         1.06939
  INLET VOLUMETRIC FLOW RATE , CUFT/HR             101,723.
```

```
  OUTLET VOLUMETRIC FLOW RATE, CUFT/HR           47,965.6
  INLET  COMPRESSIBILITY FACTOR                    0.99833
  OUTLET COMPRESSIBILITY FACTOR                    0.99725
  AV. ISENT. VOL. EXPONENT                       1.06630
  AV. ISENT. TEMP EXPONENT                       1.06801
  AV. ACTUAL VOL. EXPONENT                       1.07869
  AV. ACTUAL TEMP EXPONENT                       1.08024

BLOCK:  B2      MODEL: FSPLIT
------------------------------
 INLET STREAM:        MIX
 OUTLET STREAMS:      HEAT      SELL
 PROPERTY OPTION SET:   PENG-ROB  STANDARD PR EQUATION OF STATE

             ***  MASS AND ENERGY BALANCE  ***
                       IN           OUT       RELATIVE DIFF.
  TOTAL BALANCE
    MOLE(LBMOL/HR)         92.9861        92.9861        0.00000
    MASS(LB/HR   )        1243.81        1243.81       -0.182804E-15
    ENTHALPY(BTU/HR  )     -588622.       -588622.        0.00000

             ***  CO2 EQUIVALENT SUMMARY ***
  FEED STREAMS CO2E           3166.86      LB/HR
  PRODUCT STREAMS CO2E        3166.86      LB/HR
  NET STREAMS CO2E PRODUCTION   0.00000      LB/HR
  UTILITIES CO2E PRODUCTION    0.00000      LB/HR
  TOTAL CO2E PRODUCTION        0.00000      LB/HR

               ***  INPUT DATA  ***

 FRACTION OF FLOW            STRM=HEAT    FRAC=       0.50800

                ***  RESULTS  ***

 STREAM= HEAT         SPLIT=       0.50800    KEY=  0    STREAM-ORDER=   1
      SELL                   0.49200        0              2

BLOCK:  B3      MODEL: HEATER
------------------------------
 INLET STREAM:        FUEL
 OUTLET STREAM:       WASTE1
 PROPERTY OPTION SET:   PENG-ROB  STANDARD PR EQUATION OF STATE

             ***  MASS AND ENERGY BALANCE  ***
                       IN           OUT       RELATIVE DIFF.
  TOTAL BALANCE
```

```
    MOLE(LBMOL/HR)          1139.61        1139.61        0.00000
    MASS(LB/HR   )        32367.3        32367.3        0.00000
    ENTHALPY(BTU/HR  )      -302872.      -0.910287E+07    0.966728

             ***  CO2 EQUIVALENT SUMMARY ***
  FEED STREAMS CO2E            1730.05      LB/HR
  PRODUCT STREAMS CO2E          1730.05      LB/HR
  NET STREAMS CO2E PRODUCTION   0.00000      LB/HR
  UTILITIES CO2E PRODUCTION     0.00000      LB/HR
  TOTAL CO2E PRODUCTION         0.00000      LB/HR

               ***  INPUT DATA  ***
 TWO    PHASE  PQ  FLASH
 PRESSURE DROP                    PSI                  0.0
 SPECIFIED HEAT DUTY              BTU/HR          -8,800,000.
 MAXIMUM NO. ITERATIONS                                 30
 CONVERGENCE TOLERANCE                                 0.000100000



               ***  RESULTS  ***
 OUTLET TEMPERATURE    F                           768.70
 OUTLET PRESSURE       PSIA                       14.696
 OUTLET VAPOR FRACTION                              1.0000



 V-L PHASE EQUILIBRIUM :

   COMP          F(I)         X(I)          Y(I)         K(I)
   WATER          0.69514E-01     1.0000       0.69514E-01     464.28
   O2           0.13345       0.48385E-06    0.13345        644.12
   CO2           0.34495E-01    0.81113E-06    0.34495E-01    625.40
   N2           0.76254       0.16287E-06    0.76254        698.70

BLOCK:  B7      MODEL: MIXER
-----------------------------
 INLET STREAMS:         LIQVAP     NONCOND
 OUTLET STREAM:          MIX
 PROPERTY OPTION SET:   PENG-ROB  STANDARD PR EQUATION OF STATE

             ***  MASS AND ENERGY BALANCE  ***
                        IN            OUT        RELATIVE DIFF.
  TOTAL BALANCE
    MOLE(LBMOL/HR)          92.9861        92.9861        0.00000
    MASS(LB/HR   )        1243.81        1243.81        0.182804E-15
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   ENTHALPY(BTU/HR  )      -588622.       -588622.      -0.197776E-15

               ***  CO2 EQUIVALENT SUMMARY ***
  FEED STREAMS CO2E           3166.86     LB/HR
  PRODUCT STREAMS CO2E        3166.86     LB/HR
  NET STREAMS CO2E PRODUCTION   0.00000     LB/HR
  UTILITIES CO2E PRODUCTION     0.00000     LB/HR
  TOTAL CO2E PRODUCTION         0.00000     LB/HR

                 ***  INPUT DATA  ***
 TWO    PHASE     FLASH
 MAXIMUM NO. ITERATIONS                              30
 CONVERGENCE TOLERANCE                                0.000100000
 OUTLET PRESSURE:  MINIMUM OF INLET STREAM PRESSURES

BLOCK:  COOL     MODEL: HEATER
------------------------------
 INLET STREAM:          FDHOT
 OUTLET STREAM:         COOLEDFD
 PROPERTY OPTION SET:   PENG-ROB  STANDARD PR EQUATION OF STATE

               ***  MASS AND ENERGY BALANCE  ***
                         IN           OUT        RELATIVE DIFF.
  TOTAL BALANCE
    MOLE(LBMOL/HR)           156.724        156.724        0.00000
    MASS(LB/HR   )         7876.31        7876.31        0.00000
    ENTHALPY(BTU/HR  )      0.337423E+07   0.151504E+07    0.550998

               ***  CO2 EQUIVALENT SUMMARY ***
  FEED STREAMS CO2E           3166.86     LB/HR
  PRODUCT STREAMS CO2E        3166.86     LB/HR
  NET STREAMS CO2E PRODUCTION   0.00000     LB/HR
  UTILITIES CO2E PRODUCTION     0.00000     LB/HR
  TOTAL CO2E PRODUCTION         0.00000     LB/HR

                 ***  INPUT DATA  ***
 TWO    PHASE  TP  FLASH
 SPECIFIED TEMPERATURE             F                  100.0000
 PRESSURE DROP                     PSI              5.00000
 MAXIMUM NO. ITERATIONS                               30
 CONVERGENCE TOLERANCE                                 0.000100000



                  ***  RESULTS  ***
 OUTLET TEMPERATURE    F                          100.00
```

OUTLET PRESSURE PSIA 32.000
HEAT DUTY BTU/HR -0.18592E+07
OUTLET VAPOR FRACTION 0.57736

V-L PHASE EQUILIBRIUM :

COMP	F(I)	X(I)	Y(I)	K(I)
TOLUE-01	0.42418E-01	0.96014E-01	0.31840E-02	0.33161E-01
ETHYL-01	0.66715E-01	0.15513	0.19950E-02	0.12860E-01
STYRE-01	0.28137	0.65782	0.57999E-02	0.88169E-02
ALPHA-01	0.22723E-01	0.53468E-01	0.21681E-03	0.40550E-02
METHA-01	0.50382E-01	0.62784E-03	0.86803E-01	138.26
ETHYLENE	0.28811E-01	0.14760E-02	0.48821E-01	33.076
ETHAN-01	0.26880E-01	0.20347E-02	0.45067E-01	22.149
PROPY-01	0.19208E-01	0.41866E-02	0.30203E-01	7.2142
PROPA-01	0.18329E-01	0.44116E-02	0.28518E-01	6.4642
1-BUT-01	0.14406E-01	0.85189E-02	0.18715E-01	2.1968
ISOBUTAN	0.13906E-01	0.66931E-02	0.19186E-01	2.8665
N-BUT-01	0.13906E-01	0.91084E-02	0.17418E-01	1.9123
H2	0.40095	0.51504E-03	0.69407	1347.6

BLOCK: EBCOL MODEL: RADFRAC

INLETS - TOLBTMS STAGE 41
OUTLETS - EBOVHD STAGE 1
EBCOLBTM STAGE 100
PROPERTY OPTION SET: PENG-ROB STANDARD PR EQUATION OF STATE

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(LBMOL/HR)	57.4376	57.4376	0.123707E-15
MASS(LB/HR)	6051.66	6051.66	0.401120E-12
ENTHALPY(BTU/HR)	0.290570E+07	0.274552E+07	0.551240E-01

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

```
                    *********************
                    ****  INPUT DATA  ****
                    *********************

 ****   INPUT PARAMETERS   ****

  NUMBER OF STAGES                              100
  ALGORITHM OPTION                              STANDARD
  ABSORBER OPTION                               NO
  INITIALIZATION OPTION                         STANDARD
  HYDRAULIC PARAMETER CALCULATIONS              NO
  INSIDE LOOP CONVERGENCE METHOD                BROYDEN
  DESIGN SPECIFICATION METHOD                   NESTED
  MAXIMUM NO. OF OUTSIDE LOOP ITERATIONS        25
  MAXIMUM NO. OF INSIDE LOOP ITERATIONS         10
  MAXIMUM NUMBER OF FLASH ITERATIONS            30
  FLASH TOLERANCE                               0.000100000
  OUTSIDE LOOP CONVERGENCE TOLERANCE            0.000100000

 ****   COL-SPECS   ****

  MOLAR VAPOR DIST / TOTAL DIST                 0.0
  MOLAR DISTILLATE RATE         LBMOL/HR        10.3000
  MASS REFLUX RATIO                             45.0000

 ****   PROFILES   ****

  P-SPEC        STAGE   1  PRES, PSIA           20.0000

                    ******************
                    ****  RESULTS  ****
                    ******************


 ***   COMPONENT SPLIT FRACTIONS   ***

                    OUTLET STREAMS
                    --------------
             EBOVHD      EBCOLBTM
  COMPONENT:
  TOLUE-01    1.0000       0.0000
  ETHYL-01    .99688       .31216E-02
  STYRE-01    .11614E-03   .99988
  ALPHA-01    .10625E-12   1.0000
```

*** SUMMARY OF KEY RESULTS ***

TOP STAGE TEMPERATURE	F	298.283
BOTTOM STAGE TEMPERATURE	F	350.319
TOP STAGE LIQUID FLOW	LBMOL/HR	463.500
BOTTOM STAGE LIQUID FLOW	LBMOL/HR	47.1376
TOP STAGE VAPOR FLOW	LBMOL/HR	0.0
BOILUP VAPOR FLOW	LBMOL/HR	463.676
MOLAR REFLUX RATIO		45.0000
MOLAR BOILUP RATIO		9.83666
CONDENSER DUTY (W/O SUBCOOL)	BTU/HR	-7,165,950.
REBOILER DUTY	BTU/HR	7,005,770.

**** MAXIMUM FINAL RELATIVE ERRORS ****

DEW POINT	0.18120E-10	STAGE= 41	
BUBBLE POINT	0.10011E-10	STAGE= 50	
COMPONENT MASS BALANCE	0.39257E-08	STAGE= 41	COMP=ALPHA-01
ENERGY BALANCE	0.72752E-09	STAGE= 41	

**** PROFILES ****

NOTE REPORTED VALUES FOR STAGE LIQUID AND VAPOR RATES ARE THE FLOWS
FROM THE STAGE INCLUDING ANY SIDE PRODUCT.

STAGE	TEMPERATURE F	PRESSURE PSIA	ENTHALPY BTU/LBMOL LIQUID	ENTHALPY BTU/LBMOL VAPOR	HEAT DUTY BTU/HR
1	298.28	20.000	5846.2	20926.	-.71659+07
2	300.25	20.500	5932.3	20971.	
23	308.23	22.600	8338.9	22890.	
24	308.69	22.700	8781.2	23255.	
25	309.17	22.800	9304.2	23688.	
39	320.69	24.200	30586.	42911.	
40	321.92	24.300	32880.	45184.	
41	323.05	24.400	34747.	47067.	
42	323.59	24.500	35370.	47706.	
95	347.25	29.800	57396.	72515.	
96	347.62	29.900	57392.	72525.	
97	348.05	30.000	57366.	72520.	
99	349.31	30.200	57182.	72432.	
100	350.32	30.300	56967.	72313.	.70058+07

STAGE	FLOW RATE LBMOL/HR		FEED RATE LBMOL/HR			PRODUCT RATE LBMOL/HR	
	LIQUID	VAPOR	LIQUID	VAPOR	MIXED	LIQUID	VAPOR
1	473.8	0.000				10.3000	
2	466.1	473.8					
23	468.4	478.7					
24	468.4	478.7					
25	468.3	478.7					
39	463.1	474.1					
40	462.4	473.4		12.8693			
41	506.9	459.9	44.5682				
42	507.0	459.8					
95	511.5	464.3					
96	511.6	464.4					
97	511.5	464.4					
99	510.8	464.1					
100	47.14	463.7				47.1375	

**** MASS FLOW PROFILES ****

STAGE	FLOW RATE LB/HR		FEED RATE LB/HR			PRODUCT RATE LB/HR	
	LIQUID	VAPOR	LIQUID	VAPOR	MIXED	LIQUID	VAPOR
1	0.5025E+05	0.000				1092.4629	
2	0.4945E+05	0.5025E+05					
23	0.4969E+05	0.5079E+05					
24	0.4968E+05	0.5078E+05					
25	0.4966E+05	0.5077E+05					
39	0.4876E+05	0.4994E+05					
40	0.4866E+05	0.4985E+05		1352.9243			
41	0.5335E+05	0.4840E+05	4698.7314				
42	0.5334E+05	0.4839E+05					
95	0.5343E+05	0.4845E+05					
96	0.5345E+05	0.4847E+05					
97	0.5348E+05	0.4849E+05					
99	0.5357E+05	0.4856E+05					
100	4959.	0.4862E+05				4959.1929	

**** MOLE-X-PROFILE ****

STAGE	TOLUE-01	ETHYL-01	STYRE-01	ALPHA-01
1	0.72753E-02	0.99223	0.49127E-03	0.36533E-13
2	0.41326E-02	0.99525	0.61494E-03	0.75936E-13
23	0.20079E-03	0.95865	0.41151E-01	0.18064E-06
24	0.20043E-03	0.95020	0.49599E-01	0.35784E-06
25	0.19998E-03	0.94014	0.59655E-01	0.70696E-06
39	0.17539E-03	0.52032	0.47425	0.52605E-02

40	0.17227E-03	0.47417	0.51642	0.92358E-02
41	0.14246E-03	0.43630	0.54914	0.14412E-01
42	0.81163E-04	0.42430	0.56115	0.14472E-01
95	0.56637E-18	0.17303E-02	0.97728	0.20987E-01
96	0.30087E-18	0.14696E-02	0.97452	0.24009E-01
97	0.15916E-18	0.12379E-02	0.96966	0.29103E-01
99	0.43151E-19	0.84596E-03	0.94730	0.51851E-01
100	0.21642E-19	0.67892E-03	0.92419	0.75133E-01

**** MOLE-Y-PROFILE ****

STAGE	TOLUE-01	ETHYL-01	STYRE-01	ALPHA-01
1	0.12813E-01	0.98680	0.39108E-03	0.17475E-13
2	0.72753E-02	0.99223	0.49127E-03	0.36533E-13
23	0.35329E-03	0.96629	0.33358E-01	0.89012E-07
24	0.35301E-03	0.95937	0.40276E-01	0.17675E-06
25	0.35266E-03	0.95110	0.48542E-01	0.35014E-06
39	0.33257E-03	0.57554	0.42123	0.28928E-02
40	0.32986E-03	0.53058	0.46394	0.51461E-02
41	0.27515E-03	0.49322	0.49838	0.81249E-02
42	0.15707E-03	0.48096	0.51070	0.81873E-02
95	0.11696E-17	0.21609E-02	0.98432	0.13522E-01
96	0.62166E-18	0.18371E-02	0.98267	0.15491E-01
97	0.32922E-18	0.15499E-02	0.97963	0.18820E-01
99	0.89797E-19	0.10670E-02	0.96509	0.33840E-01
100	0.45338E-19	0.86294E-03	0.94965	0.49484E-01

**** K-VALUES ****

STAGE	TOLUE-01	ETHYL-01	STYRE-01	ALPHA-01
1	1.7611	0.99452	0.79605	0.47834
2	1.7605	0.99697	0.79888	0.48110
23	1.7595	1.0080	0.81062	0.49277
24	1.7612	1.0097	0.81204	0.49394
25	1.7635	1.0117	0.81372	0.49527
39	1.8961	1.1061	0.88821	0.54991
40	1.9148	1.1190	0.89837	0.55719
41	1.9314	1.1305	0.90756	0.56375
42	1.9352	1.1335	0.91009	0.56572
95	2.0652	1.2489	1.0072	0.64429
96	2.0662	1.2500	1.0084	0.64523
97	2.0685	1.2520	1.0103	0.64667
99	2.0810	1.2613	1.0188	0.65263
100	2.0949	1.2711	1.0276	0.65862

**** MASS-X-PROFILE ****

STAGE	TOLUE-01	ETHYL-01	STYRE-01	ALPHA-01
1	0.63202E-02	0.99320	0.48241E-03	0.40706E-13

2	0.35886E-02	0.99581	0.60360E-03	0.84574E-13
23	0.17440E-03	0.95942	0.40402E-01	0.20123E-06
24	0.17412E-03	0.95112	0.48704E-01	0.39871E-06
25	0.17376E-03	0.94124	0.58590E-01	0.78785E-06
39	0.15352E-03	0.52474	0.46920	0.59055E-02
40	0.15083E-03	0.47837	0.51110	0.10372E-01
41	0.12474E-03	0.44018	0.54351	0.16185E-01
42	0.71081E-04	0.42816	0.55551	0.16257E-01
95	0.49962E-18	0.17588E-02	0.97450	0.23746E-01
96	0.26531E-18	0.14932E-02	0.97135	0.27154E-01
97	0.14025E-18	0.12569E-02	0.96585	0.32893E-01
99	0.37910E-19	0.85634E-03	0.94072	0.58426E-01
100	0.18954E-19	0.68512E-03	0.91492	0.84397E-01

**** MASS-Y-PROFILE ****

STAGE	TOLUE-01	ETHYL-01	STYRE-01	ALPHA-01
1	0.11139E-01	0.98848	0.38430E-03	0.19486E-13
2	0.63202E-02	0.99320	0.48241E-03	0.40706E-13
23	0.30682E-03	0.96695	0.32747E-01	0.99150E-07
24	0.30662E-03	0.96015	0.39544E-01	0.19690E-06
25	0.30637E-03	0.95203	0.47667E-01	0.39013E-06
39	0.29087E-03	0.58002	0.41645	0.32451E-02
40	0.28866E-03	0.53501	0.45893	0.57760E-02
41	0.24086E-03	0.49749	0.49315	0.91224E-02
42	0.13752E-03	0.48522	0.50544	0.91944E-02
95	0.10328E-17	0.21987E-02	0.98249	0.15314E-01
96	0.54880E-18	0.18686E-02	0.98059	0.17540E-01
97	0.29050E-18	0.15758E-02	0.97712	0.21300E-01
99	0.79080E-19	0.10827E-02	0.96069	0.38222E-01
100	0.39843E-19	0.87381E-03	0.94335	0.55776E-01

****
***** HYDRAULIC PARAMETERS *****
****

*** DEFINITIONS ***

MARANGONI INDEX = SIGMA - SIGMATO
FLOW PARAM = (ML/MV)*SQRT(RHOV/RHOL)
QR = QV*SQRT(RHOV/(RHOL-RHOV))
F FACTOR = QV*SQRT(RHOV)
WHERE:

SIGMA IS THE SURFACE TENSION OF LIQUID FROM THE STAGE
SIGMATO IS THE SURFACE TENSION OF LIQUID TO THE STAGE
ML IS THE MASS FLOW OF LIQUID FROM THE STAGE
MV IS THE MASS FLOW OF VAPOR TO THE STAGE
RHOL IS THE MASS DENSITY OF LIQUID FROM THE STAGE
RHOV IS THE MASS DENSITY OF VAPOR TO THE STAGE
QV IS THE VOLUMETRIC FLOW RATE OF VAPOR TO THE STAGE

	TEMPERATURE F	
STAGE	LIQUID FROM	VAPOR TO
1	298.28	300.25
2	300.25	300.71
23	308.23	308.69
24	308.69	309.17
25	309.17	309.68
39	320.69	321.92
40	321.92	323.21
41	323.05	323.59
42	323.59	324.13
95	347.25	347.62
96	347.62	348.05
97	348.05	348.59
99	349.31	350.32
100	350.32	350.32

	MASS FLOW LB/HR		VOLUME FLOW CUFT/HR		MOLECULAR WEIGHT	
STAGE	LIQUID FROM	VAPOR TO	LIQUID FROM	VAPOR TO	LIQUID FROM	VAPOR TO
1	50253.	50253.	1076.4	0.17961E+06	106.06	106.06
2	49455.	50547.	1060.9	0.17978E+06	106.11	106.11
23	49688.	50781.	1070.6	0.16505E+06	106.08	106.08
24	49679.	50771.	1070.4	0.16440E+06	106.06	106.06
25	49665.	50757.	1070.0	0.16375E+06	106.04	106.04
39	48756.	49848.	1039.1	0.15485E+06	105.27	105.29
40	48664.	49757.	1035.8	0.15490E+06	105.23	105.25
41	53346.	48387.	1134.3	0.14945E+06	105.23	105.23
42	53337.	48378.	1133.9	0.14893E+06	105.21	105.21
95	53430.	48470.	1133.4	0.12648E+06	104.45	104.37
96	53454.	48495.	1134.2	0.12611E+06	104.49	104.42
97	53484.	48525.	1135.2	0.12573E+06	104.56	104.50
99	53574.	48615.	1137.9	0.12493E+06	104.88	104.85
100	4959.2	0.0000	105.39	0.0000	105.21	

STAGE	DENSITY LB/CUFT LIQUID FROM	DENSITY LB/CUFT VAPOR TO	VISCOSITY CP LIQUID FROM	VISCOSITY CP VAPOR TO	SURFACE TENSION DYNE/CM LIQUID FROM
1	46.685	0.27979	0.22122	0.91686E-02	16.047
2	46.615	0.28116	0.21995	0.91722E-02	15.943
23	46.411	0.30767	0.21457	0.92662E-02	15.650
24	46.413	0.30884	0.21426	0.92714E-02	15.639
25	46.417	0.30997	0.21395	0.92769E-02	15.631
39	46.923	0.32191	0.20703	0.93870E-02	15.866
40	46.984	0.32122	0.20644	0.93956E-02	15.903
41	47.031	0.32377	0.20594	0.94008E-02	15.923
42	47.039	0.32484	0.20562	0.94062E-02	15.918
95	47.140	0.38324	0.19213	0.96468E-02	15.286
96	47.128	0.38455	0.19202	0.96498E-02	15.271
97	47.115	0.38594	0.19193	0.96526E-02	15.255
99	47.080	0.38915	0.19191	0.96563E-02	15.221
100	47.054		0.19204		15.201

STAGE	MARANGONI INDEX DYNE/CM	FLOW PARAM	QR CUFT/HR	REDUCED F-FACTOR (LB-CUFT)**.5/HR
1		0.77416E-01	13946.	95005.
2	-.10411	0.75984E-01	14005.	95329.
23	-.11405E-01	0.79669E-01	13483.	91549.
24	-.10058E-01	0.79817E-01	13455.	91360.
25	-.84884E-02	0.79960E-01	13426.	91166.
39	0.29843E-01	0.81012E-01	12870.	87858.
40	0.37236E-01	0.80870E-01	12852.	87791.
41	-.29579E-02	0.91475E-01	12443.	85037.
42	-.46844E-02	0.91620E-01	12419.	84881.
95	-.14801E-01	0.99391E-01	11450.	78296.
96	-.15063E-01	0.99569E-01	11438.	78202.
97	-.15521E-01	0.99756E-01	11426.	78109.
99	-.17789E-01	0.10019	11405.	77932.
100	-.20446E-01		0.0000	0.0000

****

***** TRAY SIZING CALCULATIONS *****

****

****
*** SECTION 1 ***
****

STARTING STAGE NUMBER	2
ENDING STAGE NUMBER	99
FLOODING CALCULATION METHOD	B960-1

DESIGN PARAMETERS

PEAK CAPACITY FACTOR		1.00000
SYSTEM FOAMING FACTOR		1.00000
FLOODING FACTOR		0.80000
MINIMUM COLUMN DIAMETER	FT	1.00000
MINIMUM DC AREA/COLUMN AREA		0.100000

TRAY SPECIFICATIONS

TRAY TYPE		FLEXI
NUMBER OF PASSES		1
TRAY SPACING	FT	2.00000

***** SIZING RESULTS @ STAGE WITH MAXIMUM DIAMETER *****

STAGE WITH MAXIMUM DIAMETER		2
COLUMN DIAMETER	FT	4.20279
DC AREA/COLUMN AREA		0.100000
DOWNCOMER VELOCITY	FT/SEC	0.21243
FLOW PATH LENGTH	FT	2.88752
SIDE DOWNCOMER WIDTH	FT	0.65763
SIDE WEIR LENGTH	FT	3.05379
CENTER DOWNCOMER WIDTH	FT	0.0
CENTER WEIR LENGTH	FT	MISSING
OFF-CENTER DOWNCOMER WIDTH	FT	0.0
OFF-CENTER SHORT WEIR LENGTH	FT	MISSING
OFF-CENTER LONG WEIR LENGTH	FT	MISSING
TRAY CENTER TO OCDC CENTER	FT	0.0

**** SIZING PROFILES ****

STAGE	DIAMETER	TOTAL AREA	ACTIVE AREA	SIDE DC AREA
	FT	SQFT	SQFT	SQFT
2	4.2028	13.873	11.098	1.3873
3	4.2028	13.873	11.098	1.3873

4	4.2028	13.873	11.098	1.3873
5	4.2028	13.873	11.098	1.3873
6	4.2028	13.873	11.098	1.3873
7	4.2028	13.873	11.098	1.3873
8	4.2028	13.873	11.098	1.3873
9	4.2028	13.873	11.098	1.3873
10	4.2028	13.873	11.098	1.3873
11	4.2028	13.873	11.098	1.3873
12	4.2028	13.873	11.098	1.3873
13	4.2028	13.873	11.098	1.3873
14	4.2028	13.873	11.098	1.3873
15	4.2028	13.873	11.098	1.3873
16	4.2028	13.873	11.098	1.3873
17	4.2028	13.873	11.098	1.3873
18	4.2028	13.873	11.098	1.3873
19	4.2028	13.873	11.098	1.3873
20	4.2028	13.873	11.098	1.3873
21	4.2028	13.873	11.098	1.3873
22	4.2028	13.873	11.098	1.3873
23	4.2028	13.873	11.098	1.3873
24	4.2028	13.873	11.098	1.3873
25	4.2028	13.873	11.098	1.3873
26	4.2028	13.873	11.098	1.3873
27	4.2028	13.873	11.098	1.3873
28	4.2028	13.873	11.098	1.3873
29	4.2028	13.873	11.098	1.3873
30	4.2028	13.873	11.098	1.3873
31	4.2028	13.873	11.098	1.3873
32	4.2028	13.873	11.098	1.3873
33	4.2028	13.873	11.098	1.3873
34	4.2028	13.873	11.098	1.3873
35	4.2028	13.873	11.098	1.3873
36	4.2028	13.873	11.098	1.3873
37	4.2028	13.873	11.098	1.3873
38	4.2028	13.873	11.098	1.3873
39	4.2028	13.873	11.098	1.3873
40	4.2028	13.873	11.098	1.3873
41	4.2028	13.873	11.098	1.3873
42	4.2028	13.873	11.098	1.3873
43	4.2028	13.873	11.098	1.3873
44	4.2028	13.873	11.098	1.3873
45	4.2028	13.873	11.098	1.3873
46	4.2028	13.873	11.098	1.3873
47	4.2028	13.873	11.098	1.3873
48	4.2028	13.873	11.098	1.3873
49	4.2028	13.873	11.098	1.3873

50	4.2028	13.873	11.098	1.3873
51	4.2028	13.873	11.098	1.3873
52	4.2028	13.873	11.098	1.3873
53	4.2028	13.873	11.098	1.3873
54	4.2028	13.873	11.098	1.3873
55	4.2028	13.873	11.098	1.3873
56	4.2028	13.873	11.098	1.3873
57	4.2028	13.873	11.098	1.3873
58	4.2028	13.873	11.098	1.3873
59	4.2028	13.873	11.098	1.3873
60	4.2028	13.873	11.098	1.3873
61	4.2028	13.873	11.098	1.3873
62	4.2028	13.873	11.098	1.3873
63	4.2028	13.873	11.098	1.3873
64	4.2028	13.873	11.098	1.3873
65	4.2028	13.873	11.098	1.3873
66	4.2028	13.873	11.098	1.3873
67	4.2028	13.873	11.098	1.3873
68	4.2028	13.873	11.098	1.3873
69	4.2028	13.873	11.098	1.3873
70	4.2028	13.873	11.098	1.3873
71	4.2028	13.873	11.098	1.3873
72	4.2028	13.873	11.098	1.3873
73	4.2028	13.873	11.098	1.3873
74	4.2028	13.873	11.098	1.3873
75	4.2028	13.873	11.098	1.3873
76	4.2028	13.873	11.098	1.3873
77	4.2028	13.873	11.098	1.3873
78	4.2028	13.873	11.098	1.3873
79	4.2028	13.873	11.098	1.3873
80	4.2028	13.873	11.098	1.3873
81	4.2028	13.873	11.098	1.3873
82	4.2028	13.873	11.098	1.3873
83	4.2028	13.873	11.098	1.3873
84	4.2028	13.873	11.098	1.3873
85	4.2028	13.873	11.098	1.3873
86	4.2028	13.873	11.098	1.3873
87	4.2028	13.873	11.098	1.3873
88	4.2028	13.873	11.098	1.3873
89	4.2028	13.873	11.098	1.3873
90	4.2028	13.873	11.098	1.3873
91	4.2028	13.873	11.098	1.3873
92	4.2028	13.873	11.098	1.3873
93	4.2028	13.873	11.098	1.3873
94	4.2028	13.873	11.098	1.3873
95	4.2028	13.873	11.098	1.3873

96	4.2028	13.873	11.098	1.3873
97	4.2028	13.873	11.098	1.3873
98	4.2028	13.873	11.098	1.3873
99	4.2028	13.873	11.098	1.3873

**** ADDITIONAL SIZING PROFILES ****

STAGE	FLOODING FACTOR	PRES. DROP PSI	DC BACKUP FT	DC BACKUP/ (TSPC+WHT)
2	80.00	0.5898	3.241	149.6
3	79.90	0.5878	3.232	149.2
4	79.79	0.5857	3.222	148.7
5	79.68	0.5836	3.212	148.3
6	79.57	0.5814	3.202	147.8
7	79.45	0.5793	3.192	147.3
8	79.34	0.5772	3.182	146.9
9	79.22	0.5751	3.172	146.4
10	79.11	0.5730	3.162	146.0
11	78.99	0.5709	3.152	145.5
12	78.88	0.5688	3.143	145.0
13	78.76	0.5667	3.133	144.6
14	78.65	0.5646	3.123	144.1
15	78.53	0.5626	3.113	143.7
16	78.41	0.5605	3.103	143.2
17	78.30	0.5585	3.093	142.8
18	78.18	0.5564	3.083	142.3
19	78.06	0.5544	3.073	141.8
20	77.93	0.5523	3.063	141.3
21	77.81	0.5502	3.052	140.9
22	77.68	0.5481	3.041	140.4
23	77.54	0.5460	3.031	139.9
24	77.40	0.5438	3.019	139.4
25	77.26	0.5417	3.008	138.8
26	77.10	0.5394	2.996	138.3
27	76.94	0.5371	2.983	137.7
28	76.77	0.5347	2.970	137.1
29	76.59	0.5323	2.956	136.4
30	76.39	0.5298	2.941	135.8
31	76.19	0.5272	2.926	135.1
32	75.97	0.5246	2.910	134.3
33	75.74	0.5218	2.893	133.5
34	75.50	0.5190	2.876	132.7
35	75.25	0.5162	2.858	131.9
36	74.99	0.5133	2.840	131.1

37	74.73	0.5104	2.821	130.2
38	74.46	0.5075	2.803	129.3
39	74.20	0.5047	2.784	128.5
40	74.08	0.5039	2.776	128.1
41	73.11	0.4757	2.649	122.2
42	72.99	0.4741	2.640	121.8
43	72.87	0.4725	2.631	121.4
44	72.75	0.4708	2.622	121.0
45	72.62	0.4691	2.613	120.6
46	72.49	0.4675	2.603	120.2
47	72.36	0.4658	2.594	119.7
48	72.23	0.4642	2.585	119.3
49	72.10	0.4625	2.576	118.9
50	71.97	0.4609	2.566	118.4
51	71.84	0.4593	2.557	118.0
52	71.71	0.4576	2.548	117.6
53	71.58	0.4561	2.539	117.2
54	71.45	0.4545	2.530	116.8
55	71.33	0.4530	2.521	116.4
56	71.20	0.4514	2.513	116.0
57	71.08	0.4500	2.504	115.6
58	70.97	0.4485	2.496	115.2
59	70.86	0.4471	2.488	114.8
60	70.75	0.4457	2.481	114.5
61	70.64	0.4443	2.473	114.1
62	70.54	0.4430	2.466	113.8
63	70.44	0.4416	2.459	113.5
64	70.34	0.4403	2.452	113.2
65	70.25	0.4391	2.445	112.9
66	70.16	0.4378	2.439	112.6
67	70.07	0.4366	2.433	112.3
68	69.99	0.4354	2.426	112.0
69	69.91	0.4342	2.420	111.7
70	69.83	0.4330	2.415	111.4
71	69.75	0.4319	2.409	111.2
72	69.67	0.4307	2.403	110.9
73	69.60	0.4296	2.398	110.7
74	69.53	0.4285	2.392	110.4
75	69.46	0.4274	2.387	110.2
76	69.39	0.4263	2.382	109.9
77	69.32	0.4252	2.377	109.7
78	69.25	0.4242	2.372	109.5
79	69.18	0.4231	2.367	109.2
80	69.12	0.4221	2.362	109.0
81	69.06	0.4211	2.357	108.8
82	68.99	0.4200	2.352	108.6

83	68.93	0.4190	2.348	108.4
84	68.87	0.4180	2.343	108.1
85	68.81	0.4170	2.339	107.9
86	68.75	0.4160	2.334	107.7
87	68.69	0.4150	2.329	107.5
88	68.63	0.4141	2.325	107.3
89	68.57	0.4131	2.321	107.1
90	68.51	0.4121	2.316	106.9
91	68.46	0.4112	2.312	106.7
92	68.40	0.4102	2.308	106.5
93	68.34	0.4093	2.303	106.3
94	68.29	0.4084	2.299	106.1
95	68.23	0.4074	2.295	105.9
96	68.18	0.4065	2.291	105.7
97	68.14	0.4056	2.287	105.6
98	68.09	0.4048	2.284	105.4
99	68.06	0.4040	2.281	105.3

STAGE	HEIGHT OVER WEIR FT	DC REL FROTH DENS	TR LIQ REL FROTH DENS	FRA APPR TO SYS LIMIT
2	0.7729	0.6067	0.8079E-01	59.22
3	0.7724	0.6067	0.8095E-01	59.14
4	0.7718	0.6067	0.8111E-01	59.07
5	0.7710	0.6067	0.8128E-01	58.99
6	0.7703	0.6067	0.8145E-01	58.90
7	0.7695	0.6067	0.8162E-01	58.82
8	0.7687	0.6067	0.8179E-01	58.74
9	0.7680	0.6067	0.8196E-01	58.65
10	0.7672	0.6067	0.8213E-01	58.57
11	0.7663	0.6067	0.8231E-01	58.48
12	0.7655	0.6067	0.8248E-01	58.40
13	0.7647	0.6067	0.8265E-01	58.32
14	0.7639	0.6067	0.8283E-01	58.23
15	0.7630	0.6067	0.8300E-01	58.15
16	0.7622	0.6067	0.8317E-01	58.06
17	0.7613	0.6067	0.8335E-01	57.98
18	0.7603	0.6067	0.8353E-01	57.89
19	0.7594	0.6067	0.8371E-01	57.74
20	0.7584	0.6067	0.8389E-01	57.65
21	0.7573	0.6067	0.8407E-01	57.55
22	0.7562	0.6066	0.8426E-01	57.46
23	0.7550	0.6066	0.8445E-01	57.36
24	0.7538	0.6066	0.8464E-01	57.25
25	0.7524	0.6067	0.8484E-01	57.14
26	0.7509	0.6067	0.8505E-01	57.03

27	0.7493	0.6067	0.8526E-01	56.91
28	0.7475	0.6067	0.8548E-01	56.78
29	0.7456	0.6067	0.8571E-01	56.64
30	0.7435	0.6067	0.8595E-01	56.50
31	0.7412	0.6067	0.8620E-01	56.34
32	0.7387	0.6067	0.8645E-01	56.18
33	0.7361	0.6067	0.8672E-01	55.99
34	0.7332	0.6067	0.8699E-01	55.79
35	0.7303	0.6067	0.8728E-01	55.59
36	0.7272	0.6068	0.8757E-01	55.38
37	0.7240	0.6068	0.8786E-01	55.17
38	0.7208	0.6068	0.8815E-01	54.96
39	0.7176	0.6068	0.8845E-01	54.75
40	0.7157	0.6068	0.8853E-01	54.65
41	0.7421	0.6069	0.9183E-01	52.95
42	0.7409	0.6069	0.9202E-01	52.86
43	0.7396	0.6069	0.9222E-01	52.77
44	0.7383	0.6069	0.9242E-01	52.67
45	0.7370	0.6069	0.9262E-01	52.58
46	0.7356	0.6069	0.9282E-01	52.48
47	0.7342	0.6069	0.9302E-01	52.38
48	0.7328	0.6069	0.9323E-01	52.28
49	0.7314	0.6069	0.9343E-01	52.18
50	0.7300	0.6069	0.9363E-01	52.07
51	0.7286	0.6069	0.9384E-01	51.97
52	0.7272	0.6069	0.9404E-01	51.87
53	0.7258	0.6069	0.9424E-01	51.77
54	0.7244	0.6069	0.9444E-01	51.67
55	0.7231	0.6069	0.9464E-01	51.57
56	0.7218	0.6069	0.9484E-01	51.47
57	0.7205	0.6069	0.9503E-01	51.38
58	0.7193	0.6069	0.9523E-01	51.50
59	0.7181	0.6069	0.9541E-01	51.41
60	0.7170	0.6069	0.9560E-01	51.33
61	0.7159	0.6069	0.9579E-01	51.25
62	0.7148	0.6069	0.9597E-01	51.18
63	0.7139	0.6069	0.9615E-01	51.10
64	0.7129	0.6069	0.9632E-01	51.03
65	0.7120	0.6069	0.9650E-01	50.96
66	0.7112	0.6069	0.9667E-01	50.90
67	0.7103	0.6069	0.9684E-01	50.83
68	0.7095	0.6069	0.9701E-01	50.77
69	0.7088	0.6069	0.9717E-01	50.71
70	0.7081	0.6069	0.9734E-01	50.65
71	0.7074	0.6069	0.9750E-01	50.59
72	0.7067	0.6069	0.9767E-01	50.54

73	0.7061	0.6069	0.9783E-01	50.48
74	0.7055	0.6069	0.9799E-01	50.43
75	0.7049	0.6069	0.9814E-01	50.38
76	0.7043	0.6069	0.9830E-01	50.33
77	0.7037	0.6069	0.9846E-01	50.28
78	0.7032	0.6069	0.9861E-01	50.23
79	0.7026	0.6069	0.9877E-01	50.18
80	0.7021	0.6069	0.9892E-01	50.13
81	0.7016	0.6069	0.9908E-01	50.09
82	0.7011	0.6069	0.9923E-01	50.04
83	0.7006	0.6069	0.9938E-01	49.99
84	0.7001	0.6069	0.9953E-01	49.95
85	0.6996	0.6069	0.9968E-01	49.91
86	0.6992	0.6069	0.9983E-01	49.86
87	0.6987	0.6069	0.1000	49.82
88	0.6983	0.6069	0.1001	49.77
89	0.6978	0.6069	0.1003	49.73
90	0.6974	0.6069	0.1004	49.69
91	0.6969	0.6069	0.1006	49.65
92	0.6965	0.6069	0.1007	49.61
93	0.6961	0.6069	0.1009	49.57
94	0.6957	0.6069	0.1010	49.53
95	0.6953	0.6069	0.1012	49.49
96	0.6950	0.6069	0.1013	49.45
97	0.6947	0.6069	0.1015	49.41
98	0.6946	0.6069	0.1016	49.38
99	0.6946	0.6069	0.1017	49.35

BLOCK: FURNACE MODEL: RSTOIC

INLET STREAMS: AIR HEAT
OUTLET STREAM: FUEL
PROPERTY OPTION SET: PENG-ROB STANDARD PR EQUATION OF STATE

*** MASS AND ENERGY BALANCE ***

	IN	OUT	GENERATION	RELATIVE DIFF.
TOTAL BALANCE				
MOLE(LBMOL/HR)	1147.24	1139.61	-7.62734	0.00000
MASS(LB/HR)	32367.3	32367.3		0.00000
ENTHALPY(BTU/HR)	-302872.	-302872.		0.192185E-15

*** CO2 EQUIVALENT SUMMARY ***

FEED STREAMS CO2E	1608.76	LB/HR
PRODUCT STREAMS CO2E	1730.05	LB/HR
NET STREAMS CO2E PRODUCTION	121.285	LB/HR
UTILITIES CO2E PRODUCTION	0.00000	LB/HR

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 TOTAL CO2E PRODUCTION        121.285      LB/HR

                    ***  INPUT DATA  ***
 STOICHIOMETRY MATRIX:

 REACTION #   1:
  SUBSTREAM MIXED   :
  WATER      2.00    METHA-01  -1.00    O2        -2.00    CO2        1.00

 REACTION #   2:
  SUBSTREAM MIXED   :
  WATER      2.00    ETHYLENE  -1.00    O2        -3.00    CO2        2.00

 REACTION #   3:
  SUBSTREAM MIXED   :
  WATER      3.00    ETHAN-01  -1.00    O2        -3.50    CO2        2.00

 REACTION #   4:
  SUBSTREAM MIXED   :
  WATER      4.00    PROPA-01  -1.00    O2        -5.00    CO2        3.00

 REACTION #   5:
  SUBSTREAM MIXED   :
  WATER      3.00    PROPY-01  -1.00    O2        -4.50    CO2        3.00

 REACTION #   6:
  SUBSTREAM MIXED   :
  WATER      4.00    1-BUT-01  -1.00    O2        -6.00    CO2        4.00

 REACTION #   7:
  SUBSTREAM MIXED   :
  WATER      10.0    ISOBUTAN  -2.00    O2        -13.0    CO2        8.00

 REACTION #   8:
  SUBSTREAM MIXED   :
  WATER      10.0    N-BUT-01  -2.00    O2        -13.0    CO2        8.00

 REACTION #   9:
  SUBSTREAM MIXED   :
  WATER      2.00    H2        -2.00    O2        -1.00

 REACTION #  10:
  SUBSTREAM MIXED   :
  TOLUE-01  -1.00    WATER      4.00    O2        -9.00    CO2        7.00

 REACTION #  11:
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 SUBSTREAM MIXED   :
 ETHYL-01  -1.00    WATER      5.00    O2       -10.5    CO2       8.00

REACTION #  12:
 SUBSTREAM MIXED   :
 STYRE-01  -1.00    WATER      4.00    O2       -10.0    CO2       8.00

REACTION #  13:
 SUBSTREAM MIXED   :
 ALPHA-01  -1.00    WATER      5.00    O2       -11.5    CO2       9.00


REACTION CONVERSION SPECS: NUMBER=   13
 REACTION #   1:
 SUBSTREAM:MIXED    KEY COMP:METHA-01 CONV FRAC:  1.000
 REACTION #   2:
 SUBSTREAM:MIXED    KEY COMP:ETHYLENE CONV FRAC:  1.000
 REACTION #   3:
 SUBSTREAM:MIXED    KEY COMP:ETHAN-01 CONV FRAC:  1.000
 REACTION #   4:
 SUBSTREAM:MIXED    KEY COMP:PROPA-01 CONV FRAC:  1.000
 REACTION #   5:
 SUBSTREAM:MIXED    KEY COMP:PROPY-01 CONV FRAC:  1.000
 REACTION #   6:
 SUBSTREAM:MIXED    KEY COMP:1-BUT-01 CONV FRAC:  1.000
 REACTION #   7:
 SUBSTREAM:MIXED    KEY COMP:ISOBUTAN CONV FRAC:  1.000
 REACTION #   8:
 SUBSTREAM:MIXED    KEY COMP:N-BUT-01 CONV FRAC:  1.000
 REACTION #   9:
 SUBSTREAM:MIXED    KEY COMP:H2       CONV FRAC:  1.000
 REACTION #  10:
 SUBSTREAM:MIXED    KEY COMP:TOLUE-01 CONV FRAC:  1.000
 REACTION #  11:
 SUBSTREAM:MIXED    KEY COMP:ETHYL-01 CONV FRAC:  1.000
 REACTION #  12:
 SUBSTREAM:MIXED    KEY COMP:STYRE-01 CONV FRAC:  1.000
 REACTION #  13:
 SUBSTREAM:MIXED    KEY COMP:ALPHA-01 CONV FRAC:  1.000



TWO    PHASE  PQ  FLASH
SPECIFIED PRESSURE    PSIA                         14.6959
SPECIFIED HEAT DUTY   BTU/HR                           0.0
```

MAXIMUM NO. ITERATIONS	30
CONVERGENCE TOLERANCE	0.000100000
SIMULTANEOUS REACTIONS	
GENERATE COMBUSTION REACTIONS FOR FEED SPECIES	NO

*** RESULTS ***

OUTLET TEMPERATURE	F	1722.1
OUTLET PRESSURE	PSIA	14.696
VAPOR FRACTION		1.0000

HEAT OF REACTIONS:

REACTION NUMBER	REFERENCE COMPONENT	HEAT OF REACTION BTU/LBMOL
1	METHA-01	-0.34515E+06
2	ETHYLENE	-0.56894E+06
3	ETHAN-01	-0.61433E+06
4	PROPA-01	-0.87854E+06
5	PROPY-01	-0.82824E+06
6	1-BUT-01	-0.10925E+07
7	ISOBUTAN	-0.11387E+07
8	N-BUT-01	-0.11426E+07
9	H2	-0.10400E+06
10	TOLUE-01	-0.16218E+07
11	ETHYL-01	-0.18863E+07
12	STYRE-01	-0.18328E+07
13	ALPHA-01	-0.20935E+07

REACTION EXTENTS:

REACTION NUMBER	REACTION EXTENT LBMOL/HR
1	4.0112
2	2.2938
3	2.1400
4	1.4593
5	1.5292
6	1.1469
7	0.55357
8	0.55357
9	15.961
10	0.15173

```
   11            0.91871E-01
   12            0.26681
   13            0.99672E-02

 V-L PHASE EQUILIBRIUM :

   COMP          F(I)         X(I)         Y(I)         K(I)
   WATER         0.69514E-01  0.69514E-01  0.69514E-01  MISSING
   O2            0.13345      0.13345      0.13345      MISSING
   CO2           0.34495E-01  0.34495E-01  0.34495E-01  MISSING
   N2            0.76254      0.76254      0.76254      MISSING

BLOCK:  HEATX    MODEL: HEATX
-----------------------------
 HOT SIDE:
 ---------
 INLET STREAM:            CYCLVAP
 OUTLET STREAM:           FDHOT
 PROPERTY OPTION SET:   PENG-ROB  STANDARD PR EQUATION OF STATE
 COLD SIDE:
 ----------
 INLET STREAM:            BFWIN
 OUTLET STREAM:           BFWOUT
 PROPERTY OPTION SET:   PENG-ROB  STANDARD PR EQUATION OF STATE

            ***  MASS AND ENERGY BALANCE  ***
                       IN            OUT       RELATIVE DIFF.
  TOTAL BALANCE
    MOLE(LBMOL/HR)          262.190        262.190        0.00000
    MASS(LB/HR   )       9776.31        9776.31        0.00000
    ENTHALPY(BTU/HR  )     -0.741341E+07   -0.741341E+07    0.251253E-15

            ***  CO2 EQUIVALENT SUMMARY ***
  FEED STREAMS CO2E           3166.86     LB/HR
  PRODUCT STREAMS CO2E        3166.86     LB/HR
  NET STREAMS CO2E PRODUCTION   0.00000     LB/HR
  UTILITIES CO2E PRODUCTION    0.00000     LB/HR
  TOTAL CO2E PRODUCTION        0.00000     LB/HR

              ***  INPUT DATA  ***

 FLASH SPECS FOR HOT SIDE:
 TWO    PHASE     FLASH
 MAXIMUM NO. ITERATIONS                            30
 CONVERGENCE TOLERANCE                              0.000100000
```

```
FLASH SPECS FOR COLD SIDE:
TWO    PHASE     FLASH
MAXIMUM NO. ITERATIONS                          30
CONVERGENCE TOLERANCE                            0.000100000

FLOW DIRECTION AND SPECIFICATION:
  COUNTERCURRENT   HEAT EXCHANGER
  SPECIFIED COLD VAPOR FRACTION
  SPECIFIED VALUE                           1.0000
  LMTD CORRECTION FACTOR                          1.00000

PRESSURE SPECIFICATION:
  HOT  SIDE PRESSURE DROP      PSI              8.0000
  COLD SIDE PRESSURE DROP      PSI              0.0000

HEAT TRANSFER COEFFICIENT SPECIFICATION:
  HOT LIQUID    COLD LIQUID    BTU/HR-SQFT-R        149.6937
  HOT 2-PHASE   COLD LIQUID    BTU/HR-SQFT-R        149.6937
  HOT VAPOR     COLD LIQUID    BTU/HR-SQFT-R        149.6937
  HOT LIQUID    COLD 2-PHASE   BTU/HR-SQFT-R        149.6937
  HOT 2-PHASE   COLD 2-PHASE   BTU/HR-SQFT-R        149.6937
  HOT VAPOR     COLD 2-PHASE   BTU/HR-SQFT-R        149.6937
  HOT LIQUID    COLD VAPOR     BTU/HR-SQFT-R        149.6937
  HOT 2-PHASE   COLD VAPOR     BTU/HR-SQFT-R        149.6937
  HOT VAPOR     COLD VAPOR     BTU/HR-SQFT-R        149.6937

              ***  OVERALL RESULTS  ***

STREAMS:
            -------------------------------------
            |                          |
CYCLVAP   ----->|          HOT            |-----> FDHOT
T=  8.2723D+02  |                          |      T=  3.2145D+02
P=  4.5000D+01  |                          |      P=  3.7000D+01
V=  1.0000D+00  |                          |      V=  1.0000D+00
            |                          |
BFWOUT    <-----|          COLD           |<----- BFWIN
T=  2.9782D+02  |                          |      T=  9.0000D+01
P=  6.3000D+01  |                          |      P=  6.3000D+01
V=  1.0000D+00  |                          |      V=  0.0000D+00
            -------------------------------------

DUTY AND AREA:
  CALCULATED HEAT DUTY          BTU/HR          2232253.7641
  CALCULATED (REQUIRED) AREA     SQFT                41.4088
  ACTUAL EXCHANGER AREA         SQFT                41.4088
```

```
   PER CENT OVER-DESIGN                              0.0000

  HEAT TRANSFER COEFFICIENT:
   AVERAGE COEFFICIENT (DIRTY)    BTU/HR-SQFT-R        149.6937
   UA (DIRTY)                     BTU/HR-R           6198.6351

  LOG-MEAN TEMPERATURE DIFFERENCE:
   LMTD CORRECTION FACTOR                              1.0000
   LMTD (CORRECTED)               F                  360.1202
   NUMBER OF SHELLS IN SERIES                          1

  PRESSURE DROP:
   HOTSIDE, TOTAL                 PSI                  8.0000
   COLDSIDE, TOTAL                PSI                  0.0000

                    ***  ZONE RESULTS  ***

  TEMPERATURE LEAVING EACH ZONE:

                              HOT
        -------------------------------------------------------------
        |                                            |
HOT IN  |                    VAP                     | HOT OUT
------> |                                            |------>
 827.2  |                                            |  321.5
        |                                            |
COLDOUT |                    BOIL                    | COLDIN
<------ |                                            |<------
 297.8  |                                            |   90.0
        |                                            |
        -------------------------------------------------------------
                              COLD

  ZONE HEAT TRANSFER AND AREA:

  ZONE      HEAT DUTY      AREA      LMTD       AVERAGE U      UA
             BTU/HR         SQFT       F        BTU/HR-SQFT-R   BTU/HR-R
   1    2232253.764      41.4088   360.1202   149.6937      6198.6351

HEATX COLD-HCURVE:  HEATX    HCURVE 1
------------------------------------
  INDEPENDENT VARIABLE:  DUTY
  PRESSURE PROFILE:      CONSTANT
  PROPERTY OPTION SET:   PENG-ROB  STANDARD PR EQUATION OF STATE

----------------------------------------------------
```

DUTY BTU/HR	PRES PSIA	TEMP F	VFRAC
0.0	63.0000	90.0000	0.0
2.0293+05	63.0000	188.5392	0.0
4.0586+05	63.0000	284.8590	0.0
4.3381+05	63.0000	297.8166	BUB>0.0
6.0880+05	63.0000	297.8166	9.7299-02
8.1173+05	63.0000	297.8166	0.2101
1.0147+06	63.0000	297.8166	0.3230
1.2176+06	63.0000	297.8166	0.4358
1.4205+06	63.0000	297.8166	0.5486
1.6235+06	63.0000	297.8166	0.6615
1.8264+06	63.0000	297.8166	0.7743
2.0293+06	63.0000	297.8166	0.8872
2.2323+06	63.0000	297.8166	1.0000

HEATX HOT-HCURVE: HEATX HCURVE 1

INDEPENDENT VARIABLE: DUTY
PRESSURE PROFILE: CONSTANT
PROPERTY OPTION SET: PENG-ROB STANDARD PR EQUATION OF STATE

DUTY BTU/HR	PRES PSIA	TEMP F	VFRAC
0.0	37.0000	827.0224	1.0000
-2.0293+05	37.0000	786.2792	1.0000
-4.0586+05	37.0000	744.8197	1.0000
-6.0880+05	37.0000	702.5738	1.0000
-8.1173+05	37.0000	659.4590	1.0000
-1.0147+06	37.0000	615.3769	1.0000
-1.2176+06	37.0000	570.2086	1.0000

```
! -1.4205+06 !   37.0000 !  523.8088 !    1.0000 !
! -1.6235+06 !   37.0000 !  475.9965 !    1.0000 !
! -1.8264+06 !   37.0000 !  426.5434 !    1.0000 !
!------------+------------+------------+------------!
! -2.0293+06 !   37.0000 !  375.1563 !    1.0000 !
! -2.2323+06 !   37.0000 !  321.4521 !    1.0000 !
-----------------------------------------------------

HEATX COLD-TQCU HEATX    TQCURV INLET
-------------------------------------
  PRESSURE PROFILE:     CONSTANT2
  PRESSURE DROP:         0.0         PSI
  PROPERTY OPTION SET:   PENG-ROB  STANDARD PR EQUATION OF STATE

-----------------------------------------------------
!  DUTY      !  PRES      !  TEMP      !  VFRAC     !
!            !            !            !            !
!            !            !            !            !
!            !            !            !            !
!  BTU/HR    !  PSIA      !  F         !            !
!            !            !            !            !
!============!============!============!============!
!     0.0    !   63.0000 !  297.8166 !    1.0000 !
!  1.0630+05 !   63.0000 !  297.8166 !    0.9409 !
!  2.1260+05 !   63.0000 !  297.8166 !    0.8818 !
!  3.1889+05 !   63.0000 !  297.8166 !    0.8227 !
!  4.2519+05 !   63.0000 !  297.8166 !    0.7636 !
!------------+------------+------------+------------!
!  5.3149+05 !   63.0000 !  297.8166 !    0.7045 !
!  6.3779+05 !   63.0000 !  297.8166 !    0.6454 !
!  7.4408+05 !   63.0000 !  297.8166 !    0.5863 !
!  8.5038+05 !   63.0000 !  297.8166 !    0.5272 !
!  9.5668+05 !   63.0000 !  297.8166 !    0.4681 !
!------------+------------+------------+------------!
!  1.0630+06 !   63.0000 !  297.8166 !    0.4089 !
!  1.1693+06 !   63.0000 !  297.8166 !    0.3498 !
!  1.2756+06 !   63.0000 !  297.8166 !    0.2907 !
!  1.3819+06 !   63.0000 !  297.8166 !    0.2316 !
!  1.4882+06 !   63.0000 !  297.8166 !    0.1725 !
!------------+------------+------------+------------!
!  1.5945+06 !   63.0000 !  297.8166 !    0.1134 !
!  1.7008+06 !   63.0000 !  297.8166 !  5.4314-02 !
!  1.7984+06 !   63.0000 !  297.8166 ! BUB>0.0    !
!  1.8071+06 !   63.0000 !  293.8303 !    0.0     !
!  1.9134+06 !   63.0000 !  244.0011 !    0.0     !
!------------+------------+------------+------------!
```

```
! 2.0197+06 !   63.0000 !  193.1946 !    0.0    !
! 2.1260+06 !   63.0000 !  141.7507 !    0.0    !
! 2.2323+06 !   63.0000 !   90.0000 !    0.0    !
---------------------------------------------------

HEATX HOT-TQCUR HEATX    TQCURV INLET
-------------------------------------
  PRESSURE PROFILE:      CONSTANT2
  PRESSURE DROP:         0.0        PSI
  PROPERTY OPTION SET:   PENG-ROB  STANDARD PR EQUATION OF STATE

---------------------------------------------------
! DUTY      ! PRES      ! TEMP      ! VFRAC     !
!           !           !           !           !
!           !           !           !           !
!           !           !           !           !
! BTU/HR    ! PSIA      ! F         !           !
!           !           !           !           !
!============!============!============!============!
!    0.0    !  45.0000 !  827.2330 !    1.0000 !
! 1.0630+05 !  45.0000 !  805.9861 !    1.0000 !
! 2.1260+05 !  45.0000 !  784.5516 !    1.0000 !
! 3.1889+05 !  45.0000 !  762.9204 !    1.0000 !
! 4.2519+05 !  45.0000 !  741.0830 !    1.0000 !
!------------+------------+------------+------------!
! 5.3149+05 !  45.0000 !  719.0289 !    1.0000 !
! 6.3779+05 !  45.0000 !  696.7466 !    1.0000 !
! 7.4408+05 !  45.0000 !  674.2235 !    1.0000 !
! 8.5038+05 !  45.0000 !  651.4460 !    1.0000 !
! 9.5668+05 !  45.0000 !  628.3990 !    1.0000 !
!------------+------------+------------+------------!
! 1.0630+06 !  45.0000 !  605.0657 !    1.0000 !
! 1.1693+06 !  45.0000 !  581.4277 !    1.0000 !
! 1.2756+06 !  45.0000 !  557.4644 !    1.0000 !
! 1.3819+06 !  45.0000 !  533.1527 !    1.0000 !
! 1.4882+06 !  45.0000 !  508.4670 !    1.0000 !
!------------+------------+------------+------------!
! 1.5945+06 !  45.0000 !  483.3780 !    1.0000 !
! 1.7008+06 !  45.0000 !  457.8530 !    1.0000 !
! 1.7984+06 !  45.0000 !  433.9809 !    1.0000 !
! 1.8071+06 !  45.0000 !  431.8545 !    1.0000 !
! 1.9134+06 !  45.0000 !  405.3399 !    1.0000 !
!------------+------------+------------+------------!
! 2.0197+06 !  45.0000 !  378.2601 !    1.0000 !
! 2.1260+06 !  45.0000 !  350.5587 !    1.0000 !
! 2.2323+06 !  45.0000 !  322.1705 !    1.0000 !
```

```
---------------------------------------------------

BLOCK:  HEATX2   MODEL: HEATX
----------------------------
 HOT SIDE:
 ---------
 INLET STREAM:            WASTE1
 OUTLET STREAM:           WASTE2
 PROPERTY OPTION SET:   PENG-ROB  STANDARD PR EQUATION OF STATE
 COLD SIDE:
 ----------
 INLET STREAM:            STEAMIN
 OUTLET STREAM:           STEAMOUT
 PROPERTY OPTION SET:   PENG-ROB  STANDARD PR EQUATION OF STATE

               ***  MASS AND ENERGY BALANCE  ***
                          IN           OUT       RELATIVE DIFF.
  TOTAL BALANCE
    MOLE(LBMOL/HR)          1233.97        1233.97        0.00000
    MASS(LB/HR   )          34067.3        34067.3        0.00000
    ENTHALPY(BTU/HR  )     -0.207499E+08  -0.207499E+08    0.179533E-15

               ***  CO2 EQUIVALENT SUMMARY ***
  FEED STREAMS CO2E            1730.05      LB/HR
  PRODUCT STREAMS CO2E         1730.05      LB/HR
  NET STREAMS CO2E PRODUCTION   0.00000     LB/HR
  UTILITIES CO2E PRODUCTION     0.00000     LB/HR
  TOTAL CO2E PRODUCTION         0.00000     LB/HR

                  ***  INPUT DATA  ***

 FLASH SPECS FOR HOT SIDE:
 TWO    PHASE     FLASH
 MAXIMUM NO. ITERATIONS                              30
 CONVERGENCE TOLERANCE                                0.000100000

 FLASH SPECS FOR COLD SIDE:
 TWO    PHASE     FLASH
 MAXIMUM NO. ITERATIONS                              30
 CONVERGENCE TOLERANCE                                0.000100000

 FLOW DIRECTION AND SPECIFICATION:
   COUNTERCURRENT   HEAT EXCHANGER
   SPECIFIED COLD VAPOR FRACTION
   SPECIFIED VALUE                              1.0000
   LMTD CORRECTION FACTOR                             1.00000
```

```
PRESSURE SPECIFICATION:
  HOT  SIDE PRESSURE DROP       PSI                  0.0000
  COLD SIDE PRESSURE DROP       PSI                  0.0000

HEAT TRANSFER COEFFICIENT SPECIFICATION:
  HOT LIQUID    COLD LIQUID     BTU/HR-SQFT-R        149.6937
  HOT 2-PHASE   COLD LIQUID     BTU/HR-SQFT-R        149.6937
  HOT VAPOR     COLD LIQUID     BTU/HR-SQFT-R        149.6937
  HOT LIQUID    COLD 2-PHASE    BTU/HR-SQFT-R        149.6937
  HOT 2-PHASE   COLD 2-PHASE    BTU/HR-SQFT-R        149.6937
  HOT VAPOR     COLD 2-PHASE    BTU/HR-SQFT-R        149.6937
  HOT LIQUID    COLD VAPOR      BTU/HR-SQFT-R        149.6937
  HOT 2-PHASE   COLD VAPOR      BTU/HR-SQFT-R        149.6937
  HOT VAPOR     COLD VAPOR      BTU/HR-SQFT-R        149.6937

                 ***  OVERALL RESULTS  ***

STREAMS:
            --------------------------------------
            |                                    |
WASTE1    ----->|            HOT            |-----> WASTE2
T=  7.6870D+02  |                           |     T=  5.2731D+02
P=  1.4696D+01  |                           |     P=  1.4696D+01
V=  1.0000D+00  |                           |     V=  1.0000D+00
            |                                    |
STEAMOUT  <-----|            COLD           |<----- STEAMIN
T=  4.7892D+02  |                           |     T=  9.0000D+01
P=  5.6400D+02  |                           |     P=  5.6400D+02
V=  1.0000D+00  |                           |     V=  0.0000D+00
            --------------------------------------

DUTY AND AREA:
  CALCULATED HEAT DUTY          BTU/HR          2071373.5582
  CALCULATED (REQUIRED) AREA    SQFT                 38.5983
  ACTUAL EXCHANGER AREA         SQFT                 38.5983
  PER CENT OVER-DESIGN                                0.0000

HEAT TRANSFER COEFFICIENT:
  AVERAGE COEFFICIENT (DIRTY)   BTU/HR-SQFT-R        149.6937
  UA (DIRTY)                    BTU/HR-R            5777.9159

LOG-MEAN TEMPERATURE DIFFERENCE:
  LMTD CORRECTION FACTOR                              1.0000
  LMTD (CORRECTED)              F                   358.4984
  NUMBER OF SHELLS IN SERIES                           1
```

```
 PRESSURE DROP:
   HOTSIDE, TOTAL              PSI                  0.0000
   COLDSIDE, TOTAL              PSI                  0.0000

                    ***  ZONE RESULTS  ***

 TEMPERATURE LEAVING EACH ZONE:

                              HOT
        -------------------------------------------------------------
        |                                          |
HOT IN  |                   VAP                    | HOT OUT
------> |                                          |------>
 768.7  |                                          |  527.3
        |                                          |
COLDOUT |                   BOIL                   | COLDIN
<------ |                                          |<------
 478.9  |                                          |   90.0
        |                                          |
        -------------------------------------------------------------
                              COLD

 ZONE HEAT TRANSFER AND AREA:

 ZONE      HEAT DUTY       AREA       LMTD       AVERAGE U       UA
            BTU/HR         SQFT        F         BTU/HR-SQFT-R   BTU/HR-R
   1    2071373.558       38.5983    358.4984   149.6937        5777.9159

HEATX COLD-TQCU HEATX2   TQCURV INLET
-------------------------------------
 PRESSURE PROFILE:     CONSTANT2
 PRESSURE DROP:        0.0        PSI
 PROPERTY OPTION SET:   PENG-ROB  STANDARD PR EQUATION OF STATE

-----------------------------------------------------
! DUTY      ! PRES      ! TEMP      ! VFRAC     !
!           !           !           !           !
!           !           !           !           !
!           !           !           !           !
! BTU/HR    ! PSIA      ! F         !           !
!           !           !           !           !
!============!============!============!============!
!    0.0    !  564.0000 !  478.9234 !    1.0000 !
! 9.8637+04 !  564.0000 !  478.9234 !    0.9245 !
! 1.9727+05 !  564.0000 !  478.9234 !    0.8490 !
```

```
! 2.9591+05 ! 564.0000 ! 478.9234 !   0.7734 !
! 3.9455+05 ! 564.0000 ! 478.9234 !   0.6979 !
!-----------+-----------+-----------+-----------!
! 4.9318+05 ! 564.0000 ! 478.9234 !   0.6224 !
! 5.9182+05 ! 564.0000 ! 478.9234 !   0.5469 !
! 6.9046+05 ! 564.0000 ! 478.9234 !   0.4714 !
! 7.8909+05 ! 564.0000 ! 478.9234 !   0.3959 !
! 8.8773+05 ! 564.0000 ! 478.9234 !   0.3203 !
!-----------+-----------+-----------+-----------!
! 9.8637+05 ! 564.0000 ! 478.9234 !   0.2448 !
! 1.0850+06 ! 564.0000 ! 478.9234 !   0.1693 !
! 1.1836+06 ! 564.0000 ! 478.9234 ! 9.3782-02 !
! 1.2823+06 ! 564.0000 ! 478.9234 ! 1.8264-02 !
! 1.3061+06 ! 564.0000 ! 478.9235 ! BUB>0.0   !
!-----------+-----------+-----------+-----------!
! 1.3809+06 ! 564.0000 ! 445.9846 !   0.0     !
! 1.4796+06 ! 564.0000 ! 400.0168 !   0.0     !
! 1.5782+06 ! 564.0000 ! 351.6923 !   0.0     !
! 1.6768+06 ! 564.0000 ! 301.4906 !   0.0     !
! 1.7755+06 ! 564.0000 ! 249.8372 !   0.0     !
!-----------+-----------+-----------+-----------!
! 1.8741+06 ! 564.0000 ! 197.1241 !   0.0     !
! 1.9727+06 ! 564.0000 ! 143.7240 !   0.0     !
! 2.0714+06 ! 564.0000 !  90.0000 !   0.0     !
-------------------------------------------------

HEATX HOT-TQCUR HEATX2   TQCURV INLET
-----------------------------------
  PRESSURE PROFILE:      CONSTANT2
  PRESSURE DROP:          0.0        PSI
  PROPERTY OPTION SET:   PENG-ROB  STANDARD PR EQUATION OF STATE

-------------------------------------------------
! DUTY      ! PRES      ! TEMP      ! VFRAC     !
!           !           !           !           !
!           !           !           !           !
!           !           !           !           !
! BTU/HR    ! PSIA      ! F         !           !
!           !           !           !           !
!===========!===========!===========!===========!
!    0.0    !  14.6959 ! 768.6976 !   1.0000 !
! 9.8637+04 !  14.6959 ! 757.3761 !   1.0000 !
! 1.9727+05 !  14.6959 ! 746.0374 !   1.0000 !
! 2.9591+05 !  14.6959 ! 734.6816 !   1.0000 !
! 3.9455+05 !  14.6959 ! 723.3085 !   1.0000 !
!-----------+-----------+-----------+-----------!
```

```
! 4.9318+05 !  14.6959 !  711.9182 !   1.0000 !
! 5.9182+05 !  14.6959 !  700.5105 !   1.0000 !
! 6.9046+05 !  14.6959 !  689.0855 !   1.0000 !
! 7.8909+05 !  14.6959 !  677.6431 !   1.0000 !
! 8.8773+05 !  14.6959 !  666.1834 !   1.0000 !
!------------+------------+------------+------------!
! 9.8637+05 !  14.6959 !  654.7062 !   1.0000 !
! 1.0850+06 !  14.6959 !  643.2117 !   1.0000 !
! 1.1836+06 !  14.6959 !  631.6997 !   1.0000 !
! 1.2823+06 !  14.6959 !  620.1704 !   1.0000 !
! 1.3061+06 !  14.6959 !  617.3794 !   1.0000 !
!------------+------------+------------+------------!
! 1.3809+06 !  14.6959 !  608.6237 !   1.0000 !
! 1.4796+06 !  14.6959 !  597.0597 !   1.0000 !
! 1.5782+06 !  14.6959 !  585.4784 !   1.0000 !
! 1.6768+06 !  14.6959 !  573.8798 !   1.0000 !
! 1.7755+06 !  14.6959 !  562.2640 !   1.0000 !
!------------+------------+------------+------------!
! 1.8741+06 !  14.6959 !  550.6312 !   1.0000 !
! 1.9727+06 !  14.6959 !  538.9812 !   1.0000 !
! 2.0714+06 !  14.6959 !  527.3143 !   1.0000 !
----------------------------------------------------

BLOCK:  PYROLYZE MODEL: RYIELD
------------------------------
  INLET STREAM:          PS
  OUTLET STREAM:         NEWFEED
  PROPERTY OPTION SET:   PENG-ROB  STANDARD PR EQUATION OF STATE


   ***********************************************************************
   *                                                                     *
   *    SPECIFIED YIELDS HAVE BEEN NORMALIZED TO MAINTAIN MASS
BALANCE  *
   *                                                                     *
   ***********************************************************************


                 ***  MASS AND ENERGY BALANCE  ***
                       IN         OUT       GENERATION   RELATIVE DIFF.
  TOTAL BALANCE
  MOLE(LBMOL/HR)        80.0084      194.747       114.738     -0.145942E-15
  MASS(LB/HR   )        8333.00      8333.00                   -0.873150E-15
  ENTHALPY(BTU/HR  )   -0.353580E+07  0.532776E+07              -1.66366

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

FEED STREAMS CO2E 0.00000 LB/HR
PRODUCT STREAMS CO2E 3166.86 LB/HR
NET STREAMS CO2E PRODUCTION 3166.86 LB/HR
UTILITIES CO2E PRODUCTION 0.00000 LB/HR
TOTAL CO2E PRODUCTION 3166.86 LB/HR

*** INPUT DATA ***

TWO PHASE TP FLASH
SPECIFIED TEMPERATURE F 752.000
SPECIFIED PRESSURE PSIA 20.0000
MAXIMUM NO. ITERATIONS 30
CONVERGENCE TOLERANCE 0.000100000

MASS-YIELD
SUBSTREAM MIXED :
TOLUE-01 7.35 ETHYL-01 13.3 STYRE-01 55.1
ALPHA-01 5.05 CARBON 5.48 METHA-01 1.52
ETHYLENE 1.52 ETHAN-01 1.52 PROPY-01 1.52
PROPA-01 1.52 1-BUT-01 1.52 ISOBUTAN 1.52
N-BUT-01 1.52 H2 1.52

*** RESULTS ***

OUTLET TEMPERATURE F 752.00
OUTLET PRESSURE PSIA 20.000
HEAT DUTY BTU/HR 0.88636E+07
VAPOR FRACTION 1.0000

V-L PHASE EQUILIBRIUM :

COMP	F(I)	X(I)	Y(I)	K(I)
TOLUE-01	0.42418E-01	0.61270E-01	0.42418E-01	39.948
ETHYL-01	0.66715E-01	0.10762	0.66715E-01	35.772
STYRE-01	0.28137	0.46955	0.28137	34.577
ALPHA-01	0.22723E-01	0.42393E-01	0.22723E-01	30.929
METHA-01	0.50382E-01	0.29802E-01	0.50382E-01	97.550
ETHYLENE	0.28811E-01	0.19518E-01	0.28811E-01	85.179
ETHAN-01	0.26880E-01	0.19074E-01	0.26880E-01	81.315
PROPY-01	0.19208E-01	0.15391E-01	0.19208E-01	72.012
PROPA-01	0.18329E-01	0.14950E-01	0.18329E-01	70.745
1-BUT-01	0.14406E-01	0.13209E-01	0.14406E-01	62.932
ISOBUTAN	0.13906E-01	0.12626E-01	0.13906E-01	63.552
N-BUT-01	0.13906E-01	0.13005E-01	0.13906E-01	61.701
H2	0.40095	0.18160	0.40095	127.40

```
BLOCK:  SEP      MODEL: SEP
---------------------------
 INLET STREAM:         NEWFEED
 OUTLET STREAMS:       CHAR       S1
 PROPERTY OPTION SET:   PENG-ROB  STANDARD PR EQUATION OF STATE

              ***  MASS AND ENERGY BALANCE  ***
                        IN            OUT       RELATIVE DIFF.
  TOTAL BALANCE
    MOLE(LBMOL/HR)          194.747        194.747       0.145942E-15
    MASS(LB/HR   )          8333.00        8333.00       0.218287E-15
    ENTHALPY(BTU/HR  )      0.532776E+07   0.532776E+07    0.174806E-15

              ***  CO2 EQUIVALENT SUMMARY ***
  FEED STREAMS CO2E           3166.86     LB/HR
  PRODUCT STREAMS CO2E        3166.86     LB/HR
  NET STREAMS CO2E PRODUCTION   0.00000     LB/HR
  UTILITIES CO2E PRODUCTION     0.00000     LB/HR
  TOTAL CO2E PRODUCTION         0.00000     LB/HR


                ***  INPUT DATA  ***

 FLASH SPECS FOR STREAM CHAR
 TWO    PHASE  TP  FLASH
 PRESSURE DROP        PSI                        0.0
 MAXIMUM NO. ITERATIONS                            30
 CONVERGENCE TOLERANCE                              0.000100000

 FLASH SPECS FOR STREAM S1
 TWO    PHASE  TP  FLASH
 PRESSURE DROP        PSI                        0.0
 MAXIMUM NO. ITERATIONS                            30
 CONVERGENCE TOLERANCE                              0.000100000

 FRACTION OF FEED
  SUBSTREAM= MIXED
    STREAM= CHAR      CPT= CARBON    FRACTION=        1.00000


                ***  RESULTS  ***

 HEAT DUTY           BTU/HR                      -0.79445E-09

COMPONENT = TOLUE-01
 STREAM     SUBSTREAM    SPLIT FRACTION
```

S1 MIXED 1.00000

COMPONENT = ETHYL-01
STREAM SUBSTREAM SPLIT FRACTION
S1 MIXED 1.00000

COMPONENT = STYRE-01
STREAM SUBSTREAM SPLIT FRACTION
S1 MIXED 1.00000

COMPONENT = ALPHA-01
STREAM SUBSTREAM SPLIT FRACTION
S1 MIXED 1.00000

COMPONENT = CARBON
STREAM SUBSTREAM SPLIT FRACTION
CHAR MIXED 1.00000

COMPONENT = METHA-01
STREAM SUBSTREAM SPLIT FRACTION
S1 MIXED 1.00000

COMPONENT = ETHYLENE
STREAM SUBSTREAM SPLIT FRACTION
S1 MIXED 1.00000

COMPONENT = ETHAN-01
STREAM SUBSTREAM SPLIT FRACTION
S1 MIXED 1.00000

COMPONENT = PROPY-01
STREAM SUBSTREAM SPLIT FRACTION
S1 MIXED 1.00000

COMPONENT = PROPA-01
STREAM SUBSTREAM SPLIT FRACTION
S1 MIXED 1.00000

COMPONENT = 1-BUT-01
STREAM SUBSTREAM SPLIT FRACTION
S1 MIXED 1.00000

COMPONENT = ISOBUTAN
STREAM SUBSTREAM SPLIT FRACTION
S1 MIXED 1.00000

```
 COMPONENT = N-BUT-01
  STREAM     SUBSTREAM    SPLIT FRACTION
  S1         MIXED              1.00000

 COMPONENT = H2
  STREAM     SUBSTREAM    SPLIT FRACTION
  S1         MIXED              1.00000

BLOCK:  SEP1     MODEL: FLASH2
------------------------------
  INLET STREAM:          COOLEDFD
  OUTLET VAPOR STREAM:   NONCOND
  OUTLET LIQUID STREAM:  LIQFD
  PROPERTY OPTION SET:   PENG-ROB  STANDARD PR EQUATION OF STATE

                  ***  MASS AND ENERGY BALANCE  ***
                               IN           OUT        RELATIVE DIFF.
  TOTAL BALANCE
    MOLE(LBMOL/HR)          156.724        156.724        0.00000
    MASS(LB/HR   )          7876.31        7876.31        0.00000
    ENTHALPY(BTU/HR  )      0.151504E+07   0.151504E+07   0.263744E-09

                  ***  CO2 EQUIVALENT SUMMARY ***
  FEED STREAMS CO2E              3166.86      LB/HR
  PRODUCT STREAMS CO2E           3166.86      LB/HR
  NET STREAMS CO2E PRODUCTION   0.00000      LB/HR
  UTILITIES CO2E PRODUCTION     0.00000      LB/HR
  TOTAL CO2E PRODUCTION         0.00000      LB/HR

                    ***  INPUT DATA  ***
  TWO    PHASE  PQ  FLASH
  PRESSURE DROP         PSI                        0.0
  SPECIFIED HEAT DUTY   BTU/HR                          0.0
  MAXIMUM NO. ITERATIONS                              30
  CONVERGENCE TOLERANCE                                0.000100000

                    ***  RESULTS  ***
  OUTLET TEMPERATURE    F                          100.00
  OUTLET PRESSURE       PSIA                      32.000
  VAPOR FRACTION                                 0.57736



  V-L PHASE EQUILIBRIUM :

    COMP           F(I)         X(I)         Y(I)         K(I)
```

```
    TOLUE-01        0.42418E-01    0.96014E-01    0.31840E-02    0.33161E-01
    ETHYL-01        0.66715E-01    0.15513        0.19950E-02    0.12860E-01
    STYRE-01        0.28137        0.65782        0.57999E-02    0.88169E-02
    ALPHA-01        0.22723E-01    0.53468E-01    0.21681E-03    0.40550E-02
    METHA-01        0.50382E-01    0.62784E-03    0.86803E-01    138.26
    ETHYLENE        0.28811E-01    0.14760E-02    0.48821E-01    33.076
    ETHAN-01        0.26880E-01    0.20347E-02    0.45067E-01    22.149
    PROPY-01        0.19208E-01    0.41866E-02    0.30203E-01    7.2142
    PROPA-01        0.18329E-01    0.44116E-02    0.28518E-01    6.4642
    1-BUT-01        0.14406E-01    0.85189E-02    0.18715E-01    2.1968
    ISOBUTAN        0.13906E-01    0.66931E-02    0.19186E-01    2.8665
    N-BUT-01        0.13906E-01    0.91084E-02    0.17418E-01    1.9123
    H2              0.40095        0.51504E-03    0.69407        1347.6

BLOCK:  SEP2     MODEL: RADFRAC
-------------------------------
  INLETS   - LIQFD    STAGE   5
  OUTLETS  - LIQVAP   STAGE   1
             LIQBOT   STAGE  15
 PROPERTY OPTION SET:   PENG-ROB  STANDARD PR EQUATION OF STATE

                ***  MASS AND ENERGY BALANCE  ***
                            IN            OUT        RELATIVE DIFF.
  TOTAL BALANCE
    MOLE(LBMOL/HR)           66.2376        66.2376        0.00000
    MASS(LB/HR   )           6758.13        6758.13       -0.134578E-15
    ENTHALPY(BTU/HR  )       0.203145E+07   0.308259E+07  -0.340993

                ***  CO2 EQUIVALENT SUMMARY ***
  FEED STREAMS CO2E           16.6790     LB/HR
  PRODUCT STREAMS CO2E        16.6790     LB/HR
  NET STREAMS CO2E PRODUCTION   0.00000     LB/HR
  UTILITIES CO2E PRODUCTION     0.00000     LB/HR
  TOTAL CO2E PRODUCTION         0.00000     LB/HR



                 **********************
                 ****  INPUT DATA  ****
                 **********************

 ****   INPUT PARAMETERS   ****

  NUMBER OF STAGES                           15
  ALGORITHM OPTION                           STANDARD
  ABSORBER OPTION                            NO
```

INITIALIZATION OPTION	STANDARD
HYDRAULIC PARAMETER CALCULATIONS	NO
INSIDE LOOP CONVERGENCE METHOD	BROYDEN
DESIGN SPECIFICATION METHOD	NESTED
MAXIMUM NO. OF OUTSIDE LOOP ITERATIONS	25
MAXIMUM NO. OF INSIDE LOOP ITERATIONS	10
MAXIMUM NUMBER OF FLASH ITERATIONS	30
FLASH TOLERANCE	0.000100000
OUTSIDE LOOP CONVERGENCE TOLERANCE	0.000100000

**** COL-SPECS ****

MOLAR VAPOR DIST / TOTAL DIST		1.00000
MOLAR REFLUX RATIO		6.00000
MOLAR DISTILLATE RATE	LBMOL/HR	2.50000

**** PROFILES ****

P-SPEC STAGE 1 PRES, PSIA 75.0000

****
**** RESULTS ****
****

*** COMPONENT SPLIT FRACTIONS ***

	OUTLET STREAMS	
	LIQVAP	LIQBOT
COMPONENT:		
TOLUE-01	.16623E-02	.99834
ETHYL-01	.32350E-04	.99997
STYRE-01	.91384E-05	.99999
ALPHA-01	.53243E-06	1.0000
METHA-01	1.0000	0.0000
ETHYLENE	1.0000	.66064E-14
ETHAN-01	1.0000	.51202E-13
PROPY-01	1.0000	.13753E-10
PROPA-01	1.0000	.24369E-10
1-BUT-01	1.0000	.52255E-08
ISOBUTAN	1.0000	.17737E-08
N-BUT-01	1.0000	.11091E-07
H2	1.0000	0.0000

*** SUMMARY OF KEY RESULTS ***

TOP STAGE TEMPERATURE	F	106.638
BOTTOM STAGE TEMPERATURE	F	424.555
TOP STAGE LIQUID FLOW	LBMOL/HR	15.0000
BOTTOM STAGE LIQUID FLOW	LBMOL/HR	63.7376
TOP STAGE VAPOR FLOW	LBMOL/HR	2.50000
BOILUP VAPOR FLOW	LBMOL/HR	92.3006
MOLAR REFLUX RATIO		6.00000
MOLAR BOILUP RATIO		1.44813
CONDENSER DUTY (W/O SUBCOOL)	BTU/HR	-205,390.
REBOILER DUTY	BTU/HR	1,256,530.

**** MAXIMUM FINAL RELATIVE ERRORS ****

DEW POINT	0.16934E-05	STAGE= 2
BUBBLE POINT	0.14496E-05	STAGE= 2
COMPONENT MASS BALANCE	0.22355E-05	STAGE= 2 COMP=H2
ENERGY BALANCE	0.78820E-06	STAGE= 2

**** PROFILES ****

NOTE REPORTED VALUES FOR STAGE LIQUID AND VAPOR RATES ARE THE FLOWS
FROM THE STAGE INCLUDING ANY SIDE PRODUCT.

STAGE	TEMPERATURE F	PRESSURE PSIA	ENTHALPY BTU/LBMOL LIQUID	ENTHALPY BTU/LBMOL VAPOR	HEAT DUTY BTU/HR
1	106.64	75.000	-32101.	-28883.	-.20539+06
2	243.15	78.000	8680.3	-19905.	
3	350.41	78.120	26849.	16750.	
4	377.93	78.240	34495.	31050.	
5	390.18	78.360	40202.	37404.	
6	406.18	78.480	41735.	48264.	
13	417.71	79.320	45892.	55043.	
14	420.72	79.440	47454.	57018.	
15	424.55	79.560	49497.	59656.	.12565+07

STAGE	FLOW RATE LBMOL/HR LIQUID	FLOW RATE LBMOL/HR VAPOR	FEED RATE LBMOL/HR LIQUID	FEED RATE LBMOL/HR VAPOR	FEED RATE LBMOL/HR MIXED	PRODUCT RATE LBMOL/HR LIQUID	PRODUCT RATE LBMOL/HR VAPOR
1	15.00	2.500			2.5000		
2	11.32	17.50					

3	13.23	13.82		
4	13.64	15.73		
5	146.1	16.14	66.2375	
6	154.4	82.39		
13	156.0	92.27		
14	156.0	92.29		
15	63.74	92.30		63.7375

**** MASS FLOW PROFILES ****

STAGE	FLOW RATE LB/HR LIQUID	VAPOR	FEED RATE LB/HR LIQUID	VAPOR	MIXED	PRODUCT RATE LB/HR LIQUID	VAPOR
1	947.4	125.6			125.6324		
2	1004.	1073.					
3	1276.	1130.					
4	1352.	1401.					
5	0.1477E+05	1478.	6758.1292				
6	0.1568E+05	8137.					
13	0.1607E+05	9379.					
14	0.1614E+05	9438.					
15	6632.	9511.		6632.4967			

**** MOLE-X-PROFILE ****

STAGE	TOLUE-01	ETHYL-01	STYRE-01	ALPHA-01	METHA-01
1	0.16441	0.12796E-01	0.19946E-01	0.21128E-03	0.41440E-03
2	0.56604	0.82562E-01	0.16442	0.30213E-02	0.37954E-04
3	0.52719	0.12486	0.30333	0.86218E-02	0.41266E-04
4	0.39104	0.14586	0.42771	0.18350E-01	0.37556E-04
5	0.26252	0.15221	0.53662	0.34396E-01	0.37315E-04
6	0.27064	0.15487	0.53842	0.33812E-01	0.96820E-06
13	0.16971	0.17161	0.62033	0.38346E-01	0.62361E-17
14	0.13709	0.16959	0.64988	0.43436E-01	0.15989E-18
15	0.99614E-01	0.16121	0.68361	0.55565E-01	0.40843E-20

**** MOLE-X-PROFILE ****

STAGE	ETHYLENE	ETHAN-01	PROPY-01	PROPA-01	1-BUT-01
1	0.31446E-02	0.69787E-02	0.39817E-01	0.47533E-01	0.24038
2	0.32309E-03	0.70970E-03	0.54770E-02	0.68038E-02	0.57743E-01
3	0.21922E-03	0.38242E-03	0.16287E-02	0.18818E-02	0.10854E-01
4	0.18345E-03	0.31152E-03	0.11523E-02	0.12934E-02	0.48813E-02
5	0.17458E-03	0.29440E-03	0.10590E-02	0.11825E-02	0.40155E-02
6	0.86654E-05	0.17639E-04	0.10609E-03	0.12486E-03	0.69343E-03
13	0.46736E-14	0.34859E-13	0.72647E-11	0.12287E-10	0.20271E-08
14	0.22001E-15	0.19687E-14	0.67354E-12	0.11981E-11	0.31644E-09
15	0.10134E-16	0.10827E-15	0.59838E-13	0.11172E-12	0.46262E-10

**** MOLE-X-PROFILE ****

STAGE	ISOBUTAN	N-BUT-01	H2
1	0.16254	0.30178	0.57726E-04
2	0.34299E-01	0.78556E-01	0.71500E-05
3	0.66055E-02	0.14377E-01	0.10683E-04
4	0.32882E-02	0.58868E-02	0.99411E-05
5	0.28003E-02	0.46717E-02	0.98465E-05
6	0.43804E-03	0.86402E-03	0.86209E-07
13	0.64897E-09	0.40523E-08	0.28836E-21
14	0.92247E-10	0.67513E-09	0.25091E-23
15	0.12337E-10	0.10498E-09	0.21921E-25

**** MOLE-Y-PROFILE ****

STAGE	TOLUE-01	ETHYL-01	STYRE-01	ALPHA-01	METHA-01
1	0.42288E-02	0.13296E-03	0.15927E-03	0.75426E-06	0.16635E-01
2	0.14152	0.10987E-01	0.17119E-01	0.18121E-03	0.27316E-02
3	0.46438	0.67646E-01	0.13470	0.24747E-02	0.30413E-02
4	0.44405	0.10503	0.25513	0.72513E-02	0.26790E-02
5	0.33112	0.12328	0.36147	0.15507E-01	0.26087E-02
6	0.38856	0.14526	0.42290	0.18020E-01	0.66184E-04
13	0.26421	0.17654	0.53654	0.22713E-01	0.41354E-15
14	0.21813	0.17880	0.57662	0.26454E-01	0.10540E-16
15	0.16297	0.17538	0.62659	0.35061E-01	0.26747E-18

**** MOLE-Y-PROFILE ****

STAGE	ETHYLENE	ETHAN-01	PROPY-01	PROPA-01	1-BUT-01
1	0.39107E-01	0.53910E-01	0.11092	0.11689	0.22571
2	0.82821E-02	0.13683E-01	0.49976E-01	0.57440E-01	0.23828
3	0.73414E-02	0.10337E-01	0.24559E-01	0.26724E-01	0.88138E-01
4	0.64011E-02	0.88914E-02	0.19003E-01	0.20164E-01	0.45008E-01
5	0.62134E-02	0.86148E-02	0.18158E-01	0.19201E-01	0.39091E-01
6	0.30963E-03	0.52215E-03	0.18782E-02	0.20973E-02	0.71219E-02
13	0.16725E-12	0.10383E-11	0.13111E-09	0.21069E-09	0.21523E-07
14	0.78943E-14	0.58858E-13	0.12240E-10	0.20696E-10	0.33951E-08
15	0.36494E-15	0.32534E-14	0.10973E-11	0.19483E-11	0.50302E-09

**** MOLE-Y-PROFILE ****

STAGE	ISOBUTAN	N-BUT-01	H2
1	0.17733	0.24133	0.13646E-01
2	0.16465	0.29314	0.19989E-02
3	0.60183E-01	0.10801	0.24752E-02
4	0.33745E-01	0.50454E-01	0.21782E-02
5	0.30251E-01	0.42361E-01	0.21224E-02
6	0.49667E-02	0.82859E-02	0.17464E-04
13	0.75846E-08	0.40246E-07	0.56365E-19

14	0.10886E-08	0.67783E-08	0.48750E-21
15	0.14743E-09	0.10688E-08	0.42266E-23

**** K-VALUES ****

STAGE	TOLUE-01	ETHYL-01	STYRE-01	ALPHA-01	METHA-01
1	0.25722E-01	0.10391E-01	0.79852E-02	0.35699E-02	40.141
2	0.25002	0.13308	0.10412	0.59976E-01	71.972
3	0.88086	0.54176	0.44406	0.28703	73.699
4	1.1356	0.72012	0.59652	0.39517	71.334
5	1.2613	0.80993	0.67361	0.45084	69.910
6	1.4357	0.93792	0.78545	0.53294	68.358
13	1.5568	1.0287	0.86492	0.59231	66.315
14	1.5911	1.0543	0.88727	0.60903	65.922
15	1.6360	1.0879	0.91659	0.63099	65.488

**** K-VALUES ****

STAGE	ETHYLENE	ETHAN-01	PROPY-01	PROPA-01	1-BUT-01
1	12.436	7.7249	2.7858	2.4591	0.93897
2	25.634	19.280	9.1247	8.4424	4.1267
3	33.488	27.029	15.079	14.201	8.1205
4	34.893	28.542	16.491	15.590	9.2206
5	35.592	29.263	17.147	16.237	9.7353
6	35.732	29.601	17.704	16.797	10.271
13	35.786	29.784	18.048	17.148	10.618
14	35.881	29.898	18.173	17.274	10.729
15	36.013	30.049	18.338	17.439	10.873

**** K-VALUES ****

STAGE	ISOBUTAN	N-BUT-01	H2
1	1.0910	0.79969	236.40
2	4.8005	3.7316	279.57
3	9.1111	7.5126	231.69
4	10.263	8.5708	219.12
5	10.803	9.0675	215.55
6	11.338	9.5899	202.58
13	11.687	9.9317	195.46
14	11.801	10.040	194.29
15	11.950	10.181	192.82

**** MASS-X-PROFILE ****

STAGE	TOLUE-01	ETHYL-01	STYRE-01	ALPHA-01	METHA-01
1	0.23984	0.21509E-01	0.32891E-01	0.39533E-03	0.10526E-03
2	0.58758	0.98750E-01	0.19292	0.40226E-02	0.68596E-05
3	0.50368	0.13746	0.32758	0.10565E-01	0.68645E-05
4	0.36336	0.15617	0.44924	0.21870E-01	0.60762E-05
5	0.23932	0.15988	0.55296	0.40217E-01	0.59228E-05

6	0.24550	0.16187	0.55206	0.39338E-01	0.15291E-06
13	0.15183	0.17690	0.62728	0.43998E-01	0.97133E-18
14	0.12210	0.17403	0.65425	0.49618E-01	0.24793E-19
15	0.88205E-01	0.16447	0.68422	0.63104E-01	0.62967E-21

**** MASS-X-PROFILE ****

STAGE	ETHYLENE	ETHAN-01	PROPY-01	PROPA-01	1-BUT-01
1	0.13967E-02	0.33224E-02	0.26528E-01	0.33186E-01	0.21354
2	0.10211E-03	0.24042E-03	0.25965E-02	0.33801E-02	0.36499E-01
3	0.63770E-04	0.11924E-03	0.71066E-03	0.86045E-03	0.63145E-02
4	0.51901E-04	0.94468E-04	0.48903E-03	0.57517E-03	0.27620E-02
5	0.48454E-04	0.87583E-04	0.44088E-03	0.51590E-03	0.22290E-02
6	0.23932E-05	0.52217E-05	0.43950E-04	0.54205E-04	0.38302E-03
13	0.12730E-14	0.10177E-13	0.29681E-11	0.52605E-11	0.11042E-08
14	0.59659E-16	0.57220E-15	0.27396E-12	0.51067E-12	0.17162E-09
15	0.27320E-17	0.31286E-16	0.24198E-13	0.47344E-13	0.24944E-10

**** MASS-X-PROFILE ****

STAGE	ISOBUTAN	N-BUT-01	H2
1	0.14958	0.27771	0.18424E-05
2	0.22460E-01	0.51440E-01	0.16238E-06
3	0.39810E-02	0.86650E-02	0.22331E-06
4	0.19274E-02	0.34506E-02	0.20210E-06
5	0.16103E-02	0.26865E-02	0.19638E-06
6	0.25065E-03	0.49440E-03	0.17109E-08
13	0.36623E-09	0.22868E-08	0.56439E-23
14	0.51826E-10	0.37930E-09	0.48891E-25
15	0.68910E-11	0.58640E-10	0.42465E-27

**** MASS-Y-PROFILE ****

STAGE	TOLUE-01	ETHYL-01	STYRE-01	ALPHA-01	METHA-01
1	0.77537E-02	0.28090E-03	0.33010E-03	0.17738E-05	0.53104E-02
2	0.21267	0.19024E-01	0.29078E-01	0.34925E-03	0.71468E-03
3	0.52311	0.87803E-01	0.17151	0.35755E-02	0.59650E-03
4	0.45921	0.12516	0.29824	0.96180E-02	0.48237E-03
5	0.33313	0.14292	0.41108	0.20011E-01	0.45698E-03
6	0.36249	0.15614	0.44596	0.21561E-01	0.10750E-04
13	0.23949	0.18438	0.54973	0.26405E-01	0.65265E-16
14	0.19653	0.18563	0.58727	0.30571E-01	0.16535E-17
15	0.14573	0.18070	0.63336	0.40212E-01	0.41644E-19

**** MASS-Y-PROFILE ****

STAGE	ETHYLENE	ETHAN-01	PROPY-01	PROPA-01	1-BUT-01
1	0.21832E-01	0.32258E-01	0.92885E-01	0.10257	0.25200
2	0.37893E-02	0.67102E-02	0.34297E-01	0.41309E-01	0.21804
3	0.25180E-02	0.38000E-02	0.12635E-01	0.14407E-01	0.60459E-01

4	0.20155E-02	0.30007E-02	0.89749E-02	0.99793E-02	0.28343E-01
5	0.19033E-02	0.28285E-02	0.83433E-02	0.92450E-02	0.23949E-01
6	0.87949E-04	0.15897E-03	0.80025E-03	0.93641E-03	0.40459E-02
13	0.46157E-13	0.30712E-12	0.54275E-10	0.91398E-10	0.11880E-07
14	0.21656E-14	0.17307E-13	0.50369E-11	0.89241E-11	0.18627E-08
15	0.99359E-16	0.94942E-15	0.44814E-12	0.83379E-12	0.27390E-09

**** MASS-Y-PROFILE ****

STAGE	ISOBUTAN	N-BUT-01	H2
1	0.20511	0.27912	0.54741E-03
2	0.15608	0.27788	0.65718E-04
3	0.42766E-01	0.76753E-01	0.61004E-04
4	0.22014E-01	0.32914E-01	0.49283E-04
5	0.19199E-01	0.26884E-01	0.46718E-04
6	0.29229E-02	0.48762E-02	0.35646E-06
13	0.43367E-08	0.23012E-07	0.11178E-20
14	0.61875E-09	0.38526E-08	0.96099E-23
15	0.83163E-10	0.60292E-09	0.82690E-25

****
***** HYDRAULIC PARAMETERS *****
****

*** DEFINITIONS ***

MARANGONI INDEX = SIGMA - SIGMATO
FLOW PARAM = (ML/MV)*SQRT(RHOV/RHOL)
QR = QV*SQRT(RHOV/(RHOL-RHOV))
F FACTOR = QV*SQRT(RHOV)
WHERE:
SIGMA IS THE SURFACE TENSION OF LIQUID FROM THE STAGE
SIGMATO IS THE SURFACE TENSION OF LIQUID TO THE STAGE
ML IS THE MASS FLOW OF LIQUID FROM THE STAGE
MV IS THE MASS FLOW OF VAPOR TO THE STAGE
RHOL IS THE MASS DENSITY OF LIQUID FROM THE STAGE
RHOV IS THE MASS DENSITY OF VAPOR TO THE STAGE
QV IS THE VOLUMETRIC FLOW RATE OF VAPOR TO THE STAGE

TEMPERATURE
F
STAGE LIQUID FROM VAPOR TO

1	106.64	243.15
2	243.15	350.41
3	350.41	377.93
4	377.93	390.18
5	390.18	406.18
6	406.18	408.91
13	417.71	420.72
14	420.72	424.55
15	424.55	424.55

	MASS FLOW LB/HR		VOLUME FLOW CUFT/HR		MOLECULAR WEIGHT	
STAGE	LIQUID FROM	VAPOR TO	LIQUID FROM	VAPOR TO	LIQUID FROM	VAPOR TO
1	947.41	1073.0	24.483	1558.6	63.160	61.317
2	1004.4	1130.0	21.931	1390.5	88.763	81.794
3	1275.6	1401.2	28.673	1618.2	96.441	89.099
4	1352.3	1477.9	30.667	1678.6	99.159	91.582
5	14770.	8137.0	335.40	8591.3	101.07	98.766
6	15680.	9047.7	360.01	9444.8	101.58	99.833
13	16070.	9437.9	370.40	9614.0	103.00	102.26
14	16143.	9510.6	372.21	9634.7	103.46	103.04
15	6632.5	0.0000	152.98	0.0000	104.06	

	DENSITY LB/CUFT		VISCOSITY CP		SURFACE TENSION DYNE/CM
STAGE	LIQUID FROM	VAPOR TO	LIQUID FROM	VAPOR TO	LIQUID FROM
1	38.697	0.68846	0.16623	0.10127E-01	12.891
2	45.798	0.81265	0.19360	0.10870E-01	15.447
3	44.488	0.86594	0.15466	0.10916E-01	12.422
4	44.095	0.88043	0.15199	0.10915E-01	12.005
5	44.036	0.94713	0.15344	0.10859E-01	11.972
6	43.555	0.95796	0.14954	0.10854E-01	11.189
13	43.387	0.98168	0.15047	0.10835E-01	11.050
14	43.371	0.98712	0.15101	0.10825E-01	11.000
15	43.355		0.15165		10.952

STAGE	MARANGONI INDEX DYNE/CM	FLOW PARAM	QR CUFT/HR	REDUCED F-FACTOR (LB-CUFT)**.5/HR
1		0.11777	209.77	1293.2
2	2.5556	0.11840	186.89	1253.5
3	-3.0249	0.12701	227.99	1505.8
4	-.41624	0.12929	239.60	1575.1

5	-13.527	0.26620	1273.7	8361.1
6	-.78243	0.25702	1416.4	9244.1
13	-.37990E-01	0.25613	1462.8	9525.6
14	-.50032E-01	0.25607	1470.4	9572.5
15	-.48011E-01		0.0000	0.0000

****
***** TRAY SIZING CALCULATIONS *****
****

****
*** SECTION 1 ***
****

STARTING STAGE NUMBER 2
ENDING STAGE NUMBER 14
FLOODING CALCULATION METHOD B960-1

DESIGN PARAMETERS

PEAK CAPACITY FACTOR 1.00000
SYSTEM FOAMING FACTOR 1.00000
FLOODING FACTOR 0.80000
MINIMUM COLUMN DIAMETER FT 1.00000
MINIMUM DC AREA/COLUMN AREA 0.100000

TRAY SPECIFICATIONS

TRAY TYPE FLEXI
NUMBER OF PASSES 1
TRAY SPACING FT 2.00000

***** SIZING RESULTS @ STAGE WITH MAXIMUM DIAMETER *****

STAGE WITH MAXIMUM DIAMETER 14
COLUMN DIAMETER FT 1.47083
DC AREA/COLUMN AREA 0.16382
DOWNCOMER VELOCITY FT/SEC 0.37146
FLOW PATH LENGTH FT 0.82172
SIDE DOWNCOMER WIDTH FT 0.32455
SIDE WEIR LENGTH FT 1.21988

CENTER DOWNCOMER WIDTH	FT	0.0
CENTER WEIR LENGTH	FT	MISSING
OFF-CENTER DOWNCOMER WIDTH	FT	0.0
OFF-CENTER SHORT WEIR LENGTH	FT	MISSING
OFF-CENTER LONG WEIR LENGTH	FT	MISSING
TRAY CENTER TO OCDC CENTER	FT	0.0

**** SIZING PROFILES ****

STAGE	DIAMETER FT	TOTAL AREA SQFT	ACTIVE AREA SQFT	SIDE DC AREA SQFT
2	1.4708	1.6991	1.1424	0.27834
3	1.4708	1.6991	1.1424	0.27834
4	1.4708	1.6991	1.1424	0.27834
5	1.4708	1.6991	1.1424	0.27834
6	1.4708	1.6991	1.1424	0.27834
7	1.4708	1.6991	1.1424	0.27834
8	1.4708	1.6991	1.1424	0.27834
9	1.4708	1.6991	1.1424	0.27834
10	1.4708	1.6991	1.1424	0.27834
11	1.4708	1.6991	1.1424	0.27834
12	1.4708	1.6991	1.1424	0.27834
13	1.4708	1.6991	1.1424	0.27834
14	1.4708	1.6991	1.1424	0.27834

**** ADDITIONAL SIZING PROFILES ****

STAGE	FLOODING FACTOR	PRES. DROP PSI	DC BACKUP FT	DC BACKUP/ (TSPC+WHT)
2	9.879	0.5762E-01	0.3363	15.52
3	12.05	0.5819E-01	0.3450	15.92
4	12.66	0.5835E-01	0.3477	16.05
5	69.65	0.4296	2.471	114.1
6	77.10	0.5207	3.006	138.7
7	78.27	0.5356	3.094	142.8
8	78.52	0.5387	3.112	143.6
9	78.66	0.5403	3.122	144.1
10	78.81	0.5422	3.133	144.6
11	79.01	0.5446	3.148	145.3
12	79.26	0.5478	3.167	146.2
13	79.59	0.5520	3.191	147.3
14	80.00	0.5573	3.222	148.7

STAGE	HEIGHT OVER WEIR FT	DC REL FROTH DENS	TR LIQ REL FROTH DENS	FRA APPR TO SYS LIMIT
2	0.2299E-01	0.6062	0.4411	7.177
3	0.2916E-01	0.6054	0.4071	9.218
4	0.3097E-01	0.6052	0.3988	9.760
5	0.5762	0.6051	0.9687E-01	53.00
6	0.6525	0.6047	0.8629E-01	59.93
7	0.6646	0.6047	0.8488E-01	60.99
8	0.6673	0.6046	0.8460E-01	61.20
9	0.6690	0.6046	0.8446E-01	61.29
10	0.6708	0.6046	0.8430E-01	61.46
11	0.6732	0.6046	0.8409E-01	61.57
12	0.6762	0.6046	0.8381E-01	61.83
13	0.6799	0.6046	0.8345E-01	62.15
14	0.6846	0.6045	0.8300E-01	62.56

BLOCK: STYCOL MODEL: RADFRAC

INLETS - EBCOLBTM STAGE 13
OUTLETS - STYRENE STAGE 1
ALPHA STAGE 20
PROPERTY OPTION SET: PENG-ROB STANDARD PR EQUATION OF STATE

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(LBMOL/HR)	47.1376	47.1376	0.00000
MASS(LB/HR)	4959.19	4959.19	0.00000
ENTHALPY(BTU/HR)	0.268531E+07	0.222810E+07	0.170264

*** CO2 EQUIVALENT SUMMARY ***

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

****
**** INPUT DATA ****
****

**** INPUT PARAMETERS ****

NUMBER OF STAGES	20
ALGORITHM OPTION	STANDARD
ABSORBER OPTION	NO
INITIALIZATION OPTION	STANDARD
HYDRAULIC PARAMETER CALCULATIONS	NO
INSIDE LOOP CONVERGENCE METHOD	BROYDEN
DESIGN SPECIFICATION METHOD	NESTED
MAXIMUM NO. OF OUTSIDE LOOP ITERATIONS	25
MAXIMUM NO. OF INSIDE LOOP ITERATIONS	10
MAXIMUM NUMBER OF FLASH ITERATIONS	30
FLASH TOLERANCE	0.000100000
OUTSIDE LOOP CONVERGENCE TOLERANCE	0.000100000

**** COL-SPECS ****

MOLAR VAPOR DIST / TOTAL DIST		0.0
MOLAR REFLUX RATIO		16.0000
MOLAR DISTILLATE RATE	LBMOL/HR	42.8000

**** PROFILES ****

P-SPEC STAGE 1 PRES, PSIA 0.96684

****
**** RESULTS ****
****

*** COMPONENT SPLIT FRACTIONS ***

	OUTLET STREAMS	
	STYRENE	ALPHA
COMPONENT:		
ETHYL-01	.99974	.25865E-03
STYRE-01	.98169	.18314E-01
ALPHA-01	.52620E-03	.99947

*** SUMMARY OF KEY RESULTS ***

TOP STAGE TEMPERATURE	F	148.453
BOTTOM STAGE TEMPERATURE	F	199.321
TOP STAGE LIQUID FLOW	LBMOL/HR	684.800
BOTTOM STAGE LIQUID FLOW	LBMOL/HR	4.33758
TOP STAGE VAPOR FLOW	LBMOL/HR	0.0

BOILUP VAPOR FLOW LBMOL/HR 706.249
MOLAR REFLUX RATIO 16.0000
MOLAR BOILUP RATIO 162.821
CONDENSER DUTY (W/O SUBCOOL) BTU/HR -0.131585+08
REBOILER DUTY BTU/HR 0.127013+08

**** MAXIMUM FINAL RELATIVE ERRORS ****

DEW POINT 0.28491E-04 STAGE= 19
BUBBLE POINT 0.11350E-04 STAGE= 19
COMPONENT MASS BALANCE 0.29987E-05 STAGE= 12 COMP=ETHYL-01
ENERGY BALANCE 0.15184E-03 STAGE= 20

**** PROFILES ****

NOTE REPORTED VALUES FOR STAGE LIQUID AND VAPOR RATES ARE THE FLOWS
FROM THE STAGE INCLUDING ANY SIDE PRODUCT.

STAGE	TEMPERATURE F	PRESSURE PSIA	ENTHALPY BTU/LBMOL LIQUID	ENTHALPY BTU/LBMOL VAPOR	HEAT DUTY BTU/HR
1	148.45	0.96684	48036.	65514.	-.13159+08
2	166.48	1.4668	48832.	66121.	
9	170.59	1.6022	48958.	66250.	
10	171.24	1.6215	48926.	66243.	
11	171.97	1.6409	48850.	66215.	
12	172.83	1.6602	48696.	66150.	
13	173.89	1.6795	48430.	66031.	
14	175.31	1.6989	47982.	65816.	
19	194.81	1.7956	40946.	60503.	
20	199.32	1.8149	39692.	58936.	.12701+08

STAGE	FLOW RATE LBMOL/HR LIQUID	FLOW RATE LBMOL/HR VAPOR	FEED RATE LBMOL/HR LIQUID	FEED RATE LBMOL/HR VAPOR	FEED RATE LBMOL/HR MIXED	PRODUCT RATE LBMOL/HR LIQUID	PRODUCT RATE LBMOL/HR VAPOR
1	727.6	0.000		42.8000			
2	715.0	727.6					
9	716.2	758.9					
10	716.1	759.0					
11	715.8	758.9					
12	715.0	758.6	23.9155				
13	737.0	733.9	23.2220				
14	734.8	732.7					

19	710.6	709.8	
20	4.338	706.2	4.3375

**** MASS FLOW PROFILES ****

STAGE	FLOW RATE LB/HR		FEED RATE LB/HR			PRODUCT RATE LB/HR	
	LIQUID	VAPOR	LIQUID	VAPOR	MIXED	LIQUID	VAPOR
1	0.7578E+05	0.000			4457.7756		
2	0.7447E+05	0.7578E+05					
9	0.7465E+05	0.7908E+05					
10	0.7469E+05	0.7911E+05					
11	0.7474E+05	0.7914E+05					
12	0.7481E+05	0.7919E+05		2508.7989			
13	0.7736E+05	0.7675E+05	2450.3939				
14	0.7753E+05	0.7686E+05					
19	0.8101E+05	0.7946E+05					
20	501.4	0.8051E+05			501.4172		

**** MOLE-X-PROFILE ****

STAGE	ETHYL-01	STYRE-01	ALPHA-01
1	0.74753E-03	0.99921	0.43541E-04
2	0.53718E-03	0.99938	0.84081E-04
9	0.12378E-03	0.99407	0.58048E-02
10	0.11410E-03	0.98943	0.10458E-01
11	0.10720E-03	0.98115	0.18747E-01
12	0.10195E-03	0.96656	0.33342E-01
13	0.82257E-04	0.94269	0.57229E-01
14	0.57263E-04	0.90373	0.96214E-01
19	0.41064E-05	0.29718	0.70282
20	0.19083E-05	0.18394	0.81606

**** MOLE-Y-PROFILE ****

STAGE	ETHYL-01	STYRE-01	ALPHA-01
1	0.10554E-02	0.99892	0.21937E-04
2	0.74753E-03	0.99921	0.43541E-04
9	0.17216E-03	0.99680	0.30326E-02
10	0.15895E-03	0.99436	0.54799E-02
11	0.14982E-03	0.98998	0.98705E-02
12	0.14333E-03	0.98216	0.17692E-01
13	0.11683E-03	0.96914	0.30746E-01
14	0.82733E-04	0.94718	0.52737E-01
19	0.82231E-05	0.44413	0.55586
20	0.41199E-05	0.29788	0.70212

**** K-VALUES ****

STAGE	ETHYL-01	STYRE-01	ALPHA-01
1	1.4118	0.99971	0.50381
2	1.3915	0.99982	0.51788
9	1.3909	1.0027	0.52243
10	1.3931	1.0050	0.52401
11	1.3976	1.0090	0.52650
12	1.4059	1.0161	0.53063
13	1.4203	1.0281	0.53724
14	1.4448	1.0481	0.54812
19	2.0029	1.4946	0.79085
20	2.1590	1.6195	0.86037

**** MASS-X-PROFILE ****

STAGE	ETHYL-01	STYRE-01	ALPHA-01
1	0.76199E-03	0.99919	0.49404E-04
2	0.54756E-03	0.99936	0.95403E-04
9	0.12607E-03	0.99329	0.65815E-02
10	0.11614E-03	0.98803	0.11850E-01
11	0.10900E-03	0.97867	0.21219E-01
12	0.10345E-03	0.96223	0.37663E-01
13	0.83208E-04	0.93548	0.64440E-01
14	0.57624E-04	0.89217	0.10778
19	0.38239E-05	0.27148	0.72851
20	0.17526E-05	0.16572	0.83427

**** MASS-Y-PROFILE ****

STAGE	ETHYL-01	STYRE-01	ALPHA-01
1	0.10758E-02	0.99890	0.24891E-04
2	0.76199E-03	0.99919	0.49404E-04
9	0.17542E-03	0.99638	0.34396E-02
10	0.16191E-03	0.99362	0.62134E-02
11	0.15252E-03	0.98866	0.11185E-01
12	0.14576E-03	0.97983	0.20027E-01
13	0.11860E-03	0.96514	0.34742E-01
14	0.83739E-04	0.94050	0.59417E-01
19	0.77984E-05	0.41320	0.58679
20	0.38368E-05	0.27214	0.72785

****
***** HYDRAULIC PARAMETERS *****
****

*** DEFINITIONS ***

MARANGONI INDEX = SIGMA - SIGMATO
FLOW PARAM = (ML/MV)*SQRT(RHOV/RHOL)
QR = QV*SQRT(RHOV/(RHOL-RHOV))
F FACTOR = QV*SQRT(RHOV)
WHERE:
SIGMA IS THE SURFACE TENSION OF LIQUID FROM THE STAGE
SIGMATO IS THE SURFACE TENSION OF LIQUID TO THE STAGE
ML IS THE MASS FLOW OF LIQUID FROM THE STAGE
MV IS THE MASS FLOW OF VAPOR TO THE STAGE
RHOL IS THE MASS DENSITY OF LIQUID FROM THE STAGE
RHOV IS THE MASS DENSITY OF VAPOR TO THE STAGE
QV IS THE VOLUMETRIC FLOW RATE OF VAPOR TO THE STAGE

	TEMPERATURE F	
STAGE	LIQUID FROM	VAPOR TO
1	148.45	166.48
2	166.48	167.07
9	170.59	171.24
10	171.24	171.97
11	171.97	172.83
12	172.83	173.92
13	173.89	175.31
14	175.31	177.39
19	194.81	199.32
20	199.32	199.32

	MASS FLOW LB/HR		VOLUME FLOW CUFT/HR		MOLECULAR WEIGHT	
STAGE	LIQUID FROM	VAPOR TO	LIQUID FROM	VAPOR TO	LIQUID FROM	VAPOR TO
1	75782.	75782.	1405.5	0.33146E+07	104.15	104.15
2	74472.	78930.	1395.8	0.34104E+07	104.15	104.15
9	74650.	79108.	1402.5	0.31500E+07	104.23	104.23
10	74687.	79145.	1403.7	0.31158E+07	104.30	104.29
11	74736.	79194.	1405.2	0.30822E+07	104.41	104.40
12	74806.	79264.	1407.2	0.30846E+07	104.62	104.59
13	77357.	76855.	1455.9	0.29205E+07	104.95	104.89
14	77527.	77026.	1460.1	0.28881E+07	105.50	105.44
19	81014.	80512.	1536.1	0.27325E+07	114.01	114.00
20	501.42	0.0000	9.5210	0.0000	115.60	

STAGE	DENSITY LB/CUFT LIQUID FROM	DENSITY LB/CUFT VAPOR TO	VISCOSITY CP LIQUID FROM	VISCOSITY CP VAPOR TO	SURFACE TENSION DYNE/CM LIQUID FROM
1	53.920	0.22863E-01	0.43197	0.74846E-02	26.742
2	53.354	0.23144E-01	0.39046	0.74916E-02	25.653
9	53.226	0.25114E-01	0.38247	0.75387E-02	25.413
10	53.206	0.25401E-01	0.38157	0.75452E-02	25.380
11	53.185	0.25694E-01	0.38084	0.75517E-02	25.345
12	53.161	0.25697E-01	0.38040	0.75580E-02	25.310
13	53.133	0.26316E-01	0.38037	0.75646E-02	25.272
14	53.098	0.26670E-01	0.38097	0.75706E-02	25.229
19	52.739	0.29464E-01	0.39595	0.75420E-02	24.674
20	52.664		0.39706		24.513

STAGE	MARANGONI INDEX DYNE/CM	FLOW PARAM	QR CUFT/HR	REDUCED F-FACTOR (LB-CUFT)**.5/HR
1		0.20592E-01	68268.	0.50119E+06
2	-1.0885	0.19651E-01	71045.	0.51882E+06
9	-.33622E-01	0.20498E-01	68439.	0.49919E+06
10	-.33748E-01	0.20619E-01	68096.	0.49659E+06
11	-.34269E-01	0.20742E-01	67762.	0.49406E+06
12	-.35532E-01	0.20749E-01	67833.	0.49446E+06
13	-.36284E-01	0.22400E-01	65011.	0.47376E+06
14	-.42655E-01	0.22558E-01	64743.	0.47165E+06
19	-.16969	0.23784E-01	64606.	0.46905E+06
20	-.16131		0.0000	0.0000

```
*************************************
***** PACKING SIZING CALCULATIONS *****
*************************************


******************
*** SECTION   1 ***
******************

STARTING STAGE NUMBER                         2
ENDING STAGE NUMBER                          19
CAPACITY CALCULATION METHOD                  WALLIS
PRESSURE DROP CALCULATION METHOD             WALLIS
LIQUID HOLDUP CALCULATION METHOD             STICHL
```

PRESSURE PROFILE UPDATED NO

DESIGN PARAMETERS

OVERDESIGN FACTOR		1.00000
SYSTEM FOAMING FACTOR		1.00000
FRAC. APP. TO MAXIMUM CAPACITY		0.80000
MAXIMUM CAPACITY FACTOR	FT/SEC	MISSING
DESIGN CAPACITY FACTOR	FT/SEC	MISSING
PRESSURE DROP FOR THE SECTION	PSI	MISSING
PRESSURE DROP PER UNIT HEIGHT	IN-WATER/FT	MISSING

PACKING SPECIFICATIONS

PACKING TYPE		FLEXIRING
PACKING MATERIAL		METAL
PACKING SIZE		0.625-IN
VENDOR		KOCH
PACKING FACTOR	1/FT	70.0004
PACKING SURFACE AREA	SQFT/CUF	100.889
PACKING VOID FRACTION		0.93000
FIRST STICHLMAIR CONSTANT		3.12539
SECOND STICHLMAIR CONSTANT		13.5957
THIRD STICHLMAIR CONSTANT		1.88108
HETP	FT	1.25000
PACKING HEIGHT	FT	22.5000

***** SIZING RESULTS *****

COLUMN DIAMETER	FT	10.5688
MAXIMUM FRACTIONAL CAPACITY		0.93648
MAXIMUM CAPACITY FACTOR	FT/SEC	0.22495
PRESSURE DROP FOR THE SECTION	PSI	0.89756
AVERAGE PRESSURE DROP/HEIGHT	IN-WATER/FT	1.10420
MAXIMUM LIQUID HOLDUP/STAGE	CUFT	3.40248
MAX LIQ SUPERFICIAL VELOCITY	GPM/SQFT	2.18305

**** RATING PROFILES AT MAXIMUM COLUMN DIAMETER ****

STAGE	HEIGHT FROM TOP OF SECTION FT	FRACTIONAL CAPACITY	PRESSURE DROP PSI	PRESSURE DROP/HEIGHT IN-WATER/FT	LIQUID HOLDUP CUFT	HETP FT
2	0.000	0.9365	0.57361E-01	1.2658	3.402	1.250

3	1.250	0.9319	0.56439E-01	1.2453	3.386	1.250
4	2.500	0.9275	0.55547E-01	1.2255	3.370	1.250
5	3.750	0.9230	0.54684E-01	1.2063	3.355	1.250
6	5.000	0.9187	0.53850E-01	1.1878	3.341	1.250
7	6.250	0.9145	0.53044E-01	1.1699	3.327	1.250
8	7.500	0.9103	0.52265E-01	1.1526	3.314	1.250
9	8.750	0.9063	0.51513E-01	1.1359	3.301	1.250
10	10.00	0.9023	0.50789E-01	1.1198	3.290	1.250
11	11.25	0.8985	0.50096E-01	1.1044	3.279	1.250
12	12.50	0.8995	0.50243E-01	1.1076	3.286	1.250
13	13.75	0.8695	0.45189E-01	0.99560	3.271	1.250
14	15.00	0.8666	0.44703E-01	0.98478	3.269	1.250
15	16.25	0.8643	0.44317E-01	0.97614	3.271	1.250
16	17.50	0.8633	0.44093E-01	0.97110	3.283	1.250
17	18.75	0.8638	0.44111E-01	0.97138	3.305	1.250
18	20.00	0.8663	0.44407E-01	0.97781	3.340	1.250
19	21.25	0.8700	0.44908E-01	0.98878	3.380	1.250

STAGE	LIQUID SUPERFICIAL VELOCITY GPM/SQFT
2	1.984
3	1.985
4	1.986
5	1.988
6	1.989
7	1.990
8	1.992
9	1.993
10	1.995
11	1.997
12	2.000
13	2.069
14	2.075
15	2.085
16	2.100
17	2.122
18	2.151
19	2.183

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BLOCK:  TOLCOL   MODEL: RADFRAC
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   INLETS   - LIQBOT   STAGE  17
   OUTLETS  - TOLUENE  STAGE   1
              TOLBTMS  STAGE  50
```

PROPERTY OPTION SET: PENG-ROB STANDARD PR EQUATION OF STATE

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(LBMOL/HR)	63.7376	63.7376	0.00000
MASS(LB/HR)	6632.50	6632.50	-0.981830E-13
ENTHALPY(BTU/HR)	0.315480E+07	0.299959E+07	0.491990E-01

*** CO2 EQUIVALENT SUMMARY ***

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

****
**** INPUT DATA ****
****

**** INPUT PARAMETERS ****

NUMBER OF STAGES	50
ALGORITHM OPTION	STANDARD
ABSORBER OPTION	NO
INITIALIZATION OPTION	STANDARD
HYDRAULIC PARAMETER CALCULATIONS	NO
INSIDE LOOP CONVERGENCE METHOD	BROYDEN
DESIGN SPECIFICATION METHOD	NESTED
MAXIMUM NO. OF OUTSIDE LOOP ITERATIONS	25
MAXIMUM NO. OF INSIDE LOOP ITERATIONS	10
MAXIMUM NUMBER OF FLASH ITERATIONS	30
FLASH TOLERANCE	0.000100000
OUTSIDE LOOP CONVERGENCE TOLERANCE	0.000100000

**** COL-SPECS ****

MOLAR VAPOR DIST / TOTAL DIST		0.0
MOLAR DISTILLATE RATE	LBMOL/HR	6.30000
MASS REFLUX RATIO		16.0000

**** PROFILES ****

P-SPEC STAGE 1 PRES, PSIA 40.0000

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******************
**** RESULTS ****
******************


*** COMPONENT SPLIT FRACTIONS ***

                    OUTLET STREAMS
                    --------------
          TOLUENE     TOLBTMS
 COMPONENT:
 TOLUE-01   .98820      .11802E-01
 ETHYL-01   .22344E-02  .99777
 STYRE-01   .64254E-04  .99994
 ALPHA-01   .34035E-07  1.0000
 PROPY-01   MISSING     MISSING
 PROPA-01   MISSING     MISSING
 1-BUT-01   1.0000      0.0000
 ISOBUTAN   1.0000      0.0000
 N-BUT-01   1.0000      0.0000


*** SUMMARY OF KEY RESULTS ***

 TOP STAGE TEMPERATURE          F                 305.860
 BOTTOM STAGE TEMPERATURE       F                 390.102
 TOP STAGE LIQUID FLOW          LBMOL/HR          100.800
 BOTTOM STAGE LIQUID FLOW       LBMOL/HR          57.4376
 TOP STAGE VAPOR FLOW           LBMOL/HR          0.0
 BOILUP VAPOR FLOW              LBMOL/HR          91.2102
 MOLAR REFLUX RATIO                               16.0000
 MOLAR BOILUP RATIO                               1.58799
 CONDENSER DUTY (W/O SUBCOOL)   BTU/HR            -1,462,390.
 REBOILER DUTY                  BTU/HR            1,307,180.

**** MAXIMUM FINAL RELATIVE ERRORS ****

 DEW POINT                  0.22773E-08  STAGE= 12
 BUBBLE POINT               0.23081E-08  STAGE= 12
 COMPONENT MASS BALANCE     0.55461E-08  STAGE=  7 COMP=ALPHA-01
 ENERGY BALANCE             0.26026E-08  STAGE=  9


**** PROFILES ****
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NOTE REPORTED VALUES FOR STAGE LIQUID AND VAPOR RATES ARE THE FLOWS
FROM THE STAGE INCLUDING ANY SIDE PRODUCT.

STAGE	TEMPERATURE F	PRESSURE PSIA	ENTHALPY BTU/LBMOL LIQUID	ENTHALPY BTU/LBMOL VAPOR	HEAT DUTY BTU/HR
1	305.86	40.000	14903.	28245.	-.14624+07
2	315.54	45.000	15362.	28558.	
3	315.96	45.120	15387.	28575.	
4	316.52	45.240	15436.	28606.	
15	365.62	46.560	39185.	48857.	
16	369.55	46.680	42082.	52096.	
17	372.23	46.800	44057.	54358.	
18	372.83	46.920	44212.	54594.	
47	387.68	50.400	48471.	60901.	
48	388.23	50.520	48959.	61465.	
49	388.97	50.640	49641.	62257.	
50	390.10	50.760	50589.	63376.	.13072+07

STAGE	FLOW RATE LBMOL/HR LIQUID	FLOW RATE LBMOL/HR VAPOR	FEED RATE LBMOL/HR LIQUID	FEED RATE LBMOL/HR VAPOR	FEED RATE LBMOL/HR MIXED	PRODUCT RATE LBMOL/HR LIQUID	PRODUCT RATE LBMOL/HR VAPOR
1	107.1	0.000				6.3000	
2	104.2	107.1					
3	104.1	110.5					
4	104.0	110.4					
15	95.12	101.7					
16	94.91	101.4		12.7748			
17	145.9	88.44	50.9627				
18	146.0	88.46					
47	148.7	91.20					
48	148.7	91.24					
49	148.6	91.26					
50	57.44	91.21				57.4375	

**** MASS FLOW PROFILES ****

STAGE	FLOW RATE LB/HR LIQUID	FLOW RATE LB/HR VAPOR	FEED RATE LB/HR LIQUID	FEED RATE LB/HR VAPOR	FEED RATE LB/HR MIXED	PRODUCT RATE LB/HR LIQUID	PRODUCT RATE LB/HR VAPOR
1	9874.	0.000				580.8409	
2	9608.	9874.					
3	9609.	0.1019E+05					
4	9609.	0.1019E+05					

15	9782.	0.1032E+05	
16	9812.	0.1036E+05	1318.0731
17	0.1514E+05	9075.	5314.4236
18	0.1516E+05	9085.	
47	0.1563E+05	9572.	
48	0.1564E+05	9579.	
49	0.1564E+05	9584.	
50	6052.	9588.	6051.6558

**** MOLE-X-PROFILE ****

STAGE	TOLUE-01	ETHYL-01	STYRE-01	ALPHA-01	PROPY-01
1	0.99591	0.36442E-02	0.44439E-03	0.19133E-07	0.0000
2	0.99285	0.62100E-02	0.94093E-03	0.65248E-07	0.0000
3	0.98777	0.10304E-01	0.19264E-02	0.21281E-06	0.0000
4	0.97934	0.16790E-01	0.38695E-02	0.68203E-06	0.0000
15	0.16971	0.25305	0.56234	0.14890E-01	0.0000
16	0.13190	0.22763	0.61551	0.24959E-01	0.0000
17	0.11111	0.20481	0.64664	0.37431E-01	0.0000
18	0.10611	0.20650	0.64987	0.37515E-01	0.0000
47	0.36334E-02	0.22181	0.73373	0.40829E-01	0.0000
48	0.27693E-02	0.21270	0.74143	0.43096E-01	0.0000
49	0.19959E-02	0.19902	0.75044	0.48552E-01	0.0000
50	0.13046E-02	0.17849	0.75855	0.61660E-01	0.0000

**** MOLE-X-PROFILE ****

STAGE	PROPA-01	1-BUT-01	ISOBUTAN	N-BUT-01
1	0.0000	0.46803E-09	0.12482E-09	0.10621E-08
2	0.0000	0.40919E-10	0.95922E-11	0.10114E-09
3	0.0000	0.57092E-11	0.12429E-11	0.14853E-10
4	0.0000	0.28056E-11	0.63771E-12	0.71035E-11
15	0.0000	0.21280E-11	0.50243E-12	0.52413E-11
16	0.0000	0.20912E-11	0.49426E-12	0.51456E-11
17	0.0000	0.60764E-12	0.13132E-12	0.15844E-11
18	0.0000	0.66679E-13	0.12875E-13	0.18737E-12
47	0.0000	0.80549E-41	0.64404E-43	0.19036E-39
48	0.0000	0.87681E-42	0.62948E-44	0.22271E-40
49	0.0000	0.94927E-43	0.61241E-45	0.25896E-41
50	0.0000	0.98779E-44	0.57466E-46	0.28867E-42

**** MOLE-Y-PROFILE ****

STAGE	TOLUE-01	ETHYL-01	STYRE-01	ALPHA-01	PROPY-01
1	0.99769	0.21056E-02	0.20548E-03	0.54324E-08	0.0000
2	0.99591	0.36442E-02	0.44439E-03	0.19133E-07	0.0000
3	0.99302	0.60637E-02	0.91261E-03	0.62618E-07	0.0000
4	0.98823	0.99241E-02	0.18419E-02	0.20175E-06	0.0000
15	0.27480	0.25409	0.46313	0.79774E-02	0.0000

16	0.22103	0.23756	0.52744	0.13965E-01	0.0000
17	0.19042	0.21924	0.56879	0.21550E-01	0.0000
18	0.18242	0.22191	0.57398	0.21699E-01	0.0000
47	0.66732E-02	0.25890	0.70827	0.26157E-01	0.0000
48	0.50994E-02	0.24908	0.71810	0.27716E-01	0.0000
49	0.36911E-02	0.23424	0.73066	0.31412E-01	0.0000
50	0.24312E-02	0.21194	0.74533	0.40298E-01	0.0000

**** MOLE-Y-PROFILE ****

STAGE	PROPA-01	1-BUT-01	ISOBUTAN	N-BUT-01
1	0.0000	0.56918E-08	0.17345E-08	0.11836E-07
2	0.0000	0.46803E-09	0.12482E-09	0.10621E-08
3	0.0000	0.65279E-10	0.16164E-10	0.15595E-09
4	0.0000	0.32093E-10	0.82949E-11	0.74619E-10
15	0.0000	0.31038E-10	0.82142E-11	0.70838E-10
16	0.0000	0.31068E-10	0.82241E-11	0.70890E-10
17	0.0000	0.91312E-11	0.22089E-11	0.22091E-10
18	0.0000	0.10022E-11	0.21658E-12	0.26133E-11
47	0.0000	0.12046E-39	0.10729E-41	0.26482E-38
48	0.0000	0.13119E-40	0.10491E-42	0.31001E-39
49	0.0000	0.14225E-41	0.10221E-43	0.36106E-40
50	0.0000	0.14849E-42	0.96187E-45	0.40385E-41

**** K-VALUES ****

STAGE	TOLUE-01	ETHYL-01	STYRE-01	ALPHA-01	PROPY-01
1	1.0018	0.57780	0.46238	0.28393	24.464
2	1.0031	0.58683	0.47229	0.29323	22.603
3	1.0053	0.58846	0.47373	0.29425	22.579
4	1.0091	0.59109	0.47600	0.29581	22.568
15	1.6192	1.0041	0.82357	0.53577	26.844
16	1.6757	1.0436	0.85691	0.55950	27.202
17	1.7138	1.0705	0.87960	0.57572	27.419
18	1.7192	1.0746	0.88322	0.57840	27.401
47	1.8366	1.1672	0.96530	0.64063	26.706
48	1.8414	1.1710	0.96854	0.64313	26.701
49	1.8493	1.1770	0.97364	0.64697	26.715
50	1.8635	1.1874	0.98258	0.65355	26.762

**** K-VALUES ****

STAGE	PROPA-01	1-BUT-01	ISOBUTAN	N-BUT-01
1	22.859	12.161	13.897	11.144
2	21.153	11.438	13.012	10.502
3	21.132	11.434	13.005	10.499
4	21.123	11.439	13.007	10.504
15	25.316	14.586	16.349	13.515
16	25.671	14.856	16.639	13.777

17	25.888	15.027	16.821	13.943
18	25.873	15.030	16.822	13.947
47	25.267	14.955	16.659	13.911
48	25.265	14.963	16.666	13.920
49	25.282	14.985	16.689	13.943
50	25.331	15.032	16.738	13.990

**** MASS-X-PROFILE ****

STAGE	TOLUE-01	ETHYL-01	STYRE-01	ALPHA-01	PROPY-01
1	0.99530	0.41964E-02	0.50202E-03	0.24525E-07	0.0000
2	0.99179	0.71477E-02	0.10624E-02	0.83597E-07	0.0000
3	0.98597	0.11851E-01	0.21736E-02	0.27245E-06	0.0000
4	0.97635	0.19286E-01	0.43605E-02	0.87210E-06	0.0000
15	0.15207	0.26126	0.56956	0.17112E-01	0.0000
16	0.11757	0.23377	0.62013	0.28533E-01	0.0000
17	0.98675E-01	0.20958	0.64911	0.42635E-01	0.0000
18	0.94169E-01	0.21117	0.65195	0.42704E-01	0.0000
47	0.31846E-02	0.22400	0.72691	0.45898E-01	0.0000
48	0.24266E-02	0.21476	0.73438	0.48435E-01	0.0000
49	0.17480E-02	0.20083	0.74289	0.54537E-01	0.0000
50	0.11409E-02	0.17986	0.74984	0.69161E-01	0.0000

**** MASS-X-PROFILE ****

STAGE	PROPA-01	1-BUT-01	ISOBUTAN	N-BUT-01
1	0.0000	0.28483E-09	0.78687E-10	0.66959E-09
2	0.0000	0.24891E-10	0.60444E-11	0.63731E-10
3	0.0000	0.34702E-11	0.78260E-12	0.93527E-11
4	0.0000	0.17032E-11	0.40105E-12	0.44673E-11
15	0.0000	0.11611E-11	0.28399E-12	0.29625E-11
16	0.0000	0.11350E-11	0.27790E-12	0.28931E-11
17	0.0000	0.32859E-12	0.73563E-13	0.88760E-12
18	0.0000	0.36035E-13	0.72083E-14	0.10490E-12
47	0.0000	0.42990E-41	0.35608E-43	0.10525E-39
48	0.0000	0.46785E-42	0.34795E-44	0.12310E-40
49	0.0000	0.50624E-43	0.33833E-45	0.14306E-41
50	0.0000	0.52602E-44	0.31702E-46	0.15925E-42

**** MASS-Y-PROFILE ****

STAGE	TOLUE-01	ETHYL-01	STYRE-01	ALPHA-01	PROPY-01
1	0.99734	0.24253E-02	0.23218E-03	0.69651E-08	0.0000
2	0.99530	0.41964E-02	0.50202E-03	0.24525E-07	0.0000
3	0.99199	0.69795E-02	0.10305E-02	0.80229E-07	0.0000
4	0.98651	0.11415E-01	0.20783E-02	0.25832E-06	0.0000
15	0.24952	0.26584	0.47535	0.92905E-02	0.0000
16	0.19933	0.24685	0.53766	0.16152E-01	0.0000
17	0.17100	0.22685	0.57734	0.24820E-01	0.0000

18	0.16364	0.22937	0.58202	0.24966E-01	0.0000
47	0.58581E-02	0.26188	0.70281	0.29451E-01	0.0000
48	0.44757E-02	0.25189	0.71243	0.31200E-01	0.0000
49	0.32385E-02	0.23680	0.72462	0.35347E-01	0.0000
50	0.21311E-02	0.21406	0.73850	0.45306E-01	0.0000

**** MASS-Y-PROFILE ****

STAGE	PROPA-01	1-BUT-01	ISOBUTAN	N-BUT-01
1	0.0000	0.34647E-08	0.10938E-08	0.74637E-08
2	0.0000	0.28483E-09	0.78687E-10	0.66959E-09
3	0.0000	0.39709E-10	0.10186E-10	0.98270E-10
4	0.0000	0.19508E-10	0.52234E-11	0.46988E-10
15	0.0000	0.17162E-10	0.47050E-11	0.40575E-10
16	0.0000	0.17061E-10	0.46785E-11	0.40328E-10
17	0.0000	0.49930E-11	0.12513E-11	0.12514E-10
18	0.0000	0.54746E-12	0.12256E-12	0.14788E-11
47	0.0000	0.64394E-40	0.59414E-42	0.14665E-38
48	0.0000	0.70117E-41	0.58085E-43	0.17164E-39
49	0.0000	0.75996E-42	0.56566E-44	0.19983E-40
50	0.0000	0.79258E-43	0.53187E-45	0.22331E-41

****
***** HYDRAULIC PARAMETERS *****
****

*** DEFINITIONS ***

MARANGONI INDEX = SIGMA - SIGMATO
FLOW PARAM = (ML/MV)*SQRT(RHOV/RHOL)
QR = QV*SQRT(RHOV/(RHOL-RHOV))
F FACTOR = QV*SQRT(RHOV)
WHERE:
SIGMA IS THE SURFACE TENSION OF LIQUID FROM THE STAGE
SIGMATO IS THE SURFACE TENSION OF LIQUID TO THE STAGE
ML IS THE MASS FLOW OF LIQUID FROM THE STAGE
MV IS THE MASS FLOW OF VAPOR TO THE STAGE
RHOL IS THE MASS DENSITY OF LIQUID FROM THE STAGE
RHOV IS THE MASS DENSITY OF VAPOR TO THE STAGE
QV IS THE VOLUMETRIC FLOW RATE OF VAPOR TO THE STAGE

TEMPERATURE

	F	
STAGE	LIQUID FROM	VAPOR TO
1	305.86	315.54
2	315.54	315.96
3	315.96	316.52
4	316.52	317.31
15	365.62	369.55
16	369.55	372.67
17	372.23	372.83
18	372.83	373.45
47	387.68	388.23
48	388.23	388.97
49	388.97	390.10
50	390.10	390.10

	MASS FLOW LB/HR		VOLUME FLOW CUFT/HR		MOLECULAR WEIGHT	
STAGE	LIQUID FROM	VAPOR TO	LIQUID FROM	VAPOR TO	LIQUID FROM	VAPOR TO
1	9874.3	9874.3	215.29	18236.	92.197	92.197
2	9607.8	10189.	211.28	18765.	92.239	92.237
3	9608.8	10190.	211.36	18714.	92.308	92.302
4	9608.9	10190.	211.42	18659.	92.423	92.410
15	9781.9	10363.	215.75	17722.	102.83	102.17
16	9811.8	10393.	216.31	17749.	103.38	102.68
17	15137.	9085.5	333.59	15429.	103.75	102.71
18	15156.	9104.5	334.11	15413.	103.82	102.82
47	15630.	9578.6	347.07	14951.	105.13	104.98
48	15635.	9583.8	347.15	14929.	105.15	105.02
49	15639.	9587.5	347.17	14904.	105.21	105.11
50	6051.7	0.0000	134.30	0.0000	105.36	

	DENSITY LB/CUFT		VISCOSITY CP		SURFACE TENSION DYNE/CM
STAGE	LIQUID FROM	VAPOR TO	LIQUID FROM	VAPOR TO	LIQUID FROM
1	45.866	0.54148	0.17192	0.10152E-01	14.434
2	45.474	0.54296	0.16532	0.10155E-01	13.888
3	45.462	0.54449	0.16524	0.10159E-01	13.866
4	45.449	0.54611	0.16520	0.10162E-01	13.841
15	45.339	0.58475	0.17317	0.10148E-01	13.584
16	45.360	0.58552	0.17337	0.10146E-01	13.546
17	45.377	0.58887	0.17343	0.10148E-01	13.521
18	45.363	0.59070	0.17339	0.10149E-01	13.514
47	45.035	0.64066	0.17168	0.10192E-01	12.940

48	45.039	0.64195	0.17154	0.10196E-01	12.937
49	45.048	0.64330	0.17138	0.10199E-01	12.939
50	45.062		0.17124		12.939

STAGE	MARANGONI INDEX DYNE/CM	FLOW PARAM	QR CUFT/HR	REDUCED F-FACTOR (LB-CUFT)**.5/HR
1		0.10865	1993.2	13419.
2	-.54634	0.10304	2062.8	13827.
3	-.21810E-01	0.10320	2060.4	13809.
4	-.25204E-01	0.10337	2057.7	13789.
15	-.81157E-01	0.10720	2025.7	13552.
16	-.38795E-01	0.10726	2029.7	13582.
17	-.14119E-01	0.18980	1769.1	11840.
18	-.70428E-02	0.18996	1770.4	11846.
47	-.60458E-02	0.19463	1796.1	11967.
48	-.26063E-02	0.19477	1795.2	11961.
49	0.17941E-02	0.19493	1793.8	11954.
50	-.20276E-04		0.0000	0.0000

****
***** TRAY SIZING CALCULATIONS *****
****

****
*** SECTION 1 ***
****

STARTING STAGE NUMBER 2
ENDING STAGE NUMBER 49
FLOODING CALCULATION METHOD B960-1

DESIGN PARAMETERS

PEAK CAPACITY FACTOR 1.00000
SYSTEM FOAMING FACTOR 1.00000
FLOODING FACTOR 0.80000
MINIMUM COLUMN DIAMETER FT 1.00000
MINIMUM DC AREA/COLUMN AREA 0.100000

TRAY SPECIFICATIONS

TRAY TYPE		FLEXI
NUMBER OF PASSES		1
TRAY SPACING	FT	2.00000

***** SIZING RESULTS @ STAGE WITH MAXIMUM DIAMETER *****

STAGE WITH MAXIMUM DIAMETER		2
COLUMN DIAMETER	FT	1.57422
DC AREA/COLUMN AREA		0.100000
DOWNCOMER VELOCITY	FT/SEC	0.30153
FLOW PATH LENGTH	FT	1.08156
SIDE DOWNCOMER WIDTH	FT	0.24633
SIDE WEIR LENGTH	FT	1.14384
CENTER DOWNCOMER WIDTH	FT	0.0
CENTER WEIR LENGTH	FT	MISSING
OFF-CENTER DOWNCOMER WIDTH	FT	0.0
OFF-CENTER SHORT WEIR LENGTH	FT	MISSING
OFF-CENTER LONG WEIR LENGTH	FT	MISSING
TRAY CENTER TO OCDC CENTER	FT	0.0

**** SIZING PROFILES ****

STAGE	DIAMETER	TOTAL AREA	ACTIVE AREA	SIDE DC AREA
	FT	SQFT	SQFT	SQFT
2	1.5742	1.9463	1.5571	0.19463
3	1.5742	1.9463	1.5571	0.19463
4	1.5742	1.9463	1.5571	0.19463
5	1.5742	1.9463	1.5571	0.19463
6	1.5742	1.9463	1.5571	0.19463
7	1.5742	1.9463	1.5571	0.19463
8	1.5742	1.9463	1.5571	0.19463
9	1.5742	1.9463	1.5571	0.19463
10	1.5742	1.9463	1.5571	0.19463
11	1.5742	1.9463	1.5571	0.19463
12	1.5742	1.9463	1.5571	0.19463
13	1.5742	1.9463	1.5571	0.19463
14	1.5742	1.9463	1.5571	0.19463
15	1.5742	1.9463	1.5571	0.19463
16	1.5742	1.9463	1.5571	0.19463
17	1.5742	1.9463	1.5571	0.19463
18	1.5742	1.9463	1.5571	0.19463
19	1.5742	1.9463	1.5571	0.19463
20	1.5742	1.9463	1.5571	0.19463
21	1.5742	1.9463	1.5571	0.19463

22	1.5742	1.9463	1.5571	0.19463
23	1.5742	1.9463	1.5571	0.19463
24	1.5742	1.9463	1.5571	0.19463
25	1.5742	1.9463	1.5571	0.19463
26	1.5742	1.9463	1.5571	0.19463
27	1.5742	1.9463	1.5571	0.19463
28	1.5742	1.9463	1.5571	0.19463
29	1.5742	1.9463	1.5571	0.19463
30	1.5742	1.9463	1.5571	0.19463
31	1.5742	1.9463	1.5571	0.19463
32	1.5742	1.9463	1.5571	0.19463
33	1.5742	1.9463	1.5571	0.19463
34	1.5742	1.9463	1.5571	0.19463
35	1.5742	1.9463	1.5571	0.19463
36	1.5742	1.9463	1.5571	0.19463
37	1.5742	1.9463	1.5571	0.19463
38	1.5742	1.9463	1.5571	0.19463
39	1.5742	1.9463	1.5571	0.19463
40	1.5742	1.9463	1.5571	0.19463
41	1.5742	1.9463	1.5571	0.19463
42	1.5742	1.9463	1.5571	0.19463
43	1.5742	1.9463	1.5571	0.19463
44	1.5742	1.9463	1.5571	0.19463
45	1.5742	1.9463	1.5571	0.19463
46	1.5742	1.9463	1.5571	0.19463
47	1.5742	1.9463	1.5571	0.19463
48	1.5742	1.9463	1.5571	0.19463
49	1.5742	1.9463	1.5571	0.19463

**** ADDITIONAL SIZING PROFILES ****

STAGE	FLOODING FACTOR	PRES. DROP PSI	DC BACKUP FT	DC BACKUP/ (TSPC+WHT)
2	80.00	0.6010	3.276	151.2
3	79.91	0.5995	3.269	150.9
4	79.80	0.5978	3.261	150.5
5	79.67	0.5957	3.251	150.0
6	79.51	0.5931	3.238	149.5
7	79.29	0.5897	3.221	148.7
8	79.01	0.5853	3.200	147.7
9	78.68	0.5803	3.174	146.5
10	78.36	0.5756	3.151	145.4
11	78.17	0.5727	3.136	144.7
12	78.15	0.5724	3.135	144.7

13	78.27	0.5741	3.145	145.1
14	78.44	0.5766	3.158	145.7
15	78.56	0.5786	3.167	146.2
16	78.72	0.5812	3.180	146.8
17	71.34	0.4511	2.548	117.6
18	71.40	0.4517	2.552	117.8
19	71.47	0.4522	2.555	117.9
20	71.53	0.4528	2.559	118.1
21	71.60	0.4534	2.563	118.3
22	71.67	0.4540	2.567	118.5
23	71.74	0.4547	2.572	118.7
24	71.81	0.4553	2.576	118.9
25	71.88	0.4560	2.580	119.1
26	71.95	0.4566	2.584	119.3
27	72.02	0.4572	2.589	119.5
28	72.09	0.4578	2.593	119.7
29	72.15	0.4584	2.597	119.8
30	72.21	0.4590	2.600	120.0
31	72.27	0.4595	2.604	120.2
32	72.33	0.4600	2.607	120.3
33	72.38	0.4604	2.610	120.5
34	72.43	0.4608	2.613	120.6
35	72.47	0.4611	2.615	120.7
36	72.51	0.4614	2.618	120.8
37	72.55	0.4616	2.620	120.9
38	72.58	0.4618	2.621	121.0
39	72.61	0.4620	2.623	121.1
40	72.63	0.4621	2.624	121.1
41	72.65	0.4622	2.625	121.2
42	72.67	0.4622	2.626	121.2
43	72.68	0.4622	2.626	121.2
44	72.69	0.4621	2.626	121.2
45	72.69	0.4620	2.626	121.2
46	72.69	0.4618	2.625	121.2
47	72.67	0.4615	2.623	121.1
48	72.64	0.4611	2.621	121.0
49	72.59	0.4606	2.618	120.8

STAGE	HEIGHT OVER WEIR FT	DC REL FROTH DENS	TR LIQ REL FROTH DENS	FRA APPR TO SYS LIMIT
2	0.5194	0.6062	0.7799E-01	65.44
3	0.5190	0.6062	0.7809E-01	65.40
4	0.5186	0.6061	0.7821E-01	65.34
5	0.5180	0.6061	0.7836E-01	65.27
6	0.5171	0.6061	0.7855E-01	65.18

7	0.5159	0.6061	0.7880E-01	65.18
8	0.5142	0.6061	0.7912E-01	64.91
9	0.5122	0.6061	0.7949E-01	64.62
10	0.5107	0.6061	0.7985E-01	64.38
11	0.5105	0.6061	0.8008E-01	64.18
12	0.5119	0.6061	0.8011E-01	64.18
13	0.5145	0.6061	0.7999E-01	64.33
14	0.5172	0.6061	0.7981E-01	64.55
15	0.5193	0.6061	0.7966E-01	64.76
16	0.5210	0.6061	0.7947E-01	64.95
17	0.6278	0.6061	0.9264E-01	56.95
18	0.6288	0.6061	0.9259E-01	57.00
19	0.6297	0.6061	0.9252E-01	57.08
20	0.6307	0.6061	0.9246E-01	57.15
21	0.6317	0.6061	0.9239E-01	57.23
22	0.6327	0.6061	0.9231E-01	57.30
23	0.6338	0.6060	0.9224E-01	57.38
24	0.6349	0.6060	0.9216E-01	57.46
25	0.6359	0.6060	0.9209E-01	57.54
26	0.6370	0.6060	0.9201E-01	57.63
27	0.6380	0.6060	0.9194E-01	57.71
28	0.6390	0.6060	0.9187E-01	57.78
29	0.6400	0.6060	0.9181E-01	57.86
30	0.6409	0.6060	0.9175E-01	57.93
31	0.6418	0.6060	0.9169E-01	58.01
32	0.6427	0.6060	0.9164E-01	58.07
33	0.6435	0.6060	0.9159E-01	58.14
34	0.6443	0.6060	0.9155E-01	58.20
35	0.6451	0.6060	0.9151E-01	58.25
36	0.6458	0.6059	0.9148E-01	58.31
37	0.6464	0.6059	0.9146E-01	58.36
38	0.6470	0.6059	0.9144E-01	58.40
39	0.6476	0.6059	0.9142E-01	58.45
40	0.6481	0.6059	0.9141E-01	58.49
41	0.6485	0.6059	0.9141E-01	58.52
42	0.6489	0.6059	0.9141E-01	58.54
43	0.6493	0.6059	0.9141E-01	58.56
44	0.6496	0.6059	0.9142E-01	58.58
45	0.6498	0.6059	0.9144E-01	58.59
46	0.6500	0.6059	0.9147E-01	58.59
47	0.6500	0.6059	0.9150E-01	58.59
48	0.6499	0.6059	0.9155E-01	58.57
49	0.6496	0.6059	0.9162E-01	58.53

b) Streams Report

AIR ALPHA BFWIN BFWOUT CHAR

STREAM ID	AIR	ALPHA	BFWIN	BFWOUT	CHAR
FROM :	----	STYCOL	----	HEATX	SEP
TO :	FURNACE	----	HEATX	----	----
SUBSTREAM: MIXED					
PHASE:	VAPOR	LIQUID	LIQUID	VAPOR	SOLID
COMPONENTS: LBMOL/HR					
POLY(-01	0.0	0.0	0.0	0.0	0.0
TOLUE-01	0.0	0.0	0.0	0.0	0.0
ETHYL-01	0.0	8.2774-06	0.0	0.0	0.0
STYRE-01	0.0	0.7978	0.0	0.0	0.0
ALPHA-01	0.0	3.5397	0.0	0.0	0.0
CARBON	0.0	0.0	0.0	0.0	38.0230
AIR	0.0	0.0	0.0	0.0	0.0
WATER	0.0	0.0	105.4660	105.4660	0.0
METHA-01	0.0	0.0	0.0	0.0	0.0
ETHYLENE	0.0	0.0	0.0	0.0	0.0
ETHAN-01	0.0	0.0	0.0	0.0	0.0
PROPY-01	0.0	0.0	0.0	0.0	0.0
PROPA-01	0.0	0.0	0.0	0.0	0.0
1-BUT-01	0.0	0.0	0.0	0.0	0.0
ISOBUTAN	0.0	0.0	0.0	0.0	0.0
N-BUT-01	0.0	0.0	0.0	0.0	0.0
H2	0.0	0.0	0.0	0.0	0.0
O2	231.0000	0.0	0.0	0.0	0.0
CO2	0.0	0.0	0.0	0.0	0.0
N2	869.0000	0.0	0.0	0.0	0.0
COMPONENTS: LB/HR					
POLY(-01	0.0	0.0	0.0	0.0	0.0
TOLUE-01	0.0	0.0	0.0	0.0	0.0
ETHYL-01	0.0	8.7879-04	0.0	0.0	0.0
STYRE-01	0.0	83.0967	0.0	0.0	0.0
ALPHA-01	0.0	418.3196	0.0	0.0	0.0
CARBON	0.0	0.0	0.0	0.0	456.6941
AIR	0.0	0.0	0.0	0.0	0.0
WATER	0.0	0.0	1900.0000	1900.0000	0.0
METHA-01	0.0	0.0	0.0	0.0	0.0
ETHYLENE	0.0	0.0	0.0	0.0	0.0
ETHAN-01	0.0	0.0	0.0	0.0	0.0
PROPY-01	0.0	0.0	0.0	0.0	0.0
PROPA-01	0.0	0.0	0.0	0.0	0.0

1-BUT-01	0.0	0.0	0.0	0.0	0.0
ISOBUTAN	0.0	0.0	0.0	0.0	0.0
N-BUT-01	0.0	0.0	0.0	0.0	0.0
H2	0.0	0.0	0.0	0.0	0.0
O2	7391.7228	0.0	0.0	0.0	0.0
CO2	0.0	0.0	0.0	0.0	0.0
N2	2.4344+04	0.0	0.0	0.0	0.0
TOTAL FLOW:					
LBMOL/HR	1100.0000	4.3376	105.4660	105.4660	38.0230
LB/HR	3.1735+04	501.4172	1900.0000	1900.0000	456.6941
CUFT/HR	4.3085+05	9.5210	30.8371	1.3236+04	3.2513
STATE VARIABLES:					
TEMP F	77.0000	199.3213	90.0000	297.8166	752.0000
PRES PSIA	14.6959	1.8149	63.0000	63.0000	20.0000
VFRAC	1.0000	0.0	0.0	1.0000	0.0
LFRAC	0.0	1.0000	1.0000	0.0	0.0
SFRAC	0.0	0.0	0.0	0.0	1.0000
ENTHALPY:					
BTU/LBMOL	-3.5023	3.9692+04	-1.2345+05	-1.0229+05	2359.4337
BTU/LB	-0.1214	343.3589	-6852.5769	-5677.7065	196.4394
BTU/HR	-3852.5608	1.7217+05	-1.3020+07	-1.0788+07	8.9713+04
ENTROPY:					
BTU/LBMOL-R	1.0152	-89.0843	-39.6552	-10.8048	2.6864
BTU/LB-R	3.5188-02	-0.7706	-2.2012	-0.5998	0.2237
DENSITY:					
LBMOL/CUFT	2.5531-03	0.4556	3.4201	7.9680-03	11.6946
LB/CUFT	7.3658-02	52.6641	61.6141	0.1435	140.4642
AVG MW	28.8504	115.5983	18.0153	18.0153	12.0110

COOLEDFD CYCLVAP EBCOLBTM EBOVHD FDHOT

STREAM ID	COOLEDFD	CYCLVAP	EBCOLBTM	EBOVHD	FDHOT
FROM :	COOL	B1	EBCOL	EBCOL	HEATX
TO :	SEP1	HEATX	STYCOL	----	COOL
SUBSTREAM: MIXED					
PHASE:	MIXED	VAPOR	LIQUID	LIQUID	VAPOR
COMPONENTS: LBMOL/HR					
POLY(-01	0.0	0.0	0.0	0.0	0.0
TOLUE-01	6.6479	6.6479	1.0201-18	7.4935-02	6.6479
ETHYL-01	10.4558	10.4558	3.2003-02	10.2200	10.4558
STYRE-01	44.0971	44.0971	43.5640	5.0601-03	44.0971
ALPHA-01	3.5612	3.5612	3.5416	3.7629-13	3.5612
CARBON	0.0	0.0	0.0	0.0	0.0
AIR	0.0	0.0	0.0	0.0	0.0

WATER	0.0	0.0	0.0	0.0	0.0
METHA-01	7.8960	7.8960	0.0	0.0	7.8960
ETHYLENE	4.5154	4.5154	0.0	0.0	4.5154
ETHAN-01	4.2127	4.2127	0.0	0.0	4.2127
PROPY-01	3.0103	3.0103	0.0	0.0	3.0103
PROPA-01	2.8727	2.8727	0.0	0.0	2.8727
1-BUT-01	2.2577	2.2577	0.0	0.0	2.2577
ISOBUTAN	2.1794	2.1794	0.0	0.0	2.1794
N-BUT-01	2.1794	2.1794	0.0	0.0	2.1794
H2	62.8382	62.8382	0.0	0.0	62.8382
O2	0.0	0.0	0.0	0.0	0.0
CO2	0.0	0.0	0.0	0.0	0.0
N2	0.0	0.0	0.0	0.0	0.0
COMPONENTS: LB/HR					
POLY(-01	0.0	0.0	0.0	0.0	0.0
TOLUE-01	612.5368	612.5368	9.3995-17	6.9046	612.5368
ETHYL-01	1110.0666	1110.0666	3.3976	1085.0313	1110.0666
STYRE-01	4592.7756	4592.7756	4537.2554	0.5270	4592.7756
ALPHA-01	420.8586	420.8586	418.5398	4.4470-11	420.8586
CARBON	0.0	0.0	0.0	0.0	0.0
AIR	0.0	0.0	0.0	0.0	0.0
WATER	0.0	0.0	0.0	0.0	0.0
METHA-01	126.6743	126.6743	0.0	0.0	126.6743
ETHYLENE	126.6743	126.6743	0.0	0.0	126.6743
ETHAN-01	126.6743	126.6743	0.0	0.0	126.6743
PROPY-01	126.6743	126.6743	0.0	0.0	126.6743
PROPA-01	126.6743	126.6743	0.0	0.0	126.6743
1-BUT-01	126.6743	126.6743	0.0	0.0	126.6743
ISOBUTAN	126.6743	126.6743	0.0	0.0	126.6743
N-BUT-01	126.6743	126.6743	0.0	0.0	126.6743
H2	126.6743	126.6743	0.0	0.0	126.6743
O2	0.0	0.0	0.0	0.0	0.0
CO2	0.0	0.0	0.0	0.0	0.0
N2	0.0	0.0	0.0	0.0	0.0
TOTAL FLOW:					
LBMOL/HR	156.7237	156.7237	47.1376	10.3000	156.7237
LB/HR	7876.3059	7876.3059	4959.1929	1092.4629	7876.3059
CUFT/HR	1.7088+04	4.7966+04	105.3933	23.4007	3.4941+04
STATE VARIABLES:					
TEMP F	100.0000	827.2330	350.3191	298.2829	321.4521
PRES PSIA	32.0000	45.0000	30.3000	20.0000	37.0000
VFRAC	0.5774	1.0000	0.0	0.0	1.0000
LFRAC	0.4226	0.0	1.0000	1.0000	0.0
SFRAC	0.0	0.0	0.0	0.0	0.0
ENTHALPY:					
BTU/LBMOL	9666.9229	3.5773+04	5.6967+04	5846.2300	2.1530+04

BTU/LB	192.3537	711.8161	541.4807	55.1196	428.4023
BTU/HR	1.5150+06	5.6065+06	2.6853+06	6.0216+04	3.3742+06
ENTROPY:					
BTU/LBMOL-R	-40.0753	-9.4279	-60.2123	-88.5426	-22.9247
BTU/LB-R	-0.7974	-0.1876	-0.5723	-0.8348	-0.4562
DENSITY:					
LBMOL/CUFT	9.1714-03	3.2674-03	0.4473	0.4402	4.4854-03
LB/CUFT	0.4609	0.1642	47.0542	46.6850	0.2254
AVG MW	50.2560	50.2560	105.2068	106.0644	50.2560

FUEL HEAT LIQBOT LIQFD LIQVAP

STREAM ID	FUEL	HEAT	LIQBOT	LIQFD	LIQVAP
FROM :	FURNACE	B2	SEP2	SEP1	SEP2
TO :	B3	FURNACE	TOLCOL	SEP2	B7
SUBSTREAM: MIXED					
PHASE:	VAPOR	VAPOR	LIQUID	LIQUID	VAPOR
COMPONENTS: LBMOL/HR					
POLY(-01	0.0	0.0	0.0	0.0	0.0
TOLUE-01	0.0	0.1517	6.3492	6.3597	1.0572-02
ETHYL-01	0.0	9.1871-02	10.2750	10.2753	3.3240-04
STYRE-01	0.0	0.2668	43.5718	43.5722	3.9818-04
ALPHA-01	0.0	9.9672-03	3.5416	3.5416	1.8856-06
CARBON	0.0	0.0	0.0	0.0	0.0
AIR	0.0	0.0	0.0	0.0	0.0
WATER	79.2192	0.0	0.0	0.0	0.0
METHA-01	0.0	4.0112	2.6032-19	4.1586-02	4.1586-02
ETHYLENE	0.0	2.2938	6.4589-16	9.7768-02	9.7768-02
ETHAN-01	0.0	2.1400	6.9008-15	0.1348	0.1348
PROPY-01	0.0	1.5292	3.8139-12	0.2773	0.2773
PROPA-01	0.0	1.4593	7.1209-12	0.2922	0.2922
1-BUT-01	0.0	1.1469	2.9486-09	0.5643	0.5643
ISOBUTAN	0.0	1.1071	7.8633-10	0.4433	0.4433
N-BUT-01	0.0	1.1071	6.6914-09	0.6033	0.6033
H2	0.0	31.9218	1.3972-24	3.4115-02	3.4115-02
O2	152.0799	0.0	0.0	0.0	0.0
CO2	39.3105	0.0	0.0	0.0	0.0
N2	869.0000	0.0	0.0	0.0	0.0
COMPONENTS: LB/HR					
POLY(-01	0.0	0.0	0.0	0.0	0.0
TOLUE-01	0.0	13.9803	585.0165	585.9906	0.9741
ETHYL-01	0.0	9.7537	1090.8664	1090.9017	3.5290-02
STYRE-01	0.0	27.7884	4538.0740	4538.1155	4.1471-02
ALPHA-01	0.0	1.1779	418.5399	418.5401	2.2284-04

CARBON	0.0	0.0	0.0	0.0	0.0
AIR	0.0	0.0	0.0	0.0	0.0
WATER	1427.1569	0.0	0.0	0.0	0.0
METHA-01	0.0	64.3505	4.1763-18	0.6672	0.6672
ETHYLENE	0.0	64.3505	1.8120-14	2.7428	2.7428
ETHAN-01	0.0	64.3505	2.0750-13	4.0526	4.0526
PROPY-01	0.0	64.3505	1.6049-10	11.6694	11.6694
PROPA-01	0.0	64.3505	3.1401-10	12.8857	12.8857
1-BUT-01	0.0	64.3505	1.6544-07	31.6600	31.6600
ISOBUTAN	0.0	64.3505	4.5704-08	25.7681	25.7681
N-BUT-01	0.0	64.3505	3.8893-07	35.0668	35.0668
H2	0.0	64.3505	2.8165-24	6.8772-02	6.8772-02
O2	4866.3732	0.0	0.0	0.0	0.0
CO2	1730.0478	0.0	0.0	0.0	0.0
N2	2.4344+04	0.0	0.0	0.0	0.0
TOTAL FLOW:					
LBMOL/HR	1139.6096	47.2370	63.7376	66.2376	2.5000
LB/HR	3.2367+04	631.8551	6632.4968	6758.1292	125.6325
CUFT/HR	1.8160+06	8847.2354	152.9815	124.6314	183.1195
STATE VARIABLES:					
TEMP F	1722.0599	99.6999	424.5547	100.0000	106.6376
PRES PSIA	14.6959	32.0000	79.5600	32.0000	75.0000
VFRAC	1.0000	1.0000	0.0	0.0	1.0000
LFRAC	0.0	0.0	1.0000	1.0000	0.0
SFRAC	0.0	0.0	0.0	0.0	0.0
ENTHALPY:					
BTU/LBMOL	-265.7685	-6330.2088	4.9497+04	3.0669+04	-2.8883+04
BTU/LB	-9.3574	-473.2412	475.6580	300.5935	-574.7565
BTU/HR	-3.0287+05	-2.9902+05	3.1548+06	2.0314+06	-7.2208+04
ENTROPY:					
BTU/LBMOL-R	11.5031	-12.0146	-58.0961	-80.1589	-63.3525
BTU/LB-R	0.4050	-0.8982	-0.5583	-0.7857	-1.2607
DENSITY:					
LBMOL/CUFT	6.2754-04	5.3392-03	0.4166	0.5315	1.3652-02
LB/CUFT	1.7823-02	7.1418-02	43.3549	54.2249	0.6861
AVG MW	28.4021	13.3763	104.0594	102.0286	50.2530

MIX NEWFEED NONCOND PS S1

STREAM ID	MIX	NEWFEED	NONCOND	PS	S1
FROM :	B7	PYROLYZE	SEP1	----	SEP
TO :	B2	SEP	B7	PYROLYZE	B1

SUBSTREAM: MIXED

PHASE:	VAPOR	MIXED	VAPOR	LIQUID	VAPOR

COMPONENTS: LBMOL/HR					
POLY(-01	0.0	0.0	0.0	80.0084	0.0
TOLUE-01	0.2987	6.6479	0.2881	0.0	6.6479
ETHYL-01	0.1808	10.4558	0.1805	0.0	10.4558
STYRE-01	0.5252	44.0971	0.5248	0.0	44.0971
ALPHA-01	1.9621-02	3.5612	1.9619-02	0.0	3.5612
CARBON	0.0	38.0230	0.0	0.0	0.0
AIR	0.0	0.0	0.0	0.0	0.0
WATER	0.0	0.0	0.0	0.0	0.0
METHA-01	7.8960	7.8960	7.8545	0.0	7.8960
ETHYLENE	4.5154	4.5154	4.4176	0.0	4.5154
ETHAN-01	4.2127	4.2127	4.0779	0.0	4.2127
PROPY-01	3.0103	3.0103	2.7330	0.0	3.0103
PROPA-01	2.8727	2.8727	2.5804	0.0	2.8727
1-BUT-01	2.2577	2.2577	1.6934	0.0	2.2577
ISOBUTAN	2.1794	2.1794	1.7361	0.0	2.1794
N-BUT-01	2.1794	2.1794	1.5761	0.0	2.1794
H2	62.8382	62.8382	62.8041	0.0	62.8382
O2	0.0	0.0	0.0	0.0	0.0
CO2	0.0	0.0	0.0	0.0	0.0
N2	0.0	0.0	0.0	0.0	0.0
COMPONENTS: LB/HR					
POLY(-01	0.0	0.0	0.0	8333.0000	0.0
TOLUE-01	27.5203	612.5368	26.5462	0.0	612.5368
ETHYL-01	19.2002	1110.0666	19.1649	0.0	1110.0666
STYRE-01	54.7015	4592.7756	54.6601	0.0	4592.7756
ALPHA-01	2.3187	420.8586	2.3185	0.0	420.8586
CARBON	0.0	456.6941	0.0	0.0	0.0
AIR	0.0	0.0	0.0	0.0	0.0
WATER	0.0	0.0	0.0	0.0	0.0
METHA-01	126.6743	126.6743	126.0071	0.0	126.6743
ETHYLENE	126.6743	126.6743	123.9315	0.0	126.6743
ETHAN-01	126.6743	126.6743	122.6217	0.0	126.6743
PROPY-01	126.6743	126.6743	115.0049	0.0	126.6743
PROPA-01	126.6743	126.6743	113.7886	0.0	126.6743
1-BUT-01	126.6743	126.6743	95.0143	0.0	126.6743
ISOBUTAN	126.6743	126.6743	100.9061	0.0	126.6743
N-BUT-01	126.6743	126.6743	91.6074	0.0	126.6743
H2	126.6743	126.6743	126.6055	0.0	126.6743
O2	0.0	0.0	0.0	0.0	0.0
CO2	0.0	0.0	0.0	0.0	0.0
N2	0.0	0.0	0.0	0.0	0.0
TOTAL FLOW:					
LBMOL/HR	92.9861	194.7467	90.4861	80.0084	156.7237
LB/HR	1243.8092	8333.0000	1118.1767	8333.0000	7876.3059
CUFT/HR	1.7416+04	1.0173+05	1.6964+04	383.7952	1.0172+05

STATE VARIABLES:					
TEMP F	99.6999	752.0000	100.0000	77.0000	752.0000
PRES PSIA	32.0000	20.0000	32.0000	20.0000	20.0000
VFRAC	1.0000	0.8048	1.0000	0.0	1.0000
LFRAC	0.0	0.0	0.0	1.0000	0.0
SFRAC	0.0	0.1952	0.0	0.0	0.0
ENTHALPY:					
BTU/LBMOL	-6330.2088	2.7357+04	-5707.1017	-4.4193+04	3.3422+04
BTU/LB	-473.2412	639.3565	-461.8355	-424.3128	665.0383
BTU/HR	-5.8862+05	5.3278+06	-5.1641+05	-3.5358+06	5.2380+06
ENTROPY:					
BTU/LBMOL-R	-12.0146	-7.2841	-10.7333	-24.2667	-9.7031
BTU/LB-R	-0.8982	-0.1702	-0.8686	-0.2330	-0.1931
DENSITY:					
LBMOL/CUFT	5.3392-03	1.9144-03	5.3341-03	0.2085	1.5407-03
LB/CUFT	7.1418-02	8.1916-02	6.5916-02	21.7121	7.7429-02
AVG MW	13.3763	42.7889	12.3574	104.1515	50.2560

SELL STEAMIN STEAMOUT STYRENE TOLBTMS

STREAM ID	SELL	STEAMIN	STEAMOUT	STYRENE	TOLBTMS
FROM :	B2	----	HEATX2	STYCOL	TOLCOL
TO :	----	HEATX2	----	----	EBCOL
SUBSTREAM: MIXED					
PHASE:	VAPOR	LIQUID	VAPOR	LIQUID	LIQUID
COMPONENTS: LBMOL/HR					
POLY(-01	0.0	0.0	0.0	0.0	0.0
TOLUE-01	0.1469	0.0	0.0	0.0	7.4935-02
ETHYL-01	8.8977-02	0.0	0.0	3.1994-02	10.2520
STYRE-01	0.2584	0.0	0.0	42.7661	43.5690
ALPHA-01	9.6533-03	0.0	0.0	1.8636-03	3.5416
CARBON	0.0	0.0	0.0	0.0	0.0
AIR	0.0	0.0	0.0	0.0	0.0
WATER	0.0	94.3643	94.3643	0.0	0.0
METHA-01	3.8849	0.0	0.0	0.0	0.0
ETHYLENE	2.2216	0.0	0.0	0.0	0.0
ETHAN-01	2.0726	0.0	0.0	0.0	0.0
PROPY-01	1.4811	0.0	0.0	0.0	0.0
PROPA-01	1.4133	0.0	0.0	0.0	0.0
1-BUT-01	1.1108	0.0	0.0	0.0	0.0
ISOBUTAN	1.0723	0.0	0.0	0.0	0.0
N-BUT-01	1.0723	0.0	0.0	0.0	0.0
H2	30.9164	0.0	0.0	0.0	0.0
O2	0.0	0.0	0.0	0.0	0.0

CO2	0.0	0.0	0.0	0.0	0.0
N2	0.0	0.0	0.0	0.0	0.0
COMPONENTS: LB/HR					
POLY(-01	0.0	0.0	0.0	0.0	0.0
TOLUE-01	13.5400	0.0	0.0	0.0	6.9046
ETHYL-01	9.4465	0.0	0.0	3.3968	1088.4290
STYRE-01	26.9132	0.0	0.0	4454.1587	4537.7824
ALPHA-01	1.1408	0.0	0.0	0.2202	418.5398
CARBON	0.0	0.0	0.0	0.0	0.0
AIR	0.0	0.0	0.0	0.0	0.0
WATER	0.0	1700.0000	1700.0000	0.0	0.0
METHA-01	62.3237	0.0	0.0	0.0	0.0
ETHYLENE	62.3237	0.0	0.0	0.0	0.0
ETHAN-01	62.3237	0.0	0.0	0.0	0.0
PROPY-01	62.3237	0.0	0.0	0.0	0.0
PROPA-01	62.3237	0.0	0.0	0.0	0.0
1-BUT-01	62.3237	0.0	0.0	0.0	0.0
ISOBUTAN	62.3237	0.0	0.0	0.0	0.0
N-BUT-01	62.3237	0.0	0.0	0.0	0.0
H2	62.3237	0.0	0.0	0.0	0.0
O2	0.0	0.0	0.0	0.0	0.0
CO2	0.0	0.0	0.0	0.0	0.0
N2	0.0	0.0	0.0	0.0	0.0
TOTAL FLOW:					
LBMOL/HR	45.7492	94.3643	94.3643	42.8000	57.4376
LB/HR	611.9541	1700.0000	1700.0000	4457.7757	6051.6558
CUFT/HR	8568.5823	27.5911	1440.0730	82.6746	134.2954
STATE VARIABLES:					
TEMP F	99.6999	90.0000	478.9234	148.4533	390.1016
PRES PSIA	32.0000	564.0000	564.0000	0.9668	50.7600
VFRAC	1.0000	0.0	1.0000	0.0	0.0
LFRAC	0.0	1.0000	0.0	1.0000	1.0000
SFRAC	0.0	0.0	0.0	0.0	0.0
ENTHALPY:					
BTU/LBMOL	-6330.2088	-1.2343+05	-1.0148+05	4.8036+04	5.0589+04
BTU/LB	-473.2412	-6851.1824	-5632.7274	461.2010	480.1491
BTU/HR	-2.8960+05	-1.1647+07	-9.5756+06	2.0559+06	2.9057+06
ENTROPY:					
BTU/LBMOL-R	-12.0146	-39.6669	-13.8690	-72.7957	-60.9844
BTU/LB-R	-0.8982	-2.2018	-0.7698	-0.6989	-0.5788
DENSITY:					
LBMOL/CUFT	5.3392-03	3.4201	6.5527-02	0.5177	0.4277
LB/CUFT	7.1418-02	61.6141	1.1805	53.9196	45.0623
AVG MW	13.3763	18.0153	18.0153	104.1536	105.3606

TOLUENE WASTE1 WASTE2

STREAM ID	TOLUENE	WASTE1	WASTE2
FROM :	TOLCOL	B3	HEATX2
TO :	----	HEATX2	----
SUBSTREAM: MIXED			
PHASE:	LIQUID	VAPOR	VAPOR
COMPONENTS: LBMOL/HR			
POLY(-01	0.0	0.0	0.0
TOLUE-01	6.2742	0.0	0.0
ETHYL-01	2.2958-02	0.0	0.0
STYRE-01	2.7997-03	0.0	0.0
ALPHA-01	1.2054-07	0.0	0.0
CARBON	0.0	0.0	0.0
AIR	0.0	0.0	0.0
WATER	0.0	79.2192	79.2192
METHA-01	0.0	0.0	0.0
ETHYLENE	0.0	0.0	0.0
ETHAN-01	0.0	0.0	0.0
PROPY-01	0.0	0.0	0.0
PROPA-01	0.0	0.0	0.0
1-BUT-01	2.9486-09	0.0	0.0
ISOBUTAN	7.8633-10	0.0	0.0
N-BUT-01	6.6914-09	0.0	0.0
H2	0.0	0.0	0.0
O2	0.0	152.0799	152.0799
CO2	0.0	39.3105	39.3105
N2	0.0	869.0000	869.0000
COMPONENTS: LB/HR			
POLY(-01	0.0	0.0	0.0
TOLUE-01	578.1119	0.0	0.0
ETHYL-01	2.4374	0.0	0.0
STYRE-01	0.2916	0.0	0.0
ALPHA-01	1.4245-05	0.0	0.0
CARBON	0.0	0.0	0.0
AIR	0.0	0.0	0.0
WATER	0.0	1427.1569	1427.1569
METHA-01	0.0	0.0	0.0
ETHYLENE	0.0	0.0	0.0
ETHAN-01	0.0	0.0	0.0
PROPY-01	0.0	0.0	0.0
PROPA-01	0.0	0.0	0.0
1-BUT-01	1.6544-07	0.0	0.0
ISOBUTAN	4.5704-08	0.0	0.0
N-BUT-01	3.8893-07	0.0	0.0

H2	0.0	0.0	0.0
O2	0.0	4866.3732	4866.3732
CO2	0.0	1730.0478	1730.0478
N2	0.0	2.4344+04	2.4344+04
TOTAL FLOW:			
LBMOL/HR	6.3000	1139.6096	1139.6096
LB/HR	580.8409	3.2367+04	3.2367+04
CUFT/HR	12.6639	1.0225+06	8.2150+05
STATE VARIABLES:			
TEMP F	305.8599	768.6975	527.3143
PRES PSIA	40.0000	14.6959	14.6959
VFRAC	0.0	1.0000	1.0000
LFRAC	1.0000	0.0	0.0
SFRAC	0.0	0.0	0.0
ENTHALPY:			
BTU/LBMOL	1.4903+04	-7987.7111	-9805.3278
BTU/LB	161.6452	-281.2368	-345.2326
BTU/HR	9.3890+04	-9.1029+06	-1.1174+07
ENTROPY:			
BTU/LBMOL-R	-66.6620	6.8736	5.2271
BTU/LB-R	-0.7230	0.2420	0.1840
DENSITY:			
LBMOL/CUFT	0.4975	1.1145-03	1.3872-03
LB/CUFT	45.8659	3.1655-02	3.9400-02
AVG MW	92.1970	28.4021	28.4021