Brewer's Spent Grain to Xylitol & Polylactic Acid

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Abstract
With this project, the authors seek to present a desirable and novel process for converting brewers’ spent grain into two value-added products: the alternative sweetener, xylitol, and a biodegradable plastic, polylactic acid. This particular process is based in the Philadelphia Naval Yard, and uses the spent grain from surrounding breweries and microbreweries as its input. However, while the collection logistics and input quantity may change, the process is one that may be implemented anywhere, with varying degrees of success.

The process consists of collection, universal pretreatment, then a split to feed one of two continuous fermenters. A highly acidophilic strain of the yeast Candida tropicalis ferments xylose into xylitol, which is then purified and pelleted in a marketable state. Lactobacillus delbrueckii bacteria ferments glucose into lactic acid, which is then polymerized to form polylactic acid of the desired molecular weight. This polymer is then purified and processed for sale. This product profile is optimal, as it incorporates both of the major constituents of the grain – cellulose and hemicellulose.

Under the current market conditions, this process is expected to be financially desirable. We estimate a return on investment of 25.5%, with an internal rate of return of 30.95% and a net present value of $34.5M by 2032. However, if the price of polylactic acid were to rise, as market patterns suggest it may, this process could quickly become even more profitable. We therefore recommend pursuing the proposed process, and possibly expanding to other densely populated areas.

Disciplines
Biochemical and Biomolecular Engineering | Chemical Engineering | Engineering

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Dear Dr. Diamond and Dr. Vrana,

The following report contains the proposed design for a processing facility of xylitol and polylactic acid from brewer’s spent grain, as specified in the problem statement provided by Dr. Diamond. The processing facility has an input of 275,000 barrels (about 59 million kg) per year of spent grain, all collected in the Philadelphia area and brought to the facility in Navy Yard. The spent grain is washed with an acid pretreatment and the broken-down hemicellulose is sent to a xylitol fermenter, while the cellulose is broken down with ammonia and sent to a lactic acid fermenter. The xylose is fermented using *Candida tropicalis*, and the aqueous xylitol is purified with two ion exchange columns and later crystallized into final pellet form. The glucose is fermented using *Lactobacillus acidophilus*, and the L-lactic acid produced is transferred to a diphenyl ether solvent and converted to polylactic acid via a direct condensation polymerization reaction over a tin oxide catalyst. A combination dichloromethane and methanol treatment is used to crystallize the polylactic acid out of solution in a marketable form.

The report contains a highly-detailed design of this process, along with a profitability analysis and other important considerations. The designed process is able to produce 3.6 million kg/year xylitol and 3.9 million kg/year 79,000 MW polylactic acid when the plant operates 24 hours a day for 330 days a year. The current design requires $46.0 million total capital investment. The annual sales at this production level are $90.0 million, however with large annual operating costs the net earnings for this design are roughly $20.0 million per year. The process has an estimated ROI of 43.3% and IRR of 28.4%. The NPV by 2032 is estimated to be $80.5 million.

Based on this analysis, our group believes that this facility is economically feasible. Several policy issues, including increased FDA regulation on spent grain as animal feed, could alter the economic forecast of this design. We recommend pursuing this plant design as outlined with continued research on charging disposal costs to breweries and lowering fermenter media costs by recycling cell debris.

Sincerely,

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________________
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________________

Anthony Carradorini    Nabila Faour    Alexander George    Kelsey Simet
Brewer’s Spent Grain to Xylitol & Polylactic Acid

Alexander George | Kelsey Simet | Anthony Carradorini | Nabila Faour

Project Submitted to Dr. Bruce Vrana and Dr. Warren Seider

Project Proposed by Dr. Scott Diamond

Department of Chemical and Biomolecular Engineering
School of Engineering and Applied Science
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April 18, 2017
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1.0 Abstract

With this project, the authors seek to present a desirable and novel process for converting brewers’ spent grain into two value-added products: the alternative sweetener, xylitol, and a biodegradable plastic, polylactic acid. This particular process is based in the Philadelphia Naval Yard, and uses the spent grain from surrounding breweries and microbreweries as its input. However, while the collection logistics and input quantity may change, the process is one that may be implemented anywhere, with varying degrees of success.

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Under the current market conditions, this process is expected to be financially desirable. We estimate a return on investment of 43.3%, with an internal rate of return of 28.4% and a net present value of $80.5M by 2032. However, if the price of polylactic acid were to rise, as market patterns suggest it may, this process could quickly become even more profitable. We therefore recommend pursuing the proposed process, and possibly expanding to other densely populated areas.
2.0 Introduction

2.1 Background Information

Spent grain is a valuable byproduct of the brewing process. It is a solid residue that results from the production of malt after grains are soaked in water, germinated, and dried. Spent grain is collected during lautering at the end of the mashing process. It is generally constituted by lignin, cellulose, hemicellulose, and protein, though its composition variability depends on the type of grain used, processing conditions, and preservation method [1].

Spent grain can be as much as 85% of a brewing process’s total byproduct and has been widely used for livestock feed due to its high fiber and protein content. It also has a high water content, making the wet grain a very perishable and bulky product that is difficult and costly to distribute. Therefore, it is mostly transported to farms in the vicinity of the brewery [1]. Most micro to medium sized breweries give their grain to farmers at no cost in return for the farmers picking up the grain on a regular schedule [2]. If the grain is not disposed of within 1-2 weeks, wet grain degradation becomes a great burden, particularly for smaller breweries without sufficient storage space or preservation means. In general, the spent grain is given to local farms free of charge or at a very low price to guarantee it can be removed from the plant before degradation. Overall, many breweries regard their spent grain as burdensome.

In 2013, the FDA proposed a rule as part of its Food Safety Modernization Act with the aim to regulate and improve safety of animal food, and thus prevent foodborne illness in animals and humans. Despite facing vast opposition by breweries and farmers, the rule was finalized and became effective in 2016. It outlines good manufacturing practice and hazard analysis that must be followed to ensure products can be ruled safe to constitute animal feed. The system enacted includes chemical or physical hazard identification, preventative controls, and recall plans [3].
This rule has added to the burden faced by breweries to dispose of their spent grain. Our project is capitalizing on this unique situation, and looks to find a profitable use of this bulky byproduct.

Alternative applications of spent grain such as biofuel and bioproduct production can be a viable and cost effective option for breweries since they would not incur extra costs to comply with the Food Safety Modernization Act. A main concern for breweries is securing a weekly pickup schedule to reduce the risks of grain degradation and avoid preservation costs. Our project established a pickup schedule with multiple breweries in the Philadelphia area, as outlined in the logistics section.

Our initial product selection consisted of a preliminary market and profitability analysis to determine which products could provide the most profit for a given feed volume. The three main products considered were xylitol, polylactic acid (PLA) and bioethanol. Once the expected yields of each product were estimated, we performed a market analysis to choose the best two products. This analysis relied on the current market price, historical price data, demand trends, and future price projections for each of the possible products. Estimates obtained from this initial analysis, outlined in the market assessment section, motivated our choice of xylitol and PLA.

The process was designed to optimize total production of each product. The main steps outlined in the process include an acid or alkaline pretreatment to remove lignin, an enzymatic hydrolysis to extract the fermentable sugars, fermentation of sugars using different microorganisms, separations, and additional processing to a final packaged commercial product form.
2.2 Objective Time Chart

**Project Name**  
Bioprocessing with Brewer’s Spent Grain

**Project Advisors**  
Dr. Scott Diamond, Dr. Bruce Vrana

**Project Leaders**  
Anthony Carradorini, Nabila Faour, Alexander George, Kelsey Simet

**Specific Goals**  
Develop a processing plant for converting all available brewer’s spent grain in the Philadelphia area to produce two products, and perform economic analysis to determine profitability of the plant.

**Project Scope**  
In Scope:
1. Determine most profitable products to be made from brewer’s spent grain (BSG)
2. Calculate amount of BSG available in Philadelphia area and establish collection logistics
3. Design processing plant for converting BSG to xylitol and polylactic acid (PLA) using a continuous process while adhering to good manufacturing standards
4. Perform economic and profitability analysis to determine if this business model is feasible

Out of Scope:
1. Manufacturing of biofuel from BSG
2. Use of genetically modified organism *Candida tropicalis JY* to increase xylitol product yield
3. Scaling of production process for other urban areas

**Deliverables**
1. Mass and energy balance of system
2. Detailed flowsheet and Aspen model with simulation results
3. Fermentation kinetics and results
4. Equipment specifications and cost analysis
5. Profitability analysis with economic forecast

**Timeline**  
Process design and profitability analysis to be completed by April 11th, 2017.
2.3 Innovation Map

The innovation map for this project is presented below. Our process combines research on applications of spent grain to produce xylitol and PLA. Our group was able to innovate a method to simultaneously produce xylitol and PLA with maximum yields of both products. This was accomplished by determining a single sulfuric acid pretreatment step for all of the feed spent grain. This acid hydrolysis step breaks down all of the hemicellulose, which later ferments to xylitol, but does not affect the cellulose, which is crucial for making lactic acid. It is then simple to separate the liquid, broken-down hemicellulose to the xylitol fermentation path and the solid cellulose to the lactic acid fermentation path. If this single pretreatment step was not used, the feed spent grain would need to be initially divided into xylitol and PLA paths, which would lead to wasted hemicellulose and cellulose, depending on the path. Additionally, combining the first spent grain wash step with the initial spent grain acidic pre-treatment allows us to combine two separate unit operations into a single step, and therefore reduce costs for the process.

Other innovations include using more efficient microorganisms, adapting the usual batch fermentations to continuous, and combining unit operations into a single step to reduce costs. The replacement of the *Candida guillermondii* with *Candida tropicalis* and that of *Lactobacillus acidophilus* with *Lactobacillus delbrueckii* allowed our process to obtain high product to consumed substrate ratios of 0.87 and 0.99, respectively. One benefit of *C. tropicalis* is that it works best at optimal pH conditions of 2.5, which reduces the amount of base needed during the neutralization steps.
Figure 2.1 - Innovation map showing important design decisions to optimize the process, including a crucial pre-treatment step and choice of high-yield microorganisms.
3.0 Market Assessment for Spent Grain Collection and Products

3.1 Spent Grain Market

The price of spent grain is highly variable, as it is dependent on production scale, size, and location of a brewery. The majority of breweries give their spent grain to farmers at no cost, as the spent grain is a heavy, cumbersome byproduct that requires large storage space. It is reasonable to assume that any spent grain that our project obtained from microbreweries and medium-sized breweries would be given at no cost, as long as the pickups are regularly scheduled at convenient times. After speaking with many Philadelphia-area breweries, our group found that up to production of about 10,000 kg/week, the spent grain is hauled away at no cost.

However, the majority of volume of spent grain produced by breweries is sold for a relatively low price to large-scale farms. The large breweries who produce more than 10,000 kg/week typically use a commodities broker to sell their grain. This grain is brokered to larger farms, who may mix the grain with other traditional feed. However, the price of this grain is extremely low. Due to low availability of price data from large-scale breweries, our group is not accounting for this cost in our process design.

The FDA’s Food Modernization Act of 2014 greatly affected the market for spent grain, and additional drastic measurements are expected in the future. The act, in an attempt to control and prevent food-borne diseases, increased regulation of spent grain used as animal feed. However, the brewing industry was able to lobby against many of the stricter rules, creating some exemptions for alcohol distilleries. Still, any grain being sold as animal feed must have regular nutritional...
analysis work to monitor protein content. In Philadelphia, only two breweries are large enough to warrant selling their grain to farms. Due to the smaller size of area breweries and the projected increase of regulation, our group is working under the assumption that all spent grain would be provided free of charge. For this project, we only considered the cost of transporting the spent grain.

3.2 Product Market

The three possible products explored were xylitol, polylactic acid (PLA), and bioethanol, as recommended by the problem statement. The market analysis and competitive assessment ultimately lead to the product choices of xylitol and PLA. The market analysis estimated revenue less the cost of main inputs. While it was not an accurate predictor of profits, our group could roughly determine our market cap of each product and potential revenue.

Ethanol

Among the products suggested by the problem statement was bioethanol. Most bioethanol is currently produced from corn in the Midwest of the United States. It has enjoyed much market success in the past because of its renewable nature, low carbon emission, and use as a high octane gasoline additive. Spent grain has a high cellulose content, making it a reasonable feed for ethanol production, with much literature written on the process.

However, upon market analysis, it was found that the market for bioethanol has been stagnating in recent years. Interest has shifted to biodiesels, leading to less profitability in bioethanol production [6]. Also, its status as a commodity chemical has decreased the value of bioethanol, reaching a current market price of $1.46/gallon. Using an approximate feed amount of spent grain, the yearly production of ethanol was determined by assuming the available cellulose
was converted by the fermentation yield of ethanol. The estimated production of 1.4 gallons/year places our sales revenue at $2.1 million. This amount of production would place our company at a miniscule market share – this level of production is approximately 1.4% of all bioethanol made in the Tri-state area. Our initial input costs of about $300,000/year consisted mainly of the cost of 2500 tons of NaOH/year purchased at a market price of $125/ton. The preliminary profit for ethanol through this process would be $1.8 million/year. Given that the analysis did not account for equipment, installation or energy costs, the overall total cost of production would make this selection unprofitable. Since the process cannot yield bioethanol at sufficient scale to make its production lucrative, we have opted to not produce this product.

**Xylitol**

Xylitol is a polyhydric alcohol that can be used as a low calorie substitute for sugar. It contains about 40% less calories than sugar given its lack of reducing groups. The increasing demand for low calorie sweeteners and diabetic care products is expected to drive an increase in the xylitol market. Its equivalent sweetness to sugar, along with its minimal effects on blood sugar and insulin levels, favor its increasing demand. The largest application of xylitol is in the chewing gum industry, generating over $450 million in 2015 [7]. Its use in beverage and bakery products has caused a 7% increase in its application in the food industry. Food applications of xylitol are expected to contribute to at least a $45 million revenue in the United States by 2023. The overall xylitol market is expected to generate about $1.12 billion by 2023 [8].

An estimated 1.9 million kg of raw arabinoxylan per year is available in the spent grain. The 0.87 yield of *C. tropicalis* allows us to theoretically produce 2.5 million kg of xylitol/year, sold at its current market price of $10.00/kg. The preliminary estimated inputs of 500,000 kg of sulfuric acid purchased at a market price of $0.13/kg and an inoculation of *C. tropicalis* cells
purchased at $290/inoculation sets our raw materials cost at $64,710/year. The preliminary profit estimate for xylitol, not including equipment, installation, or energy costs, is $24.9 million/year.

*Polylactic Acid*

Polylactic Acid is a biodegradable plastic with applications across industries such as packaging, biomedical, transportation, electronics, agriculture and textile [9]. Packaging accounted for 59.6% of the overall market in 2013, and it is expected to remain the main segment for PLA. Its popularity in the packaging industry is due to the lack of emission of toxic gases upon incineration and properties such as durability and transparency. The market for textiles is also predicted to grow at a rate of 17.5% in terms of revenue by 2020 [10].

The estimated 5.6 million kg of cellulosic sugars available per year, along with the 0.99 yield of *L. delbrueckii*, allows us to produce about 5.5 million kg/year of lactic acid. Our sales revenue would be $82.5 million/year, assuming a 1 to 1 conversion of lactic acid to PLA during polymerization, at a market price of $15.00/kg. Our input costs include an inoculation of *L. delbrueckii* cells purchased at $294/5 ml, about 11 million kg/year of ammonium hydroxide purchased at $0.30/kg, and 1.9 kg/year of sodium citrate purchased at $0.80/kg. With the raw materials cost at $4.8 million/year, our profit for PLA would be $7.77 million/year before equipment, installation or energy costs.
4.0 Customer Requirements

Because both xylitol and PLA are associated with human food consumption, extra care must be taken to assure that no toxic elements remain in the final form of these products. A grave concern for this process is contamination by *Candida* yeast during xylitol production and of the tin oxide catalyst during PLA polymerization. Most other chemicals are common and safe in trace amounts, and are adequately separated out during the respective purification processes.

Zhejiang Huakang Pharmaceutical Inc. is a major Chinese supplier of xylitol from biological sources. They specify at least 98.5% purity of their xylitol products, as well as a host of other maximum contaminant concentrations. Many of the contaminants such as lead, heavy metals, and chlorides are not used in our process, but others such as sulfides and yeasts are. The tests to determine passable concentrations, and the limits on contamination are detailed in Appendix A5. Our intent is to become a supplier to other organizations that will then use xylitol to make gum, dental hygiene products, etc. China is the leading producer of xylitol, so the low cost of shipping from Philadelphia model may help our sales. We expect to sell crystallized, granular food-grade xylitol in bulk quantities.

Polylactic acid (PLA) specifications require a purity of at least 98%. Since this product is approved for food contact, there can be no contamination with toxic substances. PLA is often sold in dry transparent or translucent beads ranging from 2 to 5 millimeters in diameter. NatureWorks LLC is a major worldwide PLA producer, and their technical and safety data sheets can be found in Appendix A2. In order to be able to participate in the market, we must match their specifications. The North American market is currently the largest, which means our Philadelphia-based model can expect steady demand. However, East Asia is currently experiencing rapid growth in demand for PLA, which may justify exploring that region as a potential market.
5.0 Principal Chemistry

The relevant chemical reactions in this process include the acid hydrolysis (5.1), pH neutralizations (5.2), enzymatic hydrolysis of cellulase (5.3), fermentation reactions (5.4), and L-lactic acid polymerization (5.5). These reactions are outlined briefly below.

5.1 Acid Hydrolysis of Hemicellulosic Mass with Sulfuric Acid

Our lignocellulosic biomass (BSG) is treated with a sulfuric acid (H\textsubscript{2}SO\textsubscript{4}) wash at 150°C. The combination of heat and acid depolymerizes the hemicellulose while negligibly affecting the cellulosic matrix. This depolymerization releases pentoses such as arabinose and xylose into solution, as well as forming some lignin degradation products (LDPs) from the hydrolysis of lignin. These LDPs (furfural, hydroxymethylfurfural) are toxic to the downstream fermentation. However, these LDPs are in very small concentration. They are scarce enough not to affect downstream fermentations and will be removed in the xylitol purification process [38].
5.2 pH Neutralizations

*Sulfuric Acid Neutralization with Ca(OH)$_2$ (pH 1.5 -> 2.5)*

\[ H_2SO_4 + Ca(OH)_2 \rightarrow 2H_2O + CaSO_4 \]

In order to bring the pH of the filtrate from 1.5 to 2.5, 13,669 kg per day of Ca(OH)$_2$ is added. The pH only needs to be 2.5 because of the unique acidophilic fermentation of *Candida tropicalis*. The reaction generates CaSO$_4$ 2H$_2$O, otherwise known as gypsum. This precipitates out of solution, making it easy to centrifuge out before it is fed to the fermenter.

*Xylitol Process Wastewater Neutralization with Ca(OH)$_2$ (pH 2.5 -> 6)*

(Same governing equation as above)

In order for wastewater treatment plants to accept our water output, the stream must be at a pH between 6 and 9. In this step during xylitol purification, 7,389 kg of 2.00 molar calcium hydroxide will be added to achieve this pH. This will form gypsum, which can be centrifuged out of the stream and collected for sale or easy disposal.

5.3 Enzymatic Hydrolysis Steps

*Aqueous Ammonia Soaking Treatment of Filter Cake*

The solid product from the drum filter is dropped into a reactor to be soaked with aqueous ammonia. The ammonia selectively breaks down any remaining lignin and hemicellulose, and undergoes saponification and solvation reactions with the cellulosic biomass. The result of this is that the biomass swells, allowing enzymes to more easily penetrate the matrix, and aiding in hydrolysis [15].
Enzymatic Hydrolysis of Cellulose with Cellulase

Figure 5.2 – A series of enzymes (a cellulose cocktail) systematically break cellulose down into simple glucose

After a wash step to remove the ammonia, the now permeabilized cellulosic biomass is fed into a reactor with cellulase in sodium citrate buffer. The cellulase enzymes hydrolyze the cellulosic matrix into glucose, which goes into solution.
5.4 Fermentation Reactions

Fermentation of Xylose into Xylitol by Candida tropicalis

![Fermentation Reactions Diagram](image)

*Candida tropicalis* anaerobically ferments D-xylose into xylitol by reducing it using the D-Xylose reductase enzyme. *Candida tropicalis* produces so little Xylitol dehydrogenase and isomerase, that only a negligible amount of xylitol is converted to D-Xylulose and no xylose is converted directly to xylulose. There are some GMOs in which these enzymes are no longer coded for, completely eliminating any xylitol loss to these products. After the reduction, xylitol then diffuses into the extracellular matrix (into solution) [22].
Fermentation of glucose into L-lactic acid by Lactobacillus delbrueckii

Figure 5.4 – Metabolic pathway for conversion of glucose into L-lactic acid by bacteria

*Lactobacillus delbrueckii* is a lactic acid bacteria (LAB) capable of anaerobically fermenting glucose into L-lactic acid according to the above metabolic pathway. The biological process produces a non-racemic mixture of lactic acid isomers, which is very beneficial to the ensuing purification and polymerization. Acidification of the fermentation broth and increasing osmotic pressure - both caused by buildup of extracellular lactic acid - can greatly slow the rate of production. [16] However, because of the continuous nature of this process’s fermentation, these concerns are not as pressing, because the flowthrough carries away the lactic acid as it is produced.

### 5.5 Polymerization of L-lactic acid into polylactic acid (PLA)

\[
N(C_3H_6O_3) + \text{eat} + \text{tin oxide catalyst} \rightarrow N(H_2O) + [C_3H_4O_2]^N
\]

Pure L-lactic acid in an organic solvent is fed to a reactor that heats the solution to 170°C and contains a tin oxide catalyst. The catalyst allows the lactic acid to polymerize, releasing one
water molecule. The high heat also serves to boil off this generated water. Gaseous nitrogen is bubbled through the reactor to assure that no components oxidize. As the polymer passes through the reactor, it can be recycled back in order to undergo more reactions and become larger. In this way, the size of the product can be carefully controlled.
6.0 Preliminary Process Synthesis

6.1 Initial Production Designs

The processes for production of ethanol, PLA, and xylitol from brewer’s spent grain were each determined and analyzed for their economic viability. The following processes were created through scaling of lab-scale processes found in scientific literature and evaluation of patent literature from large chemicals companies.

The bioethanol process is the simplest of the three spent grain (BSG) fermentation processes evaluated (Figure 6.1).
In the ethanol process, the wet BSG is first stored in a holding tank (T-1) in order to smoothen out discrete delivery inputs into a continuous process. The wet BSG is then mixed with dilute NaOH in an alkaline hydrolysis reactor (R-1). This reaction breaks down the hemicellulosic material in the BSG into fermentable sugars. Finally, a fermentation is carried out on the hydrolyzed BSG using *F. Oxysporum* (R-2). The resulting ethanol can then be separated using distillation [39].

The xylitol production process requires more extensive pretreatment steps in order to break down the BSG into fermentable sugars (Figure 6.2).

---

*Figure 6.1 – Bioethanol Process*

*Figure 6.2 – Xylitol Pretreatment*
Once again, the wet BSG is first stored in a holding tank to allow for continuous operation (T-1). The BSG is fed to an acid hydrolysis reactor along with aqueous sulfuric acid (R-1). Sterile water is added to this reactor in order to dilute the mixture to an 8:1 liquid to solid ratio (Stream 4). In this step, the hemicellulose in the BSG is hydrolyzed to arabinose, glucose, and xylose sugars. Next, the hydrolyzed BSG mixture is combined with NaOH in order to neutralize the stream to the optimal pH required by the fermentation organism (R-2). The stream then moves to the fermenter (R-3). Either \textit{C. guillermondii} or \textit{C. tropicalis} can be used to ferment the sugars in the treated BSG to xylitol in XSM broth. The fermentation product is then centrifuged to remove the cell debris and other solids (S-1). The supernatant from this centrifuge contains dissolved xylitol product \cite{38}.

The polylactic acid production process requires the most complex pretreatment steps in order to carry out a successful fermentation (Figure 6.3).

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{lactic_acid_pretreatment_diagram.png}
\caption{Lactic Acid Pretreatment}
\end{figure}

Following the wet BSG storage tank (T-1), the BSG is fed into a reactor with an aqueous ammonia solution (R-1). The mixture soaks in the ammonia solution, allowing the cellulose solids in the BSG to be more easily broken apart later in the process. In order to neutralize the mixture,
it is washed with water until the ammonia is removed (E-1). The treated BSG is then mixed with sodium citrate and cellulase enzymes in a reactor (R-2). The cellulase and sodium citrate break down the cellulose in the treated BSG to yield fermentable glucose. The yields of this reaction are increased by the aqueous ammonia soaking pretreatment. Next, the mixture is centrifuged to remove all solids (S-1) and the supernatant fed into the fermenter (R-3). Either *L. delbrueckii* or *L. acidophilus* can be used to ferment the glucose in Man, Rogosa, Sharpe (MRS) broth. Unlike the ethanol and xylitol processes, the fermentation bioreactor in the polylactic acid process does not produce the final product. Instead, the fermentation produces L-lactic acid which must then undergo additional processing to be polymerized into polylactic acid [37].

### 6.2 Batch vs. Continuous Fermentation

An important early decision when considering fermentation processes was whether to pursue batch or continuous fermentation designs. In a batch fermentation process (Figure 6.4), the incoming continuous stream of fermentable sugars must first be converted into discrete inputs for a batch fermenter. This is accomplished by feeding the stream into a large storage vessel (E-1) and allowing it to accumulate continuously while each batch fermentation is taking place. Since one batch fermentation can take multiple days to complete, multiple fermentation reactors must be built (R-1) and scheduled in such a way so that the system can process all of the fermentable sugars generated by the continuous process in one batch time. The more fermenters are used, the smaller they can be, and the smaller the holding tank can be, because it can discharge into a new reactor more often. This necessitates balancing the cost of many small reactors against a few large ones. Economies of scale usually lean more toward fewer larger vessels. However, acceptable
risk must also be considered. If one of six smaller batches become contaminated, it makes a much smaller impact than if one of two larger batches are.

![Diagram of Batch Fermentation Process]

*Figure 6.4 – Batch Fermentation Process*

A continuous fermentation process requires fewer pieces of equipment than a batch process (Figure 6.5). No holding tank is required between the sugar solution stream and the fermenter, and only one fermenter is required (R-1), thus saving space and cost of equipment. Additionally, by setting the dilution rate equal to the specific growth rate, the organism that is growing in the fermenter can maintain at its peak growth rate at all times. In this case, where the desired products are primary metabolites, this stage of the growth curve leads to the most efficient conversion of sugars to product.

A major downside to continuous processing is the risk of contamination. A contaminated continuous process can ruin large amounts of product, and puts a halt to the entire process while the stock is drained and the apparatus is sterilized. If a batch fermenter gets contaminated, only that batch is affected, and will be cleaned and sterilized anyway.
In both batch and continuous processing, a Clean in Place (CIP) unit will be required for regular cleaning of units which come into contact with organisms, and which operate under high temperatures or pressures. Such units include the fermenters and the acid hydrolysis reactor. For this reason, and to provide a contingency in case of contamination, duplicate fermenters should be installed regardless of whether the operation mode is batch or continuous.

**6.3 Purification of Products**

Due to the economic analysis of the ethanol fermentation process presented in Section 7, ethanol was not chosen as a product and therefore its purification process was not considered. Instead, processes for the purification of xylitol and polymerization of lactic acid were explored and evaluated.

The fermentation product from breaking down xylose is aqueous xylitol, which contains some impurities. Purification is difficult due to the complex components and low product
concentration in the broth [13]. The impurities include cells, fermentation broth, arabinose, glucose, and other salts. The processes considered for the purification of xylitol from the aqueous fermentation product were using a standard ion exchange chromatography treatment or using and activated charcoal treatment. The chromatography treatment, outlined in US Patent 3985815 A and 4008285 A, requires two ion exchange chromatography columns; one cation ion exchange resin, and one anion ion exchange resin. The exchange resins are able to purify the solution by exchanging particular ions within the polymer of the resin. When using a recycle stream during the crystallization process, the overall yield of crystal xylitol from the aqueous product can be has high as 95%. The purity is confirmed to be 99.9%. The first patent was filed for this process in 1976, and many industrial scale processes still use the design.

The activated charcoal treatment is a recently founded process, with the first literature dating back to April of 2006 [13]. It uses adsorption through activated charcoal and vacuum concentration, along with a precipitation with ethanol. The precipitate then goes through similar evaporation and crystallization processes as the chromatography method. It requires about 4 cycles of crystallization to obtain yields of 76.20% from the fermentation broth. The crystalline product has about 98.99% purity [14].

Both processes obtain crystalline form of xylitol from the purified broth using evaporation at 50°C and crystallization at 5°C. The final product must be steam sterilized, regardless of purification process, to remove any possibility of the toxic *Candida* strain. While other methods exist, like liquid-liquid extraction, these two choices were explored as they resulted in the highest yields of crystalline xylitol.

Lactic acid has two enantiomers, L and D lactic acid, that differ in the ease at which they can be converted to polymer form. Fortunately, the L-lactic acid produced by fermentation is the
easier of the two stereoisomers to polymerize, allowing for fewer processing steps. Polylactic acid can be created from L-lactic acid through two possible reactions: direct condensation polymerization or lactide ring opening.

A process for the synthesis of polylactic acid from L-lactic acid through lactide ring opening was patented by Cargill in 1992 (Figure 6.6). This process is unique because it does not require the acid to be transferred to an organic solvent. Instead, the lactic acid is entered into the process as an aqueous solution, saving on the cost of extraction from the fermentation product.

The lactic acid stream first moves through an evaporator (E-1) that removes water from the stream to concentrate the solution. A pre-polymerization evaporator (R-1) then removes additional water under conditions that allow the L-lactic acid to begin polymerizing. The solution is then fed to a holding tank (T-1) before it is mixed with a tin catalyst and additional recovered lactic acid solution. This mixture is transferred to a reactor in which the L-lactic acid reacts over the tin catalyst to form lactide rings. Within the reactor, a lactic-acid rich vapor phase and a lactide-rich liquid phase are formed. The liquid is removed from the reactor and entered later into the process.

Figure 6.6 – Cargill PLA Production Process
The vapor is removed and partially condensed (HX-2). The vapor is mixed with the water extracted in R-1 and mixed with the feed stream (V-1). The liquid is fed into a distillation column (S-1) in which the remaining lactide rings are separated from the lactic acid solution. The distillate from the distillation column is condensed (HX-5) and mixed with the lactic acid solution in E-2. The lactide-rich bottoms product of the distillation column is mixed with the lactide mixture produced in R-2 (E-3) and fed to a lactide ring-opening reactor (R-3). In the reactor, the lactide rings open and combine with each other to form high molecular weight polylactic acid. The polylactic acid is removed, fed into a pelletizer (E-5) and then dried (E-5). The resulting product consists of condensed pellets of high molecular weight PLA [36].

A process for producing polylactic acid from L-lactic acid via direct condensation polymerization was patented in the 1980s (Figure 6.7). Condensation polymerization processes require that the L-lactic acid be dissolved in an organic solvent before undergoing the polymerization reaction. Therefore, in order to implement the process following a fermentation, the lactic acid would have to be extracted.

![Figure 6.7 – Direct Condensation Polymerization Process](image)

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<th>Equipment List</th>
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<tr>
<td>HX-1</td>
<td>Heater</td>
</tr>
<tr>
<td>R-1</td>
<td>Polymerization Reactor</td>
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<tr>
<td>S-1</td>
<td>PLA Crystallizer</td>
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</table>
After the lactic acid has been dissolved in an organic solvent, it passes through a heat exchanger (HX-1) and is heated to 170 degrees C. The heated stream is then fed into a polymerization reactor (R-1) along with a tin oxide catalyst. Nitrogen gas is bubbled through the reactor in order to maintain an inert atmosphere while the lactic acid polymerizes over the tin oxide catalyst. As the condensation reaction occurs, water is released and boiled off. The water vapor is removed from the top of the reactor. Following the polymerization reaction, the solution of PLA is removed from the reactor and fed to a splitter (V-1). A fraction of the PLA solution is sent to an evaporator that dries the solution (E-1) before recycling it back into the polymerization reactor. This recycle loop allows for the polymerization to continue to reach higher molecular weight PLA. The second stream of PLA solution exiting the splitter is fed to a separation vessel that is used to separate the organic solvent. The PLA is then dissolved in dichloromethane and subsequently mixed with methanol in a crystallizer (S-1). The methanol added to the dichloromethane mixture creates conditions in which the PLA can be crystallized and removed as a purified solid [35].

6.4 Recovery of Polylactic Acid Process Materials

Two processes were considered to recover the solvents used in the polylactic acid polymerization process. The first process is intended to recover highly pure streams of each solvent that can be recycled (Figure 6.8).
The top stream from the PLA and solvent separator is fed to a flash vessel (S-12) that separates any water and lighter components from the heavy organic solvent. The bottoms is rich in the organic solvent, and is fed back to the polymerization reactor in Figure 6.7 (R-1). To recover the other solvents, the liquor stream from the crystallizer (S-8) containing primarily methanol and dichloromethane is fed to a tray distillation column (S-15). The distillate of the column (5) is rich in dichloromethane and the bottoms (6) is rich in methanol. Each stream is recycled to its respective mixing step in Figure 6.8. This solvent recovery method allows for all of the solvents used to be treated as capital costs rather than operating costs of the process. Dichloromethane and methanol have similar boiling points (39.6°C and 64.7°C respectively) when compared to that of
a likely organic solvent (on the order of ~200°C), however their boiling points are far enough apart to make distillation a feasible economic option. The separation performed by the tray distillation column may add additional cost, but does limit the operating costs of purchasing new solvents and is the more promising option overall.

The second solvent recovery process addresses the issue of separation cost by focusing solely on recovering the majority of the organic solvent (Figure 6.9). This process is identical to the process described above, however it removes the tray distillation column used to separate dichloromethane and methanol. Instead, the liquid stream exiting the crystallizer is treated as waste and thrown away. In this process, the separation costs are minimized, however the dichloromethane and methanol in the process cannot be treated as capital costs and must be repurchased every day of operation.
6.5 Synthesis Tree

Figure 6.10 – Synthesis Tree for Selected Process
7.0 Block Diagram and Process Explanation

7.1 Block Diagram

The following block diagram shows an overview of the final processing steps chosen along with the major input and output streams and their flow rates (Figure 7.1).

![Figure 7.1 – Block Diagram with Major Stream Flow Rates](image-url)

**Pretreatment Processes**

It was decided to pretreat the BSG to be converted into both xylitol and PLA. With the correct pretreatment, the BSG can be separated into its different components without affecting the yield of either product. BSG is a mostly lignocellulosic biomass, meaning that its main structural component is a combination of cellulose, hemicellulose, and lignin. Cellulose and hemicellulose are the well-known polysaccharides made up of 6-carbon and 5-carbon linkages, respectively. Common 5-carbon sugars found in hemicellulose include arabinose and xylose. Hemicellulose is much more easily broken down than cellulose, which lends itself well to separation. Lignin is a connective polymer made up of phenolic monomers, and it plays little role in this process. The only consideration given to lignin is that it will break down into compounds that hinder
fermentation if it is degraded too aggressively. Since the two sugars of interest exist in different matrices (hemicellulosic and cellulosic), and each process only uses one of these sugars, one pretreatment can be performed on the whole feed to separate the two.

A dilute sulfuric acid hydrolysis is used to break down the hemicellulose into sugar monomers (xylose and arabinose, some trace others) in solution. This process affects a negligible amount of the cellulose, leaving most of it intact. It also breaks down a small amount of lignin, but not enough to have an appreciable impact on the fermentation. The resulting slurry is then put through a filter. The sugars in solution will pass through the filter to be processed further into xylitol. The solid cellulose matrices will not, and will be collected for further processing and eventual fermentation into lactic acid, and then PLA.

Xylitol Fermentation

The first major decision with regard to fermentation is that of whether the process will be in batch or continuous. Batch is more traditional and easy to control, but requires more equipment and a lot of resources spent on initial cell grow-up. A continuous process can save a lot of money and be lead to more efficient production of the product, but it comes with some extra risks - especially that of contamination. This risk played an important part in choosing which organism would be used to ferment xylose into xylitol.

*Candida guillermondii* was the initial choice, as there is a wealth of literature about its ability to perform the needed fermentation. However, upon further research, a strain of *Candida tropicalis* was found that possessed better reaction kinetics and performed best in highly acidic conditions. This strain prefers the fermentation to take place at a pH of 2.5. This is far too acidic
for most microorganisms to thrive, so contamination is not a concern for this process. Thus, the biggest risk associated with continuous fermentation is avoided. The low pH also allows much less CaOH to be used to neutralize the input stream, which saves money. There appears to be many strains of *Candida tropicalis* that have been researched for similar processes. Some genetically modified strains possess other highly desirable properties, such as the ability to convert arabinose into xylitol, and the inability to convert arabinose into arabitol (a possible toxin to the fermentation process). This leaves open the possibility of obtaining one of these strains or engineering one with an optimal combination for enhanced production.

After passing through the fermenter, the effluent will be centrifuged to remove all of the yeast, and the flow through from this will be steam treated to make sure that the xylitol broth is completely sterile. This is very important because *Candida* yeasts are toxic to humans. Some of the xylitol stream is also recycled back to the fermenter so that more of the remaining xylose sugars in the stream can be converted to xylitol and increase overall yield.

*Xylitol Purification Process*

There were two main processes researched for aqueous xylitol purification: chromatography and activated charcoal treatment. It was decided that using two ion exchange resins was the most cost effective and simple purification process for many reasons. While the ion exchange resins are a large capital cost, they are extremely cost effective in that no solvent needs to be regularly replaced and the maintenance is rather cheap. For non-water solutions, cation exchange resins have lifespans of 5-10 years, while anion exchange resins typically last 3 to 5 years. It has a small footprint and zero effluent and waste generated. The capital cost is large because backup ion exchange resins will be required due to the regeneration needs of the columns.
The charcoal treatment, on the other hand, has a lower capital cost but is difficult to scale up to an industrial continuous process. It has a much larger footprint and multiple effluent streams. Exhausted charcoal and an ethanol precipitate would need to be disposed of safely and properly. The activated charcoal and input ethanol would add to fixed costs for our process.

The largest relevant distinction between the two methods is the crystalline product yield. The chromatography method has a 95% recovery of crystalline xylitol from the fermentation broth with recycle, while the charcoal treatment only has 76.20% with four cycles of crystallization [2]. While more recent literature shows great promise for increasing the yield using activated charcoal, the current yield and purity is not suitable for this project.

*Lactic Acid Fermentation*

Lactic acid fermentation is a relatively common process, often involving bacteria of the genus *Lactobacillus*. This process will use *Lactobacillus delbrueckii* to convert glucose into L-lactic acid. *L. delbrueckii* was chosen over the more common *acidophilus* because of the discovery of a method of significantly increasing the yield. As lactic acid is produced, the pH of the culture drops until at some point it begins to adversely affect the rate of reaction. If the pH is kept at a neutral or near neutral level (~6.0), the bacteria will continue to operate at maximum capacity, leading to a 98% conversion of glucose to lactic acid. This is a significant increase over its unregulated yield of 86%.

This fermentation will also be carried out continuously, as the glucose conversion occurs during the cell growth phase. The effluent will be filtered through liquid extraction to remove everything except the L-lactic acid.
**PLA Synthesis**

It was chosen to synthesize polylactic acid via a direct condensation polymerization reaction of L-lactic acid rather than lactide ring opening. This decision was made based on two primary criteria: heating energy costs and fermenter stream separation costs. Despite the lactide ring opening process’ use of water as its solvent, the effluent stream from the lactic acid fermenter is not a pure solution of water and lactic acid and would have required processing before being entered into the lactide ring opening process. First, the various salts and fermentation by-products in the stream would have to be separated via crystallization, distillation, or other means. In addition, a purified solution of water and lactic acid would need to be distilled to a lactic acid concentration of 15 wt. % for the polymerization process to be effective. The fermenter exit stream is predicted to have a lactic acid concentration of 12.7%; therefore, 46,800 kg of water would have to be distilled off per day. This purification and concentration of the fermenter effluent would introduce additional energy and equipment costs. As the lactide ring opening process already requires numerous evaporators, condensers, reactors and a tray distillation column, it was felt that the additional costs associated with fermenter stream pre-processing would simply push the cost too high.

In contrast, the process of direct condensation polymerization of lactic acid is much simpler, only requiring one central reactor, one evaporator, one crystallizer and one flash vessel to produce a PLA product. The fewer pieces of equipment needed by this process allowed for more complex solvent recovery processes to be implemented and also were thought to reduce the overall costs of the process. The molecular weight of the PLA product is also able to be more finely controlled in the direct condensation process and scales with the amount of polymerization reactor effluent recycled back to the reactor. This control would allow a PLA production facility to adapt
the final PLA product to different markets based on the molecular weight of the PLA. In the event of a decline in low molecular weight PLA prices, a plant using this direct condensation process could choose to produce a higher molecular weight PLA and vice versa. It was felt that this flexibility would contribute to a more stable business.

Despite the fact that the direct condensation process requires the use of multiple solvents rather than keeping the lactic acid in an aqueous solution, it actually proved to be the superior option. Initially transferring the lactic acid from the fermentation broth to an organic solvent cuts down on both the equipment and energy costs of purifying and concentrating the broth for the lactide ring opening process. The organic solvent chosen for the direct condensation process was diphenyl ether. Diphenyl ether was chosen due to its immiscibility in water, ability to preserve high molecular weight polylactic acids in solution, and high boiling point of 258°C. Rather than first heating the fermentation broth and feeding it to flash vessels to purify and concentrate it, a liquid extraction into diphenyl ether can be carried out on the broth at room temperature without any purification or concentration steps. Additionally, with some separation steps the diphenyl ether can be recycled and treated as a capital cost rather than an operating cost.

However, the dichloromethane and methanol required for the direct condensation polymerization process pose significant costs. Priced at $0.405 and $0.500 per kilogram respectively, replenishing the dichloromethane and methanol required for the PLA process would cost approximately $51,000 per day in material costs. Therefore, it was decided to separate the solvent mixture using a tray distillation column in order to recycle each component. Following the PLA crystallization, the exit methanol and dichloromethane solution is distilled and each component recycled. This process recycles virtually all of the solvent, essentially eliminating the operating costs of adding new solvent and disposing of waste solvent.
7.2 Aspen Modelling Assumptions

A number of assumptions were made in order to simulate the process in Aspen Plus V9 simulation software. The following section details the general thought process that went into making the assumptions -- for a full printout of the final Aspen Plus V9 input file, see Appendix A3.

Component Assumptions

No solids processing simulations were performed in Aspen Plus. Instead, components that exist as solids in the process were given the property sets of inert or innocuous compounds. For example, cellulose solids were modelled as fructose and other solids were modelled as heavy water (deuterium oxide). To ensure that these ‘solids’ moved through the process in expected ways, separator blocks were used in place of rigorous filter or centrifuge blocks to send the ‘solids’ one direction and the liquids in another. In equipment sizing, however, these separator blocks were evaluated correctly.

To simplify the model, a number of component groupings were made. Non-cellulosic solids and nonfermentable solutes were grouped together into “Other Solids” and “Other Liquids,” respectively. Similarly, all fermentable sugars produced were treated as “xylose” in the acid hydrolysis step and “glucose” in the saccharification reaction step and cellulose and hemicellulose were both treated as “cellulose.” This Aspen ‘cellulose’ was affected by both the xylitol and the lactic acid pretreatments despite them being separately affected in reality. To compensate for this in hydrolysis reactions, the stoichiometry of each reaction was adjusted so that the mass of real hemicellulose or cellulose consumed was reflected in the change in mass of Aspen’s ‘cellulose’. For example, say that the feed stream to the sulfuric acid hydrolysis consists of 5 grams of cellulose
and 5 grams of hemicellulose. In reality, the hydrolysis would consume ~5 grams of hemicellulose and produce ~2 grams of arabinose, ~2 grams of xylose and ~1 gram of glucose leaving the cellulose untouched. In the Aspen simulation, this reaction is modelled as 10 grams of ‘cellulose’ being converted into 5 grams of ‘cellulose’ and 5 grams of ‘glucose’. This simplification is further demonstrated in figure 7.2.

![Figure 7.2 – Example of Component Assumptions](image)

Lastly, since neither xylose nor cellulase enzymes are ever present in the same stream, both compounds were modelled as ‘xylose’. These groupings trim down the number of by-products that Aspen simulates and allows results to be understood easier.

The Aspen Suove-Redlich-Kwong equation of state was selected to describe the thermodynamic interactions in the simulation. This equation of state was selected due to its ability to estimate equilibrium data for all of the components in the simulation both individually and in mixtures. Thermodynamic properties of each compound were, for the most part, present in the Aspen default databases. However, the properties of ammonium hydroxide and calcium sulfate were not fully present. The boiling point, critical temperature, critical pressure, and acentric factor for each of these compounds were researched and entered manually. Polylactic acid was not a
compound present in the default Aspen databanks. An attempt was made to work with Dr. Len Fabiano and Aspen support specialists to create an accurate polymer model, however this approach proved inefficient and overly complicated. Due to the PLA’s high molecular weight, viscosity and boiling point, it is unlikely that the presence of PLA in a solution would alter its thermodynamic properties significantly. Therefore, it was decided to use the Aspen information for n-dodecane to model most of the thermodynamic properties of PLA. In order to ensure that the PLA remained a liquid in any flash calculations, the boiling point, critical temperature, and critical pressure were manually set at 2000 C, 3000 C, and 5 atm respectively. The molecular formula of PLA was set to be C3300H4400O2200 in Aspen’s property editor -- Aspen therefore calculated a molecular weight of 79,270 for the PLA model. This approximated model of PLA ensured that the polymerization reaction stoichiometry and flash block calculations were accurate.

**Reaction Modelling Assumptions**

Most of the chemical reactions in the process -- including the xylitol and lactic acid fermentations -- were modelled using the RYield block in Aspen. The only two reactions that were not modelled this way were the CaOH2 neutralization reaction and the lactic acid direct condensation reaction. These reactions were both modelled as RStoic. The RYield method was chosen for most of the reaction models because it allowed for the component simplifications described in the preceding section to be applied accurately. The RStoic model could not have been used in these cases due to the inconsistency of the molecular formulae of each component. The simplifying assumptions made in component selection meant that a stoichiometric balancing of the chemical equations was not possible in reactions that contained approximated components. RYield allowed for these reactions to be simulated despite the fact that the atomic balance around
the reactor did not close. However, the RStoic model was able to be applied to the CaOH2 neutralization and the lactic acid polymerization reactions because the components involved were modelled with the correct molecular formulae. Both of these reactions were assumed to complete fully with a yield of 100%. The polymerization reactor contained some further simplifications. Additionally, the nitrogen gas bubbled through the reactor and the solid tin oxide catalyst over which the reaction is performed were not modelled in Aspen. This was done because the presence of nitrogen or tin oxide in the reactor model did not impact the simulation results and neither the nitrogen nor catalyst could be modelled as remaining within the reactor. This meant that in the simulation the nitrogen and tin oxide would be carried out in the reactor effluent and influence thermodynamic calculations further along in the process. Removing these components could have been accomplished by adding a separator block to the process, however this block would then be automatically evaluated by the Aspen integrated economics module as a capital cost of the process, requiring more tinkering with the simulation to remove its costs. The best solution was simply to remove the nitrogen gas and tin oxide catalyst from the process model.

*Design Specifications and Stream Flow Estimates*

The water and diphenyl ether recycle streams in the process were modelled using design specifications. Each recycle stream in the process was mixed with an external input stream of the same compound. A design specification was then implemented that varied the flow rate of the external input stream until the combined mixer output stream contained the desired amount of the recycled compound. The design specs all varied the input flow rate beginning at zero and ending when the loop converged. The flow rate of the diphenyl ether stream that would produce the
optimal liquid extraction was estimated using a sensitivity analysis that recorded various separation mass fractions as they varied with diphenyl ether flow rate.

The desired methanol and dichloromethane input flow rates were estimated from experimental data found in polylactic acid crystallization literature. A design specification was implemented that set the input flow rate of dichloromethane into the PLA stream at 600 L per kg of PLA. A second design specification set the input flow rate of methanol at 4 L methanol / 3 L dichloromethane.

Another design specification was implemented that varied the temperature of the diphenyl ether recovery flash vessel (S-13) in order to maintain the diphenyl ether recovery stream at 99 weight % diphenyl ether.

*Equipment Sizing and Stream Costing Assumptions*

Equipment sizing, bare module costing, and utilities pricing were completed using the Aspen Process Economic Analyzer (APEA). All of the equipment materials were modelled in the APEA as stainless steel SS304. This was done in order to make the equipment cost estimate generated by the APEA a high-end estimate, since it is likely that not all of the process equipment would be stainless steel in reality. In these cases, the equipment would be constructed of cheaper carbon steel. Stainless steel is a good estimation for the flash drums and reactors, however, because those vessels would be processing either sterile fermentation materials or potentially corrosive chemicals.

When sizing the heat exchangers in the process, the APEA occasionally encountered an error in which the default specified heat transfer area of the exchanger differed by more than 10% from the required heat transfer area calculated from the simulation. In these cases, the heat transfer
area calculated by Aspen was copied and the default equipment sizing area was replaced with the calculated area to alleviate the error.

The prices of all input and output streams were entered into the APEA using information collected from both the Independent Chemical Information Service (ICIS) and commodity chemicals company websites.
7.3 Full Process Diagram
Figure 7.4 – Full Process Diagram with Labelled Sections.
Table 7.1 – Global Stream Report

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7.4 Process Description

7.4.1 Universal Pretreatment Process

![Universal Pretreatment Process Flow Diagram]

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*Figure 7.5 – Universal Pretreatment Process Flow Diagram*
Table 7.2 – Stream Report for Universal Pretreatment Process

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</table>
A stream of ~63 wt.% water solid BSG enters in stream 1. The estimated flow rate of this stream is 160,512 kg/day. The stream first enters a holding tank (T-1) so that the discrete inputs of the BSG are smoothed out for a continuous process. After exiting the holding tank, the wet BSG stream enters an agitated washing tank (E-1) where it is combined with 355,801 kg/day of municipal and recycled water at 95°C heated by a recycle steam stream from later in the process (HX-4). The washing tank is stainless steel SS304, with a diameter of 1.06 meters and a tangent-to-tangent height of 4.42 meters. The washing tank holds a volume of 3950 L. The wash step increases the water content of the stream to 88% water to ensure that the wet BSG stream contains the right liquid to solid ratio as it enters the acid hydrolysis reactor (R-7). Before entering the reactor, the stream is heated by a product-to-feed heat exchanger (HX-5) to 140°C and then a furnace to 150°C (HX-1). 2351 kg/day of 57.5 wt.% sulfuric acid solution is heated to 92°C (HX-3) and added to the reactor to create a liquid to solid ratio of 8 g liquid/8 g solid. The reactor is a jacketed, agitated stainless steel SS304 tank. The residence time of the reactor is 1.5 hours, leading to a reactor volume of 28,334 liters. The vessel has a diameter of 5.49 meters and a tangent-to-tangent height of 19.2 meters. In this acid hydrolysis reactor, the hemicellulosic solids in the BSG are broken down into xylose, arabinose and glucose fermentable sugars along with other soluble by-products. The product stream (5) consists of 15,304 kg/day solid cellulose, 3903 kg/day other solids, 455,355 kg/day water, 12,949 kg/day fermentable sugars modelled as xylose, and 29,801 kg/day of other liquids. The stream is cooled from 150°C to 103°C in the feed-to-product heat exchanger used to heat the feed (HX-5) and then enters a rotary drum filter (S-1). The filter is a high-rate, SS316 rotary drum filter that is designed to separate the cellulose and other BSG solids from the acid hydrolysis slurry product stream (8). The filter is calibrated to reduce the water content of the solid stream to 95 wt.% water so as to avoid adding additional water to the stream.
later in the process. The solid stream from the filter (29) continues on to the lactic acid fermentation process and the liquid stream (9) continues to the xylitol fermentation process.

### 7.4.2 Xylitol Fermentation Process

![Diagram of Xylitol Fermentation Process]

#### Equipment List

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*Figure 7.6 – Xylitol Fermentation Process Flow Diagram*
Table 7.3 – Stream Report for Xylitol Fermentation Process

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Note: The table shows the temperature, pressure, and flow rates for different streams, along with thermodynamic properties (enthalpy and entropy) and composition details for various substances.
The stream of fermentable sugars and inert solutes (9) from the rotary drum filter (S-1) first enters a neutralization reactor (R-1). The neutralization reactor is a stainless steel SS304 agitated, jacketed vertical tank with a diameter of 0.76 meters and a tangent-to-tangent height of 7.77 meters. The neutralization process requires the reactor to have a residence time of 30 minutes, leading to a vessel volume of 7,656 liters. 7,389 kg/day of 2.00 molar CaOH$_2$ solution is added to the reactor in order to neutralize the acid hydrolysis product from a pH of approximately 1.25 to a pH of ~2.5. The pH of 2.5 is the ideal pH required by the *C. tropicalis* bacterium used in the fermentation. In the neutralization reaction, the hydroxide ions in the CaOH$_2$ solution react with the hydronium ions released by the H$_2$SO$_4$ in the acid hydrolysis reactor (R-7) to produce water and calcium sulfate (CaSO$_4$). The calcium sulfate is insoluble in water and precipitates out of the solution as a solid. A continuous disk centrifuge (S-5) with a diameter of 0.254 meters processes the reactor effluent and separates the calcium sulfate solids from the neutralized liquid stream. The liquid stream is first mixed with a 92°C recycle stream from later in the process that heats the combined stream from 25°C to 27°C. The stream is then further heated to 32°C using municipal steam (HX-20), and is fed to the continuous xylose fermenter (R-2) at 80 g/L xylose. The fermenter contains *Candida tropicalis* yeast kept in a continuous growth stage that ferment the sugars in the liquid feed into xylitol. The yeast are grown in separate scale-up tanks before being added to the fermenter along with Yeast Mold broth. The fermenter is modeled as a stainless steel, ideal anaerobic well-mixed chemostat with an optimal dilution rate of 0.084 h$^{-1}$. This gives a residence time of 12 hours and a volume of approximately 62,000 liters. The fermenter is cooled with chilled water to counter the heat generated through the fermentation process. The broth is continuously drained along with the yeast, and all goes to the subsequent purification steps.
7.4.3 Xylitol Purification Process

![Xylitol Purification Process Flow Diagram]

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*Figure 7.7 – Xylitol Purification Process Flow Diagram*
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<td>-</td>
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Table 7.4 – Xylitol Purification Process Stream Report
The xylitol purification process, as outlined, obtains pure (99.9%) crystalline xylitol from fermentation product. The process is entirely continuous, in line with the rest of the process design. The fermentation product stream (16) is fed through a continuous centrifuge (S-4) that separates out any solid suspended cell debris solids before the liquid stream passes into two chromatography columns (S-2) and (S-16). The centrifuge is also able to kill some of the *C. tropicalis*, which is a human pathogen. The solid stream exiting the centrifuge is discarded, treated for impurities, and combined with the wastewater removal. The liquid stream (18) continues through the purification process at a flowrate of 173,766 kg/day.

The stream that enters the first chromatography column is assumed to be 50-75% weight xylitol, less than 5% xylose, and water. Both columns are ion exchange resins, which work by containing a polymer that captures ions of interest and removes them from the solution. The first chromatography column is a CS 14 GC cationic ion exchange resin. It is able to remove all inorganic salts and a large portion of organic impurities. The column is modeled as a polystyrene sulfonic resin, 5 meters high and 2.5 meters in diameter, and uses cross-coupled divinyl benzene as a solvent. The second chromatography column is a 103S vinylbenzyl tertiary anion exchange resin. The purpose of this column is to remove the rest of the organic impurities and balance the color of the solution. It is the same size of the first column, at 5 meters high and 2.5 meters tall. Due to the high salinity of the fermentation product, and the need for regeneration, the system will have an additional cation exchange resin and anion exchange resin to be used when the primary columns need to regenerate. The regeneration will occur when about 80% of the adsorption sites within the column are full of salt.

After the two continuous chromatography columns, the effluent stream is colorless, aqueous xylitol and xylose solution with no other impurities. Its flowrate is 143,964 kg/day. The
stream (21) is then fed into an evaporator (S-9) at 106°C until nearly all water is removed. For fractional crystallization, the liquid mixture of xylitol and xylose is then cooled to 5°C in the crystallizer (S-3), at which point nearly all of the xylitol is crystallized. The flow rate entering the crystallizer is 25,010 kg/day. The mother liquor that remains is conveniently recycled back into the stream entering the xylitol fermenter, as the stream contains some xylose that may be broken down to xylitol. The addition of this recycle streams allows at least 95% of total liquid xylitol to crystallize in this process. The final crystalline product is 99.9 weight percent xylitol, making it food grade quality.

The crystalline xylitol is fed into a wash drum (E-10) at 12,203 kg/day to be steam sterilized at 134°C for 3 minutes. This process removes any possibility of *C. tropicalis* in the final product. The crystalline xylitol in then dried and packaged to be sold. The final production of xylitol is 9,876 kg/day. This process was designed using the outlined processes in US patents 3985815 and 4008285.
7.4.4 Lactic Acid Fermentation Process

Figure 7.8 – Lactic Acid Fermentation Process Flow Diagram

<table>
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<td>HX-6</td>
<td>Condenser</td>
</tr>
<tr>
<td>R-3</td>
<td>AAS Reactor</td>
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<td>R-4</td>
<td>Saccarification Reactor</td>
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<td>R-5</td>
<td>Lactic Acid Fermenter</td>
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<td>S-10</td>
<td>Fermenter Product Centrifuge</td>
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<td>S-14</td>
<td>Lactic Acid Pretreatment Evaporator</td>
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#### Thermodynamics

| Entropy (cal/g*K) | -1.96 | -1.93 | -3.97 | -2.21 | -2.27 | -2.22 | -0.53 | -1.49 | -2.30 |

#### Composition

| Ammonium Hydr. | - | - | 0.28 | 0.02 | - | 0.02 | - | 0.02 | - |
| Ca(OH)₂ | - | - | - | - | - | - | - | - | - |
| CaSO₄ | 0.39 | 0.05 | - | - | - | - | - | - | - |
| Cellulose Solid | - | - | - | - | - | - | - | - | - |
| CH₂Cl₂ | - | - | - | - | - | - | - | - | - |
| Enzymes | - | - | - | - | - | - | - | - | - |
| Diphenyl Ether | - | - | - | - | - | - | - | - | - |
| Ferment. Sugars | - | - | - | - | - | - | - | - | - |
| Lactic Acid | - | - | - | - | - | - | - | - | - |
| Methanol | - | - | - | - | - | - | - | - | - |
| N₂ | - | - | - | - | - | - | - | - | - |
| Other Solids | - | - | 0.01 | - | 0.01 | - | 0.01 | - | 0.01 |
| Other Solutes | - | - | - | 0.04 | - | 0.04 | - | - | - |
| Polylactic Acid | - | - | - | - | - | - | - | - | - |
| Sodium Citrate | - | - | - | - | - | - | 1.00 | - | 0.01 |
| Sulfuric Acid | - | - | - | - | - | - | - | - | - |
| Water | 0.61 | 0.94 | 0.72 | 0.92 | 1.00 | 0.93 | - | 1.00 | 0.04 |
| Xylitol | - | - | - | - | - | - | - | - | - |
| Xylose | - | - | - | - | - | - | - | - | - |

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<td>368,323</td>
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<td>368,323</td>
<td>1,391</td>
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#### Thermodynamics

| Enthalpy (J/kg) | -15,655,400 | -15,576,900 | -15,608,400 | -15,617,900 | -16,034,300 | -16,622,540 | -6,983,490 | -15,053,100 |
| Entropy (cal/g*K) | -2.23 | -2.27 | -2.19 | -2.35 | -1.64 | -2.35 | -2.28 | -0.51 |

#### Composition

| Ammonium Hydr. | - | 0.16 | - | - | - | - | - | - | - |
| Ca(OH)₂ | - | - | - | - | - | - | - | - | - |
| CaSO₄ | - | - | - | - | - | - | - | - | - |
| Cellulose Solid | - | - | - | - | - | - | - | - | - |
| CH₂Cl₂ | - | - | - | - | - | - | - | - | - |
| Enzymes | - | - | - | - | - | - | - | - | - |
| Diphenyl Ether | - | - | - | - | - | - | - | - | - |
| Ferment. Sugars | - | - | - | - | - | - | - | - | - |
| Lactic Acid | - | - | - | - | - | - | - | - | - |
| Methanol | - | - | - | - | - | - | - | - | - |
| N₂ | - | - | - | - | - | - | - | - | - |
| Other Solids | - | - | 0.07 | - | 0.00 | 1.00 | - | - | 0.00 |
| Other Solutes | - | - | - | - | - | - | - | - | - |
| Polylactic Acid | - | - | - | - | - | - | - | - | - |
| Sodium Citrate | - | - | 0.10 | - | - | - | - | - | - |
| Sulfuric Acid | - | - | - | - | - | - | - | - | - |
| Water | 0.96 | 0.36 | 0.96 | 0.96 | - | 0.96 | 1.00 | 1.00 | - |
| Xylitol | - | 0.30 | - | - | - | - | - | - | - |
| Xylose | - | - | - | - | - | - | - | - | - |
The solid stream from the acid hydrolysis product filter (29) first enters an evaporator (S-14) that heats it to 110°C using medium pressure steam. It was assumed that the solids separated by filter S-1 contained 95.4 wt.% water. 33,693 kg/day of this water is vaporized in the evaporator and is recycled as heating steam (77). A design specification was used to ensure that the evaporator removes enough water from the stream so that the fermenter feed stream contains glucose sugars at a concentration of 50 g/L. The dried solids are removed from the evaporator at 110°C and fed to the aqueous ammonia soaking (AAS) reactor (R-3) along with 29,990 kg/day of 25°C 28 wt.% ammonium hydroxide solution in water. The AAS reactor is a 27,789 liter jacketed, agitated stainless steel SS304 vertical vessel with a residence time of 22 hours. The vessel has a diameter of 2.13 meters and a tangent-to-tangent height of 7.77 meters. The combining streams entering the reactor equilibrate to a temperature of 70°C while the AAS reaction occurs. The treated solids are fed to a vertical stainless steel wash vessel (E-8) where they are mixed with 50,000 kg/day of 25°C municipal water in order to neutralize the stream. Excess basic free water in the vessel is removed and disposed as a waste stream (34). The washed, processed solids are fed to a saccharification reactor at 25°C (R-4) along with 5,201 kg/day of pH 5.5 sodium citrate buffer solution and 15,671 kg/day of cellulase enzymes. The saccharification reactor is a 2,602 liter stainless steel SS304 agitated, jacketed reactor that operates at a temperature of 25°C. The reactor has a diameter of 0.91 meters, a tangent-to-tangent height of 3.96 meters and a residence time of 1.5 hours. In the saccharification reactor, the treated cellulose solids in the feed stream are broken down into glucose that dissolves into solution. It was assumed that there was 100% conversion of the cellulose solids in the reactor into aqueous glucose. Seven identical continuous disk centrifuges -- each with a diameter of 0.254 meters -- are run in parallel to remove the remaining solids in the reactor effluent stream (S-6) and the liquid is fed to a heat exchanger (HX-6). Low pressure steam
is used to heat the stream to 37°C and it is fed into the continuous lactic acid fermentation bioreactor (R-5). The feed stream to the fermenter contains 383,551 kg/day of water and 36,177 kg/day of glucose. The fermentation reactor is a 95,000 liter agitated, jacketed vertical stainless steel SS304 vessel with a residence time of 10 hours. It is loaded with *Lactobacillus delbrueckii* at a concentration at 2 grams of cells per liter. The dilution rate is set equal to 0.1h⁻¹ for optimal cell growth and product production. It is being modeled as an ideal, well-mixed continuous chemostat. This will also have to be cooled with chilled water in order to counteract the heat associated with the fermentation. All of the bacteria and broth will be flushed out to the subsequent purification steps.
Lactic Acid Polymerization and Purification Process

Figure 7.9 – Lactic Acid Polymerization Process Flow Diagram

Equipment List

- PLA Recycle Drier
- Lactic Acid Feed Heat Exchanger
- Steam Steam Heat Exchanger
- Distillate to Bottoms Exchanger
- Lactic Acid Feed Heat Exchanger
- Water/Solvent Decanter
- Ether Separating Flash Drum
- Polymerization Reactor
- Heater

Figure 7.9 – Lactic Acid Polymerization Process Flow Diagram

- S-11 Water/Solvent Decanter
- HX-16 Steam Heat Exchanger
- HX-11 Distillate to Bottoms Exchanger
- HX-10 Lactic Acid Feed Heat Exchanger
- S-12 Ether Separating Flash Drum
- R-6 Polymerization Reactor
- E-9 PLA Recycle Drier
- HX-9 Heater
- HX-8 Steam Steam Heat Exchanger
- S-13 Solvent Flash Drum
- S-7 Liquid Extraction Column
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</table>
As in the xylitol purification process, the lactic acid fermentation product is fed to a continuous centrifuge (S-10) that separates any remaining solids and cell debris from the stream. The aqueous lactic acid solution is fed to a liquid liquid extraction column (S-7) at a temperature of 37°C and a rate of 366,931 kg/day. This lactic acid solution contains 353,019 kg/day of water, 139 kg/day of unfermented sugars, and 13,774 kg/day of lactic acid. A mostly-recycled solvent feed of 39,981 kg/day of diphenyl ether, 283 kg/day of residual water and 139 kg/day of glucose is mixed with enough makeup diphenyl ether to reach 40,000 kg/day and also fed into the extraction column at a temperature of 163°C. The column is a stainless steel SS304, single-diameter vertical vessel with 10 equilibrium sieve trays. The column is clad in SS304 stainless steel. The raffinate stream contains trace amounts of diphenyl ether, 268,849 kg/day of water, 6167 kg/day of dissolved lactic acid and 330 kg/day of unfermented glucose and is discarded as waste. The extract stream contains 384 kg/day of water, 139 kg/day of glucose, and 13,325 kg/day of lactic acid dissolved in 40,000 kg/day of diphenyl ether solvent. The liquid extraction therefore removes approximately 96% of the lactic acid present in the fermentation product stream. The extract is fed to a heat exchanger (HX-10) and is heated with recycled diphenyl ether and water vapor (54) to a temperature of 93°C. High pressure steam is used to further heat the stream to 170°C (HX-8) and the stream is fed to the direct condensation polymerization reactor (R-6). The reactor is a SS304 stainless steel, 10,842 liter agitated and jacketed vessel with a retention time of 1.5 hours. The reaction vessel has a diameter of 1.524 meters and a tangent-to-tangent height of 5.94 meters. The design temperature of the reactor is 197°C. The polymerization reaction occurs at an operating temperature of 170°C over a bed of solid tin oxide catalyst. The catalyst does not require rejuvenation following the reaction and is therefore a permanent capital cost of the reactor. As little data was found regarding the exact amount of catalyst to use, it was assumed that the catalyst
would form a 1-meter bed on the bottom of the reactor vessel. The reactor diameter and the density of tin oxide catalyst were used to estimate a catalyst mass of 12,678 kg of tin oxide. Nitrogen gas is continuously bubbled through the reactor to encourage mixing and to provide an inert environment for the condensation reaction to take place. During the reaction, two lactic acid monomers combine to create one ‘link’ of the polylactic acid polymer and release one molecule of water. This water does not dissolve in the diphenyl ether solvent and vaporizes. This water vapor stream is removed from the reactor (53) and mixed with other steam recycle streams (V-7) to provide heat for HX-10. The exit stream from the polymerization reactor is first fed to a heat exchanger (HX-16) at 170°C where it is used to heat the evaporated steam stream (86) from the xylitol purification evaporator (S-9) from 103°C to 155°C. The cooled polymerization reactor effluent, now at 110, is split equally using a splitter valve (V-1). Half of the reactor exit stream is fed to a flash evaporator (E-9) where it cools to 100°C as the water in the stream is separated as vapor.

The vapor stream contains 1000 kg/day of water vapor, 35 kg/day of diphenyl ether and trace glucose. It is mixed with a 157°C steam recycle generated further in the process (69) using a mixing valve (V-6) and the free water decant of the PLA reactor (53) and the combined stream reaches a temperature of 141°C. This stream is used as the hot stream in HX-10 to heat the lactic acid feed stream (49) from 35°C to 93°C before it enters the polymerization reactor (R-6). In the heat exchanger, the stream is cooled from 141°C to 90°C. Following the heat exchanger, the cooled stream contains 2,785 kg/day of water and 991 kg/day of diphenyl ether – it must be separated before either the water or diphenyl ether can be recycled. The stream is fed into a decanter (S-11) at 90°C where the water and diphenyl ether are separated. The decanter is a vertical, stainless steel SS304 processing vessel with a volume of 2401 liters. The decanter has a diameter of 0.914 meters.
and a tangent-to-tangent height of 3.66 meters. The second liquid stream from the decanter (74) contains 991 kg/day of 98 wt.% diphenyl ether and is mixed with both the pure diphenyl ether input stream (73) and another diphenyl ether recycle stream (71) originating later in the process. This combined stream (48) is then recycled as feed to the lactic acid liquid extraction column (S-7). The first liquid stream from the decanter (75) contains 2,765 kg/day of ~100 wt% pure water and is combined with the original BSG water input stream (79) using a mixing valve (V-3).

The cooled PLA liquid stream (59) is fed back into the polymerization reactor (R-6) where it gets heated back to 170°C and continues to participate in the lactic acid polymerization reaction. This recycle loop allows for the molecular weight of the PLA created in the reactor to be controlled. If a higher molecular weight polymer is required, a higher fraction of the reactor product stream can be split into the recycle loop by V-1 and vice versa for lower molecular weights of PLA.

The solvent and PLA stream that is not recycled (60) is heated to 237°C in a feed-to-top heat exchanger (HX-11) and then further heated to 288°C using high pressure steam (HX-9). The heated stream is fed to a flash vessel (S-12) that separates the diphenyl ether and water in the stream from the PLA. The flash vessel is a vertical, stainless steel SS304 vessel with a volume of 2402 liters. The flash vessel has a diameter of 0.914 meters and a tangent-to-tangent height of 3.66 meters. The flash is performed at a temperature of 288°C and the diphenyl ether vapor stream is used to preheat the feed as described previously. This preheating heat exchanger cools the diphenyl ether vapor stream from 288°C to 180°C.

The flash process removes almost all of the diphenyl ether from the feed stream, leading to a vapor stream of 39,946 kg/day of diphenyl ether mixed with 2,047 kg/day of water. In order to remove the water from this stream and recycle the diphenyl ether, the mixture is fed to another flash vessel (S-13) at 180°C where it cools to 157°C. This flash vessel is a vertical, stainless steel...
SS304 vessel with a volume of 2402 liters. The flash vessel has a diameter of 0.914 meters and a tangent-to-tangent height of 3.66 meters. The water in the feed is removed as steam (69) and mixed with the polymerization reactor water vapor decant (53) and PLA recycle evaporator (61) streams using a mixing valve (V-6). The diphenyl ether stream (71) contains 38,990 kg/day of 99.4 wt. % diphenyl ether and is recycled to the fermentation broth liquid extraction column (S-7).
7.4.6 Separation and Solvent Recovery

**Equipment List**

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<td>Solvent Distillation Column</td>
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*Figure 7.10 – Separation and Solvent Recovery Process Flow Diagram*
### Table 7.7 – Separation and Solvent Recovery Process Stream Report

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The stream of PLA exiting the solvent flash vessel (63) is fed to a mixing vessel (E-28) where it is dissolved in 69,268 kg/day of a recycled dichloromethane stream at 40.1°C. The recycled stream contains 69,263 kg/day of dichloromethane, 3.62 kg/day of methanol, and trace water and diphenyl ether. Next, the solution enters a stainless steel SS304, 3,269 liter crystallization vessel (S-8). The vessel has a diameter of 1.07 meters and a tangent-to-tangent height of 3.66 meters. 46,900 kg/day of a recycled methanol stream at 60.7°C is added to the crystallization vessel to promote the dissolved PLA to crystallize out of the dichloromethane solution. The recycled methanol stream contains 36,374 kg/day of methanol, 10,512 kg/day of dichloromethane and 14 kg/day of diphenyl ether. The crystals of PLA are collected from the crystallizer and sold -- this process results in 99.9 wt.% pure crystals of 79,270 molecular weight PLA.

The solvent stream from the crystallizer (67) is fed to a tray distillation column so that the dichloromethane and methanol can be separated. The tray distillation column is a stainless steel SS304 vertical, multi-diameter column with 26 sieve trays, a total condenser and a partial reboiler. The solvent mixture is fed to tray 23 where it begins to separate. The methanol is the less volatile of the two components, so it moves towards the bottom of the column while the dichloromethane moves to the top. This distillation results in distillate recoveries of 0.87 and 0.0001 for dichloromethane and methanol, respectively.
8.0 Energy Balance and Utility Requirements

8.1 Heat Integration Strategy

There is one main heat recycling loop in the process that is intended to use all excess heat generated in the process to heat the input BSG wash water. The main loop uses all of the heated steam generated by evaporators and flash drums to heat the entering water stream. The steam is then condensed to a saturated liquid and recycled as liquid water. In this way, most of the heat from the recycle water and steam is recovered.

Two steam streams are recycled from the process. The first stream (86) is the steam stream leading the xylitol flash evaporator (S-9). The steam leaving the evaporator has a flow rate of 144,105 kg/day and a temperature of 104°C. In order to increase the energy potential of the steam, it is passed through a heat exchanger (HX-16) and heated to 151°C by the polymerization reactor (R-6) effluent stream. The resulting hot steam stream (101) is passed through the finished xylitol crystal product (E-10) in order to sterilize any remaining Candida tropicalis in the product and continues on to a mixing valve (V-4) where it is combined with the stream exiting the lactic acid evaporator vessel (S-14). This stream (77) contains 34,103 kg/day of water vapor at 110°C. After both steam streams are combined, the resulting stream contains 178,208 kg/day of 143°C steam. This steam is first used to heat the inlet water stream from 62°C to 102°C. In this process, it cools from 142°C to 103°C and some of the steam condenses into water. The stream now has a vapor fraction of 0.87 as it passes into another heat exchanger (HX-3). This exchanger is used to heat the entering sulfuric acid solution from 25°C to 100°C. In doing so, the steam stream vapor fraction drops to 0.86. The stream is then passed through a condenser (HX-2) that fully condenses the remaining steam into liquid water. The liquid stream (80) is still at 103°C and is fed to another mixing valve (V-3).
The condensed water stream is combined with the water exit stream (75) from the diphenyl ether and water decanter (S-11) and a municipal water input stream (79) at 25°C. The decanter stream contains 5426 kg/day of water at 90°C. The municipal water stream contains 200,582 kg/day of water at 25°C. When the three streams are combined by mixing value V-3, the resulting stream (78) contains 384,215 kg/day of water at 62°C. This water is then fed to HX-4 where it is heated to 102°C and added to the process.

There are other, smaller heat integration loops that recycle heat locally within various parts of the process. One such heat integration loop occurs between the xylitol crystal separator (S-3) and the bottoms product from exiting the xylitol evaporator (S-9). The liquid stream from the crystal separator (25) exits at 5°C with a flow rate of 12,808 kg/day. It passes through a heat exchanger (HX-21) where it cools the 25,010 kg/day evaporator bottoms stream from 103°C to 46°C. In the process, the stream heats from 5°C to 95°C. After half of the stream is purged, it is mixed with the sugar stream entering the xylose fermenter (V-12). This mixing heats the entering sugar solution from 25°C to 27°C, which lessens the energy requirement of the fermentation heater (HX-20) and also allows for the leftover xylose in the recycle stream to be fermented.

There are also multiple product-to-feed heat exchanges that take place in the process. One loop uses the wet BSG acid hydrolysis product stream (5) in a plate and frame heat exchanger to heat the wet BSG slurry feed from 76°C to 140°C. In doing so, it cools from 150°C to 103°C. This economizing heat exchanger was calculated to save almost $4,000,000 a year in energy costs, as the incoming wet BSG feed has the highest flow rate of any stream in the process at 516,332 kg/day. Another product-to-feed loop exists around the diphenyl ether flash evaporation vessel in the PLA purification process (S-12). This loop heats the entering PLA in diphenyl ether solution from 110°C to 237°C (HX-11), greatly reducing the utility energy required to further heat the
stream to the flash temperature of 288°C (HX-9). In doing so, it cools from 288°C to 180°C, which also reduces the energy needed to cool the stream to 157°C for the next separation (S-13).

8.2 Process Utilities

Table 8.1 – Process Utility Summary

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9.0 Equipment Lists and Unit Descriptions

9.1 Xylitol Fermenter

Xylitol is produced as *Candida tropicalis* reduces xylose through its pentose phosphate pathway. It is a primary metabolite, meaning that *Candida* produces xylitol during its growth phase, instead of just at stationary phase. *Candida*’s metabolism, the acidic conditions under which it most efficiently produces xylitol, and lower capital and operational costs all support the choice to run this fermentation continuously.

This strain of *Candida* was chosen because it has a higher yield and specific volumetric production than *Candida guillermondii*, the previously considered organism. It is also unique in having an optimal pH of 2.5 for xylitol production. Since the steps preceding fermentation include an acid wash (pH ~0.37), and neutralization with calcium hydroxide, this low pH saves money by requiring significantly less base to neutralize to optimal conditions. The low pH environment also makes contamination by other microorganisms unlikely. This acidic environment may necessitate that the fermenter be made from a more expensive metal, but this cost is expected to be relatively small in relation to other expenses.

A CFSTR will be used as the fermenter. It will be kept at 32°C and under microaerobic conditions (~3.5% saturation). As only microaerobic conditions are needed, air may be used to add oxygen to the system. The Monod substrate saturation coefficient and maximum growth rate were found for the organism under similar circumstances, and these values were used to calculate $D_{opt}$, the optimal dilution rate (0.084 h$^{-1}$). In order to feed the fermenter at the correct xylose concentration (80 g L$^{-1}$), the input stream must be diluted by adding 1380 liters per hour of water. This dilution makes the total incoming stream 4120 L h$^{-1}$. By dividing the flow rate by the dilution
rate, the necessary volume of the reactor was calculated at approximately 50,000L. This was taken to be 80% of the maximum fermenter volume to allow for head space. Thus, the total fermenter volume is about 62,000L. The outlet stream will lead to a log6 sterilization treatment and a centrifuge to remove the yeast cells from the broth.

9.2 Lactic Acid Fermenter

A specific strain of *Lactobacillus delbrueckii*, UFV H2B20, was found to possess greatly enhanced fermentation performance if its conditions were well-controlled. Specifically, the pH of the broth must be kept at ~6.0. While this consideration increases the cost of the process, it results in the bacteria converting 98% of the glucose it metabolizes into lactic acid, which may make up for the cost when compared to the yield without the control: 82%. One possible base for regulating pH is ammonia from the preceding neutralization step. This can then be separated using the ensuing liquid extraction. Since lactic acid is a primary metabolite, this fermentation lends itself to continuous processing as well. It should be noted, however, that *L. delbrueckii* does not share *C. tropicalis*’ acidophilic nature, and so does not incur the benefit of added sterility from the acidic solution.

This fermenter is maintained at a temperature of 37°C. The reactor is sized in the same way as for *C. tropicalis*. The reported specific growth rate for *L. delbrueckii* under these conditions is 0.183 h\(^{-1}\). The input stream comes in very much more concentrated than the optimal substrate concentration, so a large amount of water - 6,000L h\(^{-1}\) - must be added to the stream to achieve the optimal concentration. This brings the total inlet volume to 7,600L h\(^{-1}\), which means that in order to maintain steady state, the reactor must be 76,000L. To account for headspace, the actual fermenter size is taken to be 95,000L.
As *L. delbrueckii* is GRAS, and has a precedent of being used in food-related applications, stringent sterilization steps need not be taken, although thorough filtration will still be important. The lactic acid is released to the supernatant, so they need not be lysed and there is little to no concern over toxins, as they are gram positive. The bacteria is separated out during the liquid extraction step.

### 9.3 Heat Exchangers

All heat exchangers were shell-in-tube with the exception of the acid hydrolysis feed heat exchanger (HX-5). In order to maximize the heat transfer area of the exchanger, it is modelled as a plate heat exchanger. This allowed for all of the BSG feed to be heated using four identical exchangers. Each identical exchanger has a heat transfer area of 1,672 meters squared and a design pressure and temperature of 4 atm and 177.8°C, respectively. Another notable heat exchanger is the inlet water heat exchanger (HX-3), which uses recycle steam to heat the entering municipal water and condensed steam combined stream. This heat exchanger is modelled as a shell-in-tube exchanger with a heat transfer area of 30.91 square meters. The shell material is 321S stainless steel, the tubes are at a pitch of 0.03 with a length of 6.1 meters and an operating temperature of 85°C. The shell contains the hot fluid and operates at a temperature of 145°C.

The cooling heat exchanger for the xylitol crystallization (HX-21) is constructed of 321S stainless steel with a heat transfer area of 3.05 square meters. It consists of 6.1 meter long tubes at a pitch of 0.03 meters and a tube operating temperature of 95°C. The shell has an operating temperature of 103°C. The following exchanger used to cool the xylitol stream further (HX-7) is also constructed of 321S stainless steel. The exchanger has a tube side operating temperature of -24°C and a shell operating temperature of 103°C.
9.4 PLA Solvent Distillation Column

The tray distillation column used to separate the PLA solvent mixture (S-15) is constructed out of stainless steel SS304. The column has a diameter of 1.07 meters, a tangent-to-tangent height of 10.97 meters and 12 sieve trays at a tray spacing of 0.61 meters. The design temperature of the column is 121°C and the operating temperature of the column is 63.3°C. The column is designed with a total distillate condenser and a partial reboiler for the bottoms product.
10.0 Equipment Cost Summary

The purchased and installed costs for our equipment units were calculated using Aspen
Plus, and are summarized in Table 11.1. Our total bare module costs for this process would be
$26,937,310. This analysis showed that the most expensive units in the process are the two
fermenters, accounting for 33.2% of the total bare module costs. All equipment was modelled as
stainless steel units to prevent corrosion by some of the strong acids and bases.

Table 10.1 – Equipment Cost Summary

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Unit Number</th>
<th>Equipment Cost ($)</th>
<th>Installed Cost ($)</th>
<th>Bare Module Cost ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Agitated Reactors</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Xylitol Fermenter</td>
<td>R-2</td>
<td>1,163,700</td>
<td>386,400</td>
<td>1,550,100</td>
</tr>
<tr>
<td>L.A. Fermenter</td>
<td>R-5</td>
<td>2,829,200</td>
<td>571,200</td>
<td>3,400,400</td>
</tr>
<tr>
<td>Neutrlizing Reactor</td>
<td>R-1</td>
<td>98,100</td>
<td>172,000</td>
<td>270,100</td>
</tr>
<tr>
<td>AAS Reactor</td>
<td>R-3</td>
<td>408,300</td>
<td>241,300</td>
<td>649,600</td>
</tr>
<tr>
<td>Saccharification Reactor</td>
<td>R-4</td>
<td>115,100</td>
<td>175,800</td>
<td>290,900</td>
</tr>
<tr>
<td><strong>Polymerization Reactor</strong></td>
<td>R-6</td>
<td>196,900</td>
<td>187,100</td>
<td>384,000</td>
</tr>
<tr>
<td>Acid Hydrolysis Reactor</td>
<td>R-7</td>
<td>378,500</td>
<td>241,500</td>
<td>620,000</td>
</tr>
<tr>
<td><strong>Vertical Vessels</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water/Ether decanter</td>
<td>S-11</td>
<td>27,700</td>
<td>143,100</td>
<td>170,800</td>
</tr>
<tr>
<td>PLA/Ether Flash</td>
<td>S-12</td>
<td>27,900</td>
<td>157,700</td>
<td>185,600</td>
</tr>
<tr>
<td>Ether Recovery Flash</td>
<td>S-13</td>
<td>27,900</td>
<td>145,600</td>
<td>173,500</td>
</tr>
<tr>
<td>Lactic Acid Dryer</td>
<td>S-14</td>
<td>33,600</td>
<td>159,300</td>
<td>192,900</td>
</tr>
<tr>
<td>PLA Recycle Dryer</td>
<td>E-9</td>
<td>27,700</td>
<td>143,600</td>
<td>171,300</td>
</tr>
<tr>
<td>Xylitol Crystallizer</td>
<td>E-6</td>
<td>27,700</td>
<td>145,800</td>
<td>173,500</td>
</tr>
<tr>
<td>Chromatography Column</td>
<td>S-2</td>
<td>31,200</td>
<td>134,900</td>
<td>166,100</td>
</tr>
<tr>
<td>Chromatography Column</td>
<td>S-16</td>
<td>31,200</td>
<td>134,900</td>
<td>166,100</td>
</tr>
<tr>
<td>Xylitol Evaporator</td>
<td>S-9</td>
<td>32,900</td>
<td>158,700</td>
<td>191,600</td>
</tr>
<tr>
<td>PLA Crystallizer</td>
<td>S-8</td>
<td>31,200</td>
<td>134,900</td>
<td>166,100</td>
</tr>
<tr>
<td><strong>Mixers</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PLA Steam Recovery</td>
<td>V-6</td>
<td>27,900</td>
<td>145,600</td>
<td>173,500</td>
</tr>
<tr>
<td>Water Recovery</td>
<td>V-2</td>
<td>15,400</td>
<td>94,700</td>
<td>110,100</td>
</tr>
<tr>
<td><strong>Trayed Towers</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L.A. Extraction Column</td>
<td>S-7</td>
<td>435,605</td>
<td>295,200</td>
<td>730,805</td>
</tr>
<tr>
<td>Category</td>
<td>Code</td>
<td>Capacity</td>
<td>Current</td>
<td>Total</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>------</td>
<td>----------</td>
<td>---------</td>
<td>----------</td>
</tr>
<tr>
<td><strong>PLA Solvent Recover</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Centrifuges</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PLA Ferm. Centrifuge</td>
<td>S-15</td>
<td>236,100</td>
<td>160,000</td>
<td>396,100</td>
</tr>
<tr>
<td>Xylitol Ferm. Centrifuge</td>
<td>S-10</td>
<td>39,300</td>
<td>149,700</td>
<td>189,000</td>
</tr>
<tr>
<td>Sacc. Centrifuge</td>
<td>S-4</td>
<td>31,200</td>
<td>134,900</td>
<td>166,100</td>
</tr>
<tr>
<td>Neutralizer Centrifuge</td>
<td>S-6</td>
<td>1,533,700</td>
<td>366,000</td>
<td>1,899,700</td>
</tr>
<tr>
<td><strong>Filters</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pretreatment Filter</td>
<td>S-5</td>
<td>219,100</td>
<td>52,300</td>
<td>271,400</td>
</tr>
<tr>
<td>Xylitol Crystal Filter</td>
<td>S-1</td>
<td>240,200</td>
<td>114,000</td>
<td>354,200</td>
</tr>
<tr>
<td><strong>Mixed Tanks</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pretreatment Wash</td>
<td>E-1</td>
<td>93,800</td>
<td>131,900</td>
<td>225,700</td>
</tr>
<tr>
<td>AAS Wash</td>
<td>E-8</td>
<td>82,700</td>
<td>130,200</td>
<td>212,900</td>
</tr>
<tr>
<td>Xylitol Wash</td>
<td>E-10</td>
<td>31,700</td>
<td>107,800</td>
<td>139,500</td>
</tr>
<tr>
<td><strong>Heat Exchangers</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wet BSG Heater</td>
<td>HX-1</td>
<td>566,000</td>
<td>1,851,900</td>
<td>2,417,900</td>
</tr>
<tr>
<td>Steam Condenser</td>
<td>HX-2</td>
<td>65,700</td>
<td>103,500</td>
<td>169,200</td>
</tr>
<tr>
<td>Inlet Water HX</td>
<td>HX-3</td>
<td>8,400</td>
<td>46,900</td>
<td>55,300</td>
</tr>
<tr>
<td>Inlet Sulfuric Acid HX</td>
<td>HX-4</td>
<td>39,000</td>
<td>109,100</td>
<td>148,100</td>
</tr>
<tr>
<td>Wet BSG Recycle HX</td>
<td>HX-5</td>
<td>10,800</td>
<td>72,900</td>
<td>83,700</td>
</tr>
<tr>
<td>L.A. Ferm. HX</td>
<td>HX-6</td>
<td>10,000</td>
<td>69,400</td>
<td>79,400</td>
</tr>
<tr>
<td>Xylitol Cooling HX</td>
<td>HX-7</td>
<td>10,500</td>
<td>87,000</td>
<td>97,500</td>
</tr>
<tr>
<td>L.A. Polymerization HX</td>
<td>HX-8</td>
<td>13,500</td>
<td>75,200</td>
<td>88,700</td>
</tr>
<tr>
<td>PLA Ether Flash HX</td>
<td>HX-9</td>
<td>16,100</td>
<td>77,100</td>
<td>93,200</td>
</tr>
<tr>
<td>Polymerization Feed HX</td>
<td>HX-10</td>
<td>9,500</td>
<td>72,400</td>
<td>81,900</td>
</tr>
<tr>
<td>Feed Ether HX</td>
<td>HX-11</td>
<td>15,000</td>
<td>74,300</td>
<td>89,300</td>
</tr>
<tr>
<td>Xylose Heating HX</td>
<td>HX-20</td>
<td>8,400</td>
<td>45,800</td>
<td>54,200</td>
</tr>
<tr>
<td>PLA Steam HX</td>
<td>HX-16</td>
<td>19,200</td>
<td>88,100</td>
<td>107,300</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td>9,383,505</td>
<td>8,170,300</td>
<td>17,553,805</td>
</tr>
</tbody>
</table>

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11.0 Economic Analysis

11.1 Sensitivity Analysis

A sensitivity analysis was performed to assess the percent changes in ROI caused by a 1%, 5%, and 10% change in both directions of various inputs. The effect on ROI of changes in xylitol price, PLA price, utility cost, and raw materials cost is summarized in Table 11.1.

Table 11.1. The percent change in ROI due to 1%, 5%, and 10% changes in both directions of various inputs to the process

<table>
<thead>
<tr>
<th>% Change in ROI</th>
<th>+1%</th>
<th>-1%</th>
<th>+5%</th>
<th>-5%</th>
<th>+10%</th>
<th>-10%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Xylitol Price</td>
<td>0.69%</td>
<td>-0.70%</td>
<td>3.56%</td>
<td>-3.59%</td>
<td>6.68%</td>
<td>-7.71%</td>
</tr>
<tr>
<td>PLA Price</td>
<td>1.37%</td>
<td>-1.17%</td>
<td>5.66%</td>
<td>-6.39%</td>
<td>10.54%</td>
<td>-13.95%</td>
</tr>
<tr>
<td>Utilities</td>
<td>0.00%</td>
<td>0.00%</td>
<td>0.00%</td>
<td>0.23%</td>
<td>-0.23%</td>
<td>0.46%</td>
</tr>
<tr>
<td>Raw Materials</td>
<td>-0.46%</td>
<td>0.46%</td>
<td>-2.12%</td>
<td>2.26%</td>
<td>-4.59%</td>
<td>4.20%</td>
</tr>
</tbody>
</table>

The analysis shows that ROI is mostly sensitive to changes in the price of PLA, followed by changes in xylitol price, changes in raw material costs, and finally changes in utility costs. The ROI would be greatly affected by a decrease in the price of PLA, which implies that we must competitively sell this product at its current price for the ROI to remain attractive to investors. Regarding our variable costs, the ROI would be greatly affected at a 10% increase in raw materials cost. However, ROI is not very sensitive to changes in utility costs, so even a 10% increase in this variable cost would not reduce ROI by much.
11.2 Profitability Analysis

Raw Materials

Following the preliminary analysis described in the product selection section, an in-depth assessment of all the raw materials needed to produce each of the selected products was carried out. While the preliminary analysis focused mainly on the cost of the most abundant materials (acids, bases, and buffers), this complete thorough assessment also includes enzymes, catalysts, fermentation media and solvents. Price quotes for yearly bulk orders of these materials were obtained from contacting different chemical manufacturers in the northeast region. In all cases where available, manufacturers were chosen over distributors to avoid higher resale prices. Table 11.2 details the providers and costs of raw materials.

*Table 11.2 Providers and costs of raw materials*

<table>
<thead>
<tr>
<th>Material</th>
<th>Provider</th>
<th>Quantity/year (kg)</th>
<th>Price/kg</th>
<th>Cost/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen</td>
<td>Air Products</td>
<td>50,000</td>
<td>$0.21</td>
<td>$10,500</td>
</tr>
<tr>
<td>Calcium Hydroxide</td>
<td>Chemetall</td>
<td>369,745</td>
<td>$0.20</td>
<td>$73,949</td>
</tr>
<tr>
<td>Sulfuric Acid</td>
<td>Hibrett Puratex</td>
<td>493,115</td>
<td>$0.13</td>
<td>$64,105</td>
</tr>
<tr>
<td>Sodium Citrate</td>
<td>Essential Fine Ingredients Inc.</td>
<td>1,898,365</td>
<td>$0.80</td>
<td>$1,518,692</td>
</tr>
<tr>
<td>Ammonium Hydroxide</td>
<td>Hibrett Puratex</td>
<td>10,946,350</td>
<td>$0.30</td>
<td>$3,283,905</td>
</tr>
<tr>
<td>Cellulase</td>
<td>Amano Enzyme Inc</td>
<td>15,671</td>
<td>$3.00</td>
<td>$47,013</td>
</tr>
<tr>
<td>YM Medium</td>
<td>Teknova</td>
<td>50,000</td>
<td>$26.00</td>
<td>$1,300,000</td>
</tr>
<tr>
<td>MRS Medium</td>
<td>Alpha Biosciences</td>
<td>228,900</td>
<td>$36.00</td>
<td>$8,240,400</td>
</tr>
<tr>
<td><strong>Total Cost/Year</strong></td>
<td></td>
<td></td>
<td></td>
<td><strong>$14,538,564</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Material</th>
<th>Provider</th>
<th>Quantity/year (kg)</th>
<th>Price/kg</th>
<th>Cost/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>C. tropicalis Cells</td>
<td>ATCC</td>
<td>1 inoc.</td>
<td>N/A</td>
<td>$290</td>
</tr>
<tr>
<td>L. delbrueckii Cells</td>
<td>ATCC</td>
<td>1 inoc.</td>
<td>N/A</td>
<td>$294</td>
</tr>
<tr>
<td>Methanol</td>
<td>Hibrett Puratex</td>
<td>36,158</td>
<td>$0.50</td>
<td>$18,079</td>
</tr>
<tr>
<td>Dichloromethane</td>
<td>Akzo Nobel</td>
<td>80,000</td>
<td>$0.41</td>
<td>$32,400</td>
</tr>
<tr>
<td>Diphenyl Ether</td>
<td>Crescent Chemical Co</td>
<td>40,000</td>
<td>$2.10</td>
<td>$84,000</td>
</tr>
<tr>
<td>Tin Oxide</td>
<td>Belmont Metals Inc</td>
<td>15776.5</td>
<td>$40.00</td>
<td>$631,060</td>
</tr>
</tbody>
</table>

**Extra Raw Materials Cost** $765,539

The tin oxide catalyst and the organic solvents (methanol, dichloromethane and diphenyl ether) are not factored into the yearly cost of raw materials since they are purchased once and
recycled throughout the process as they are not consumed. These materials, as well as their respective transport costs, are therefore factored into direct permanent investment costs under “Costs of Other Materials”.

Water Costs

Using the current water usage rate of $0.00145/kg provided by the Philadelphia Water Department, our yearly input costs would be $132,784. A total of 91,575,215 kg of freshwater are required for streams 79 (input to HX4) and 33 (input to E8) on the process flow diagram.

Water disposal costs were also estimated using a disposal rate of $0.00108 provided by the Philadelphia Water Department. The water effluent streams that are not recycled into the process are streams 47 (aqueous waste from S7) and 84 (purge from V5). The total water effluent from our process is 131,308,297 kg/year, which would account for a water discharge cost of $141,813 per year.

Transport Costs

The yearly transport costs of delivering raw materials from providers to the plant and BSG from breweries are summarized in Table 11.3. The Logistics section includes a detailed analysis on the delivery scheduling for BSG, as well as how transport costs were obtained based on type of material, distance, and freight type.
**Table 11.3. Yearly transport costs for all raw materials delivered to the plant**

<table>
<thead>
<tr>
<th>Material Type</th>
<th>Cost/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>BSG</td>
<td>$65,700</td>
</tr>
<tr>
<td>Treatment Chemicals</td>
<td>$41,803</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$107,503</strong></td>
</tr>
</tbody>
</table>

**Fixed Costs**

The plant will run continuously 24 hours a day, and it is assumed it will be operating fully for 330 days a year. Each day will have 3 shifts, with 22 operators working during each shift. The number operators for each section of the process are as follows:

- [4] for solid BSG input to filter process, including H2SO4 reactor
- [4] for solid-liquids handling of hemicellulose to xylitol fermenter
- [2] for xylitol fermenter
- [2] for liquids handling of xylitol purification process
- [4] for solid-liquids handling of cellulose to lactic acid fermenter
- [2] for lactic acid fermenter
- [4] for lactic acid polymerization to PLA process
### Table 11.4. General Information Summary of the Project

<table>
<thead>
<tr>
<th><strong>General Information</strong></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Process Title</strong></td>
<td>Bioprocessing with Brewer’s Spent Grain</td>
</tr>
<tr>
<td><strong>Products</strong></td>
<td>Xylitol and Polylactic Acid</td>
</tr>
<tr>
<td><strong>Plant Site Location</strong></td>
<td>Philadelphia, PA</td>
</tr>
<tr>
<td><strong>Site Factor</strong></td>
<td>1</td>
</tr>
<tr>
<td><strong>Operating Hours per Year</strong></td>
<td>8400</td>
</tr>
<tr>
<td><strong>Operating Days per Year</strong></td>
<td>350</td>
</tr>
<tr>
<td><strong>Operating Factor</strong></td>
<td>0.9</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Product Information</strong></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>This process will yield</strong></td>
<td>3,605,105 kg/year Xylitol</td>
</tr>
<tr>
<td></td>
<td>4,062,476 kg/year PLA</td>
</tr>
<tr>
<td><strong>Price Xylitol</strong></td>
<td>$10/kg</td>
</tr>
<tr>
<td><strong>Price PLA</strong></td>
<td>$15/kg</td>
</tr>
</tbody>
</table>
### Table 11.5. Chronology of the Project

<table>
<thead>
<tr>
<th>Year</th>
<th>Action</th>
<th>Distribution of Permanent Investment</th>
<th>Production Capacity</th>
<th>Depreciation 5 year MACRS</th>
<th>Product Prices</th>
</tr>
</thead>
<tbody>
<tr>
<td>2017</td>
<td>Construction</td>
<td>100%</td>
<td>0.0%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2018</td>
<td>Production</td>
<td>0%</td>
<td>45.0%</td>
<td>20.00%</td>
<td>$10.00/$15.00</td>
</tr>
<tr>
<td>2019</td>
<td>Production</td>
<td>0%</td>
<td>67.5%</td>
<td>32.00%</td>
<td>$10.00/$15.00</td>
</tr>
<tr>
<td>2020</td>
<td>Production</td>
<td>0%</td>
<td>90%</td>
<td>19.20%</td>
<td>$10.00/$15.00</td>
</tr>
<tr>
<td>2021</td>
<td>Production</td>
<td>90%</td>
<td>11.52%</td>
<td></td>
<td>$10.00/$15.00</td>
</tr>
<tr>
<td>2022</td>
<td>Production</td>
<td>90%</td>
<td>11.52%</td>
<td></td>
<td>$10.00/$15.00</td>
</tr>
<tr>
<td>2023</td>
<td>Production</td>
<td>90%</td>
<td>5.76%</td>
<td></td>
<td>$10.00/$15.00</td>
</tr>
<tr>
<td>2024</td>
<td>Production</td>
<td>90%</td>
<td></td>
<td></td>
<td>$10.00/$15.00</td>
</tr>
<tr>
<td>2025</td>
<td>Production</td>
<td>90%</td>
<td></td>
<td></td>
<td>$10.00/$15.00</td>
</tr>
<tr>
<td>2026</td>
<td>Production</td>
<td>90%</td>
<td></td>
<td></td>
<td>$10.00/$15.00</td>
</tr>
<tr>
<td>2027</td>
<td>Production</td>
<td>90%</td>
<td></td>
<td></td>
<td>$10.00/$15.00</td>
</tr>
<tr>
<td>2028</td>
<td>Production</td>
<td>90%</td>
<td></td>
<td></td>
<td>$10.00/$15.00</td>
</tr>
<tr>
<td>2029</td>
<td>Production</td>
<td>90%</td>
<td></td>
<td></td>
<td>$10.00/$15.00</td>
</tr>
<tr>
<td>2030</td>
<td>Production</td>
<td>90%</td>
<td></td>
<td></td>
<td>$10.00/$15.00</td>
</tr>
<tr>
<td>2031</td>
<td>Production</td>
<td>90%</td>
<td></td>
<td></td>
<td>$10.00/$15.00</td>
</tr>
<tr>
<td>2032</td>
<td>Production</td>
<td>90%</td>
<td></td>
<td></td>
<td>$10.00/$15.00</td>
</tr>
</tbody>
</table>
**Table 11.6 Input Summary**

<table>
<thead>
<tr>
<th>Classification</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fixed Costs</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Operations</strong></td>
<td></td>
</tr>
<tr>
<td>Operators per shift</td>
<td>22 (assuming 3 shifts)</td>
</tr>
<tr>
<td>Direct Wages and Benefits</td>
<td>$40/ operator hour</td>
</tr>
<tr>
<td>Direct Salaries and Benefits</td>
<td>15% of Direct Wages and Benefits</td>
</tr>
<tr>
<td>Operating Supplies and Services</td>
<td>6% of Direct Wages and Benefits</td>
</tr>
<tr>
<td>Technical Assistance to Manufacturing</td>
<td>$60,000 per year, per (operator/shift)</td>
</tr>
<tr>
<td>Control Lab</td>
<td>$65,000 per year, per (operator/shift)</td>
</tr>
<tr>
<td><strong>Maintenance</strong></td>
<td></td>
</tr>
<tr>
<td>Wages and Benefits</td>
<td>4.50% of Total Depreciable Capital</td>
</tr>
<tr>
<td>Salaries and Benefits</td>
<td>25% of Maintenance Wages and Benefits</td>
</tr>
<tr>
<td>Materials and Services</td>
<td>100% of Maintenance Wages and Benefits</td>
</tr>
<tr>
<td>Maintenance Overhead</td>
<td>5% of Maintenance Wages and Benefits</td>
</tr>
<tr>
<td><strong>Operating Overhead</strong></td>
<td></td>
</tr>
<tr>
<td>General Plant Overhead</td>
<td>7.10% of Maintenance and Operations Wages and Benefits</td>
</tr>
<tr>
<td>Mechanical Department Services</td>
<td>2.40% of Maintenance and Operations Wages and Benefits</td>
</tr>
<tr>
<td>Employee Relations Department</td>
<td>5.90% of Maintenance and Operations Wages and Benefits</td>
</tr>
<tr>
<td>Business Services</td>
<td>7.40% of Maintenance and Operations Wages and Benefits</td>
</tr>
<tr>
<td><strong>Property Taxes and Insurance</strong></td>
<td></td>
</tr>
<tr>
<td>Property Taxes and Insurance</td>
<td>2.00% of Total Depreciable Capital</td>
</tr>
<tr>
<td><strong>Straight Line Depreciation</strong></td>
<td></td>
</tr>
<tr>
<td>Direct Plant:</td>
<td>8.00% of Total Depreciable Capital, less 1.18 times the Allocated Costs for Utility Plants and Related Facilities</td>
</tr>
<tr>
<td>Allocated Plant:</td>
<td>6.00% of 1.18 times the Allocated Costs for Utility Plants and Related Facilities</td>
</tr>
<tr>
<td><strong>Other Annual Expenses</strong></td>
<td></td>
</tr>
<tr>
<td>Rental Fees (Office, Laboratory)</td>
<td>$32,500</td>
</tr>
<tr>
<td>Licensing Fees</td>
<td>$0</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>$0</td>
</tr>
<tr>
<td><strong>Depletion Allowance</strong></td>
<td></td>
</tr>
<tr>
<td>Annual Depletion Allowance</td>
<td>$0</td>
</tr>
<tr>
<td><strong>Variable Costs</strong></td>
<td></td>
</tr>
</tbody>
</table>
### General Expenses

<table>
<thead>
<tr>
<th>Expense</th>
<th>Percentage of Sales</th>
</tr>
</thead>
<tbody>
<tr>
<td>Selling/Transfer Expenses</td>
<td>3.00%</td>
</tr>
<tr>
<td>Direct Research</td>
<td>4.80%</td>
</tr>
<tr>
<td>Allocated Research</td>
<td>0.50%</td>
</tr>
<tr>
<td>Administrative Expense</td>
<td>2.00%</td>
</tr>
<tr>
<td>Management Incentive Compensation</td>
<td>1.25%</td>
</tr>
</tbody>
</table>

### Working Capital

<table>
<thead>
<tr>
<th>Capital</th>
<th>Days</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accounts Receivable</td>
<td>30</td>
</tr>
<tr>
<td>Cash Reserves (excluding Raw Materials)</td>
<td>30</td>
</tr>
<tr>
<td>Accounts Payable</td>
<td>30</td>
</tr>
<tr>
<td>PLA &amp; Xylitol Inventory</td>
<td>4</td>
</tr>
<tr>
<td>Raw Materials</td>
<td>2</td>
</tr>
</tbody>
</table>

### Total Permanent Investment

<table>
<thead>
<tr>
<th>Capital</th>
<th>Percentage of Total Bare Module Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost of Site Preparations</td>
<td>5.00%</td>
</tr>
<tr>
<td>Cost of Service Facilities</td>
<td>5.00%</td>
</tr>
<tr>
<td>Allocated Costs for Utility Plants and related facilities</td>
<td>$0</td>
</tr>
<tr>
<td>Cost of Contingencies and Contractor fees</td>
<td>18.00%</td>
</tr>
<tr>
<td>Cost of Land</td>
<td>2.00%</td>
</tr>
<tr>
<td>Cost of Royalties</td>
<td>$0</td>
</tr>
<tr>
<td>Cost of Plant Start-up</td>
<td>10.00%</td>
</tr>
</tbody>
</table>

### Table 11.7. Cost Summary

#### Cost Summary

**Fixed Costs**
<table>
<thead>
<tr>
<th>Category</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Operations</strong></td>
<td></td>
</tr>
<tr>
<td>Direct Wages and Benefits</td>
<td>$5,280,000</td>
</tr>
<tr>
<td>Direct Salaries and Benefits</td>
<td>$792,000</td>
</tr>
<tr>
<td>Operating Supplies and Services</td>
<td>$316,800</td>
</tr>
<tr>
<td>Technical Assistance to</td>
<td></td>
</tr>
<tr>
<td>Manufacturing</td>
<td>$3,960,000</td>
</tr>
<tr>
<td>Control Lab</td>
<td>$4,290,000</td>
</tr>
<tr>
<td><strong>Total Operations</strong></td>
<td>$14,638,800</td>
</tr>
<tr>
<td><strong>Maintenance</strong></td>
<td></td>
</tr>
<tr>
<td>Wages and Benefits</td>
<td>$1,573,408.3</td>
</tr>
<tr>
<td>Salaries and Benefits</td>
<td>$393,352</td>
</tr>
<tr>
<td>Materials and Services</td>
<td>$1,573,408.3</td>
</tr>
<tr>
<td>Maintenance Overhead</td>
<td>$78,670.4</td>
</tr>
<tr>
<td><strong>Total Maintenance</strong></td>
<td>$3,618,839</td>
</tr>
<tr>
<td><strong>Operating Overhead</strong></td>
<td></td>
</tr>
<tr>
<td>General Plant Overhead</td>
<td>$570,752</td>
</tr>
<tr>
<td>Mechanical Department Services</td>
<td>$192,930</td>
</tr>
<tr>
<td>Employee Relations Department</td>
<td>$474,287</td>
</tr>
<tr>
<td>Business Services</td>
<td>$594,868</td>
</tr>
<tr>
<td><strong>Total Operating Overhead</strong></td>
<td>$1,832,837</td>
</tr>
<tr>
<td><strong>Property Taxes and Insurance</strong></td>
<td></td>
</tr>
<tr>
<td>Property Taxes and Insurance</td>
<td>$699,293</td>
</tr>
<tr>
<td><strong>Straight Line Depreciation</strong></td>
<td></td>
</tr>
<tr>
<td>Direct Plant</td>
<td>$2,797,170</td>
</tr>
<tr>
<td>Allocated Plant</td>
<td>$0</td>
</tr>
<tr>
<td><strong>Other Annual Expenses</strong></td>
<td></td>
</tr>
<tr>
<td>Rental Fees (Office, Laboratory</td>
<td>$32,500</td>
</tr>
<tr>
<td>Space)</td>
<td></td>
</tr>
<tr>
<td>Licensing Fees</td>
<td>$0</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>$0</td>
</tr>
</tbody>
</table>
### Total Other Annual Expenses

<table>
<thead>
<tr>
<th>Description</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depletion Allowance</td>
<td>$0.00</td>
</tr>
<tr>
<td>Total Fixed Costs</td>
<td>$23,619,439</td>
</tr>
</tbody>
</table>

### Variable Costs

#### General Expenses

<table>
<thead>
<tr>
<th>Description</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Selling/Transfer Expenses</td>
<td>$2,618,681</td>
</tr>
<tr>
<td>Direct Research</td>
<td>$4,189,890</td>
</tr>
<tr>
<td>Allocated Research</td>
<td>$436,447</td>
</tr>
<tr>
<td>Administrative Expense</td>
<td>$1,745,787</td>
</tr>
<tr>
<td>Management Incentive</td>
<td>$1,091,117</td>
</tr>
<tr>
<td>Total General Expenses</td>
<td>$10,081,922</td>
</tr>
</tbody>
</table>

#### Raw Materials (Transport)

<table>
<thead>
<tr>
<th>Description</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost per kg of Products</td>
<td>$4.22</td>
</tr>
<tr>
<td>Total</td>
<td>$14,646,067</td>
</tr>
</tbody>
</table>

#### Byproducts

<table>
<thead>
<tr>
<th>Description</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost per kg of Products</td>
<td>$0.00</td>
</tr>
<tr>
<td>Total</td>
<td>$0</td>
</tr>
</tbody>
</table>

#### Utilities

<table>
<thead>
<tr>
<th>Description</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost per kg of Products</td>
<td>$0.20</td>
</tr>
<tr>
<td>Total</td>
<td>$1,139,030</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Description</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Variable Costs</td>
<td>$25,867,019</td>
</tr>
</tbody>
</table>

### Total Bare Module Costs

<table>
<thead>
<tr>
<th>Description</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>$17,553,800</td>
</tr>
</tbody>
</table>

### Direct Permanent Investment

<table>
<thead>
<tr>
<th>Description</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost of Site Preparations</td>
<td>$877,690</td>
</tr>
<tr>
<td>Cost of Service Facilities</td>
<td>$877,690</td>
</tr>
<tr>
<td>Allocated Costs for Utility Plants and related facilities</td>
<td>$0.0</td>
</tr>
<tr>
<td>Cost of Other Materials</td>
<td>$766,206</td>
</tr>
<tr>
<td>Total</td>
<td>$20,075,400</td>
</tr>
</tbody>
</table>

### Total Depreciable Capital

<table>
<thead>
<tr>
<th>Description</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost of Contingencies and Contractor fees</td>
<td>$3,613,600</td>
</tr>
</tbody>
</table>
### Total Depreciable Capital

$23,689,000

### Total Permanent Investment

- Cost of Land: $473,780
- Cost of Royalties: $0.0
- Cost of Plant Start-up: $2,368,900

#### Total Permanent Investment - Unadjusted

$26,531,700

- Site Factor: 1

#### Total Permanent Investment

$26,531,700

### Working Capital

<table>
<thead>
<tr>
<th></th>
<th>2018</th>
<th>2019</th>
<th>2020</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accounts Receivable</td>
<td>$3,637,057</td>
<td>$5,455,586</td>
<td>$7,274,114</td>
</tr>
<tr>
<td>Cash Reserves (excluding Raw Materials)</td>
<td>$727,375</td>
<td>$1,091,063</td>
<td>$1,454,750</td>
</tr>
<tr>
<td>Accounts Payable</td>
<td>$549,228</td>
<td>$823,841</td>
<td>$1,098,455</td>
</tr>
<tr>
<td>PLA &amp; Xylitol Inventory</td>
<td>$484,941</td>
<td>$727,411</td>
<td>$969,882</td>
</tr>
<tr>
<td>Raw Materials</td>
<td>$36,615</td>
<td>$54,923</td>
<td>$73,230</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>$4,336,466</td>
<td>$6,505,142</td>
<td>$8,673,521</td>
</tr>
<tr>
<td>Present Value at 15%</td>
<td>$3,771,096</td>
<td>$4,918,822</td>
<td>$5,702,981</td>
</tr>
<tr>
<td><strong>Total Capital Investment</strong></td>
<td></td>
<td></td>
<td><strong>$40,924,600</strong></td>
</tr>
</tbody>
</table>

### Profitability Measures

- **Internal Rate of Return (IRR)**: 28.4%
- **Net Present Value (NPV) in 2017**: $80,584,500

### ROI Analysis (3rd Production Year)

- **Annual Sales**: 87,289,400
- **Annual Costs**: (49,486,500)
- **Depreciation**: (4,548,300)
- **Income Tax**: (13,301,900)
- **Net Earnings**: 19,952,700

#### Total Capital Investment

$46,047,100

- **ROI**: 43.3%
Figure 11.1. Annual Cash Flows for each year of the plant’s lifetime

Figure 11.2. Cumulative Discounted cash flows for each year of the plant’s lifetime
Table 11.9: Cash Flow Summary

<table>
<thead>
<tr>
<th>Year</th>
<th>Cash Flow from Operating Activities</th>
<th>Cash Flow from Investing Activities</th>
<th>Cash Flow from Financing Activities</th>
<th>Net Cash Flow</th>
<th>Free Cash Flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>1,234,567</td>
<td>789,012</td>
<td>123,456</td>
<td>2,088,023</td>
<td>1,567,890</td>
</tr>
<tr>
<td>2001</td>
<td>1,345,678</td>
<td>890,123</td>
<td>134,567</td>
<td>2,370,368</td>
<td>1,890,123</td>
</tr>
<tr>
<td>2002</td>
<td>1,456,789</td>
<td>901,234</td>
<td>145,678</td>
<td>2,513,691</td>
<td>2,123,456</td>
</tr>
<tr>
<td>2003</td>
<td>1,567,890</td>
<td>912,345</td>
<td>156,789</td>
<td>2,676,984</td>
<td>2,345,678</td>
</tr>
<tr>
<td>2004</td>
<td>1,678,901</td>
<td>923,456</td>
<td>167,890</td>
<td>2,869,247</td>
<td>2,567,891</td>
</tr>
<tr>
<td>2005</td>
<td>1,789,012</td>
<td>934,567</td>
<td>178,901</td>
<td>3,021,479</td>
<td>2,789,012</td>
</tr>
<tr>
<td>2006</td>
<td>1,890,123</td>
<td>945,678</td>
<td>189,012</td>
<td>3,194,813</td>
<td>2,989,012</td>
</tr>
<tr>
<td>2007</td>
<td>1,901,234</td>
<td>956,789</td>
<td>190,123</td>
<td>3,393,142</td>
<td>3,190,123</td>
</tr>
<tr>
<td>2008</td>
<td>2,012,345</td>
<td>967,890</td>
<td>201,234</td>
<td>3,495,479</td>
<td>3,391,234</td>
</tr>
<tr>
<td>2009</td>
<td>2,123,456</td>
<td>978,901</td>
<td>212,345</td>
<td>3,624,702</td>
<td>3,592,345</td>
</tr>
<tr>
<td>2010</td>
<td>2,234,567</td>
<td>989,012</td>
<td>223,456</td>
<td>3,877,085</td>
<td>3,893,456</td>
</tr>
</tbody>
</table>

Note: The figures are hypothetical and for illustration purposes only.
12.0 Other Important Considerations

12.1 Safety & Good Manufacturing Practices

All personnel will be trained to safely operate equipment around the facility. All materials will be clearly labeled, and will be handled and disposed of according to the safety data sheets. Extra care will be taken with the installation and use of compressed nitrogen gas in cylinders. Personnel will be expected to comply with laboratory and industrial safety measures and report any anomalies observed with the process immediately. Appropriate clothing will be worn at all times and jewelry or other accessories will be removed before entering the plant. Extra care will be taken to avoid microorganism cross-contamination between the two production chains. The plant will contain sanitary facilities and an adequate disposal system. [28]

12.2 Logistics

BSG Collection

By contacting and surveying multiple breweries in the Philadelphia area, we were able to obtain accurate estimates of how much spent grain would be available for processing on a weekly basis. Our main partner throughout the project has been Dock Street Brewery, which has also provided us with spent grain samples for analysis. Other Microbreweries that expressed interest in our project were Iron Hill, Manayunk, Crime and Punishment, Tired Hands and Philadelphia Brewing Company. Two larger scale breweries, Yards and Flying Fish, have also expressed interest. Based on the numbers these breweries have provided us, we estimated the number of barrels each brewery in the area can offer us yearly according to their size. Realistically there are about 30 microbreweries in the area; however for estimation purposes, very small scale
microbreweries such as Crime and Punishment or 2nd Story have been grouped as one small scale microbrewery. These estimates are outlined in Table 12.1.

*Table 12.1 Barrels of spent grain per year available from breweries in the Philadelphia area.*

<table>
<thead>
<tr>
<th>Brewery Size</th>
<th>Barrels/year</th>
<th>Number of Breweries</th>
<th>Total Barrels/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Micro</td>
<td>6,000</td>
<td>10</td>
<td>60,000</td>
</tr>
<tr>
<td>Medium</td>
<td>30,000</td>
<td>3</td>
<td>90,000</td>
</tr>
<tr>
<td>Macro</td>
<td>125,000</td>
<td>1</td>
<td>125,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>14</strong></td>
<td></td>
<td><strong>275,000</strong></td>
</tr>
</tbody>
</table>

With a total estimate of 275,000 barrels of wet spent grain per year, we would be obtaining around 2.5 million lb/week. By renting heavy duty (80,000lb capacity) trucks, about 32 loads of spent grain will need to be performed to transport wet grain from breweries to our plant. Penske Truck Rental has provided us with rental information and pricing for a Tandem Axle Day Cab 80,000 lb capacity truck. By mapping out the area travelled by the trucks from the breweries to our plant (Figure 12.1), we have estimated that it could take a truck up to 4~5 hours to complete a route circuit, including loading and unloading time. Assuming that each truck can pick up spent grain twice a day (morning and afternoon), only 8 trucks would be needed per day if collection is carried out over the course of two days. The transportation costs incurred are summarized in Table 12.2.
Table 12.2. Summary of rental cost per week

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Loads/week</td>
<td>32</td>
</tr>
<tr>
<td>Loads/Truck</td>
<td>2</td>
</tr>
<tr>
<td>Number of Trucks/day</td>
<td>8</td>
</tr>
<tr>
<td>Collection Days</td>
<td>2</td>
</tr>
<tr>
<td>Truck Rental Price/day</td>
<td>$180</td>
</tr>
<tr>
<td>Total Rental Cost/week</td>
<td>$2880</td>
</tr>
<tr>
<td>Total Rental Cost/year</td>
<td>$65,700</td>
</tr>
</tbody>
</table>

Transportation of Materials

Based on the type and quantity of raw materials needed, transportation options from the manufacturers to our plant were considered. Since our process uses mostly common chemicals and a few biological compounds, sourcing materials from nearby states seemed to be the most cost-effective alternative to avoid high shipping costs. Manufacturers of the materials were chosen according to bulk price quotes and location. Freight rates for trucks were more economical than rates for rail transport due to the short distances traveled. The truckload type selected for delivery was 53ft trailers with a 45,000 lb capacity. Table 12.3 details the logistics.

Table 12.3. Transportation logistics of raw materials

<table>
<thead>
<tr>
<th>Material</th>
<th>Provider</th>
<th>Location</th>
<th>Quantity/ year (kg)</th>
<th>Price/ Truck</th>
<th>Number of Trucks</th>
<th>Cost/ year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen</td>
<td>Air Products</td>
<td>Allentown, PA</td>
<td>50,000</td>
<td>82</td>
<td>3</td>
<td>$246</td>
</tr>
<tr>
<td>Calcium Hydroxide</td>
<td>Chemetall</td>
<td>New Providence, NJ</td>
<td>369,745</td>
<td>70</td>
<td>19</td>
<td>$1,330</td>
</tr>
<tr>
<td>Sulfuric Acid</td>
<td>Hibrett Puratex</td>
<td>Pennsauken, NJ</td>
<td>493,115</td>
<td>48</td>
<td>25</td>
<td>$1,200</td>
</tr>
<tr>
<td>Sodium Citrate</td>
<td>Essential Fine Ingredients Inc</td>
<td>Port Washington, NJ</td>
<td>1,898,365</td>
<td>84</td>
<td>94</td>
<td>$7,896</td>
</tr>
<tr>
<td>Raw Material</td>
<td>Supplier/Company</td>
<td>Location</td>
<td>Quantity</td>
<td>Frequency</td>
<td>Cost per Unit</td>
<td>Total Cost/Year</td>
</tr>
<tr>
<td>----------------------------------</td>
<td>---------------------------</td>
<td>-------------------------------</td>
<td>----------</td>
<td>-----------</td>
<td>---------------</td>
<td>-----------------</td>
</tr>
<tr>
<td>Ammonium Hydroxide</td>
<td>Hibrett Puratex</td>
<td>Pennsauken, NJ</td>
<td>10,946,350</td>
<td>48</td>
<td>537</td>
<td>$25,776</td>
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<tr>
<td>Cellulase</td>
<td>Amano Enzyme Inc</td>
<td>Elgin, IL</td>
<td>15,671</td>
<td>375</td>
<td>1</td>
<td>$375</td>
</tr>
<tr>
<td>YM Medium</td>
<td>Teknova</td>
<td>Hollister, CA</td>
<td>50,000</td>
<td>90</td>
<td>3</td>
<td>$3900</td>
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<tr>
<td>MRS Medium</td>
<td>Alpha Biosciences</td>
<td>Baltimore, MD</td>
<td>228,900</td>
<td>90</td>
<td>12</td>
<td>$1080</td>
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</table>

Total Cost/Year: $41,803

<table>
<thead>
<tr>
<th>Raw Material</th>
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<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methanol</td>
<td>Hibrett Puratex</td>
<td>Pennsauken, NJ</td>
</tr>
<tr>
<td>Dichloromethane</td>
<td>Akzo Nobel</td>
<td>Malvern, PA</td>
</tr>
<tr>
<td>Diphenyl Ether</td>
<td>Crescent Chemical Co</td>
<td>Islandia, NY</td>
</tr>
<tr>
<td>Tin Oxide</td>
<td>Belmont Metals Inc</td>
<td>Brooklyn, NY</td>
</tr>
</tbody>
</table>

Extra Raw Materials Transportation Cost: $667

The transport costs for the tin oxide catalyst and the organic solvents (methanol, dichloromethane and diphenyl ether) are not factored into the yearly transport cost since they are purchased once and recycled throughout the process as they are not consumed. These extra transport costs are therefore factored into fixed costs.
12.3 Plant Location & Sizing

Sizing

After obtaining the dimensions of our equipment with Aspen Plus, the horizontal surface area occupied by each was calculated and summarized in Table 12.4. If the plant is to be built in only one floor, around 1500 ft\(^2\) are needed solely for equipment. To account for piping in between pieces of equipment and to leave enough space for the operator to control the equipment, we would estimate about double the surface area (3000 ft\(^2\)) for the processing area. However, this can be reduced if the plant is built across two floors, with each product process on its own floor. The largest pieces of equipment, the two fermenters, would be tall enough to occupy both floors so this will be taken into account during construction. By splitting the process into two floors, horizontal surface area needed for the process would be around 1500 ft\(^2\). An extra 2000-3000 ft\(^2\) will account for storage areas, disposal facilities, and administrative office space.

*Table 12.4. Surface areas of main equipment units.*

<table>
<thead>
<tr>
<th>Equipment Sizing</th>
<th>Unit Number</th>
<th>Surface Area (ft(^2))</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Agitated Reactors</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Xylitol Fermenter</td>
<td>R-2</td>
<td>154.3</td>
</tr>
<tr>
<td>L.A. Fermenter</td>
<td>R-5</td>
<td>207.5</td>
</tr>
<tr>
<td>Neutralizing Reactor</td>
<td>R-1</td>
<td>4.91</td>
</tr>
<tr>
<td>AAS Reactor</td>
<td>R-3</td>
<td>44.2</td>
</tr>
<tr>
<td>Saccharification Reactor</td>
<td>R-4</td>
<td>9.62</td>
</tr>
<tr>
<td>Polymerization Reactor</td>
<td>R-6</td>
<td>19.6</td>
</tr>
<tr>
<td>Acid Hydrolysis Reactor</td>
<td>R-7</td>
<td>38.5</td>
</tr>
<tr>
<td><strong>Vertical Vessels</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water/Ether decanter</td>
<td>S-11</td>
<td>7.07</td>
</tr>
<tr>
<td>Equipment</td>
<td>Location</td>
<td>Temperature</td>
</tr>
<tr>
<td>------------------------------------</td>
<td>----------</td>
<td>-------------</td>
</tr>
<tr>
<td>PLA/Ether Flash</td>
<td>S-12</td>
<td>7.07</td>
</tr>
<tr>
<td>Ether Recovery Flash</td>
<td>S-13</td>
<td>7.07</td>
</tr>
<tr>
<td>Lactic Acid Dryer</td>
<td>S-14</td>
<td>12.6</td>
</tr>
<tr>
<td>PLA Recycle Dryer</td>
<td>E-9</td>
<td>7.07</td>
</tr>
<tr>
<td>Xylitol Crystallizer</td>
<td>E-6</td>
<td>7.07</td>
</tr>
<tr>
<td>Chromatography Column</td>
<td>E-2</td>
<td>9.62</td>
</tr>
<tr>
<td>Chromatography Column</td>
<td>E-16</td>
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<tr>
<td>Xylitol Evaporator</td>
<td>S-9</td>
<td>12.6</td>
</tr>
<tr>
<td>PLA Crystallizer</td>
<td>S-8</td>
<td>9.62</td>
</tr>
<tr>
<td><strong>Mixers</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PLA Steam Recovery</td>
<td>V-6</td>
<td>7.07</td>
</tr>
<tr>
<td>Water Recovery</td>
<td>V-2</td>
<td>7.07</td>
</tr>
<tr>
<td><strong>Trayed Towers</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L.A. Extraction Column</td>
<td>S-7</td>
<td>11.6</td>
</tr>
<tr>
<td>PLA Solvent Recover</td>
<td>S-15</td>
<td>3.14</td>
</tr>
<tr>
<td><strong>Centrifuges</strong></td>
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<td></td>
</tr>
<tr>
<td>PLA Ferm. Centrifuge</td>
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<td>15.91</td>
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<tr>
<td>Xylitol Ferm. Centrifuge</td>
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</tr>
<tr>
<td>Sacc. Centrifuge</td>
<td>S-6</td>
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<tr>
<td>Neutralizer Centrifuge</td>
<td>S-5</td>
<td>0.55</td>
</tr>
<tr>
<td><strong>Filters</strong></td>
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<td></td>
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<tr>
<td>Pretreatment Filter</td>
<td>S-1</td>
<td>21.00</td>
</tr>
<tr>
<td>Xylitol Crystal Filter</td>
<td>S-3</td>
<td>1.15</td>
</tr>
<tr>
<td><strong>Mixed Tanks</strong></td>
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<td></td>
</tr>
<tr>
<td>Pretreatment Wash</td>
<td>E-1</td>
<td>9.62</td>
</tr>
<tr>
<td>AAS Wash</td>
<td>E-8</td>
<td>7.07</td>
</tr>
<tr>
<td>Xylitol Wash</td>
<td>E-10</td>
<td>0.79</td>
</tr>
<tr>
<td><strong>Heat Exchangers</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wet BSG Heater</td>
<td>HX-1</td>
<td>65.62</td>
</tr>
<tr>
<td>Steam Condenser</td>
<td>HX-2</td>
<td>65.62</td>
</tr>
<tr>
<td>Inlet Water HX</td>
<td>HX-3</td>
<td>65.62</td>
</tr>
<tr>
<td>Inlet Sulfuric Acid HX</td>
<td>HX-4</td>
<td>65.62</td>
</tr>
<tr>
<td>Wet BSG Recycle HX</td>
<td>HX-5</td>
<td>65.62</td>
</tr>
<tr>
<td>Location</td>
<td></td>
<td></td>
</tr>
<tr>
<td>--------------------------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Based on plant sizing, terrain available and the geographic layout of the city, we have determined that a potential location for our plant could be in south Philadelphia, by the Navy Yard area. This location is signaled in Figure 12.1. The Navy Yard area has seen an increasing volume of manufacturing companies and has become a prominent industrial area in Philadelphia. This location would be geographically favorable to reduce transport costs of BSG from the breweries to our plant. Our research yielded a rental price of $6.50/ft² each year, which would place our yearly rental costs at $32,500 for a 5,000 ft² plant.</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure 12.1. Map of Philadelphia and surrounding areas showing current locations of breweries as well as the potential location of the plant.
12.4 FDA Concerns

Steps need to be taken to ensure good manufacturing practice and address FDA concerns. The use of *Candida tropicalis* may raise FDA concerns if not properly addressed given that *Candida* is the genus of yeast responsible for the most common fungal infections in humans. Recent research conducted in 2016 has reported the involvement of *C. tropicalis* in Crohn’s disease [29]. A purified tropiase isolated from *C. tropicalis* has demonstrated hemorrhagic activity and an increase in capillary permeability [30]. Since xylitol is to be used in the food industry, the presence of *Candida* pathogens raises great health concerns.

Due to pathogenicity caused to humans, *C. tropicalis* needs to be thoroughly eliminated from the xylitol product. Sterility assurance level should be $10^6$, or one in a million probability of non-sterility. After exploring different techniques on microbial disinfection, steam sterilization seemed to be the most effective to achieve the required sterility assurance level on an industrial scale. Steam inactivates microorganisms by denaturing proteins or causing cell lysis. Steam at 134°C would be sufficient to inactivate the microorganisms after 3-4 minutes of exposure. Fungal inactivation by UV light irradiation also seemed to be a simple, cost-effective disinfection method. A study investigating the inactivation of several *Candida* pathogens grown at 35°C used Philips 20W/C fluorescent lights with an emission spectrum of 250-370 nm and a peak at 254 nm. The results of this study show that *C. tropicalis* was inactivated after 20 minutes of UV exposure [31]. However, while this was successful at laboratory scale, it may be difficult to achieve $10^6$ sterilization on an industrial scale.

Our process would need to include steam exposure of the aqueous xylitol fermentation product before the crystallization procedure. The aqueous xylitol and a steam stream could flow
through a pipe system with a residence distribution time of 3-4 minutes. Since our process
generates a vast quantity of steam, this would be readily available. The short exposure time of 3-4
minutes would not add a bottleneck to the process, and steam is an environmentally friendly
disinfection option since no additional substances are produced.

Additionally, all materials used for general pretreatment and xylitol processing will be of
food grade quality (U.S.P or A.C.S. grade). Materials used only in the PLA process will be of
technical grade quality.

12.5 Environmental Concerns

Gas Emissions

Our fermenters will release CO$_2$ as a byproduct of fermentation. This greenhouse gas will
be treated with CO$_2$ scrubbers before it is released into the atmosphere to ensure that the gas does
contain any toxic substances or organisms.

Wastewater Management

Throughout our plant, water is an effluent in various processes. Taking safety measures
into consideration, these water streams can be recycled into the process to reduce the amount of
clean water input. Processes that include water both as an input and an effluent, such as the aqueous
ammonia soaking wash step, could reuse part of the effluent stream as an input source to the
aqueous ammonia soaking reactor, given that the stream would not contain any extra contaminants.
Water recovered as steam through evaporation can also be inputted back into the process as a water
heating source. An important consideration when reusing wastewater from the xylitol process is
to ensure that *C. tropicalis* is inactive before using the water streams in other parts of the process to prevent pathogenic contamination. This can be accounted for by inactivating the microorganism as soon as the aqueous xylitol exits the fermenter.

Water that is not reused in our process will be treated for solids and cell debris removal before directing it to Philadelphia wastewater treatment plants. Filtration with coarse and fine screens will be used in effluent water streams containing solids or cell debris. Water streams that are free from solids will be directed mainly to the Southwest Water Pollution Control Plant as it is the closest to our plant. The Philadelphia Water Department Industrial Waste Unit issues permits specifying water requirements to regulate water discharges to the sewers and wastewater treatment plants. Following these guidelines, we will need to ensure that water streams are of pH no less than 6 and no higher than 9 before they enter the sewer system. Streams outside this pH range will need further neutralization.

12.6 Chemical & Biological Waste Management

*Calcium Sulfate*

The calcium sulfate precipitated out in the xylitol pre-fermentation process should be handled and disposed in a waste disposal container according to local, state, and federal regulations. Calcium sulfate is a recyclable substance that has applications in the construction industry, so the product can be disposed of through collection by a recycling facility.
Solvents

Solvents used in the lactic acid polymerization process, such as methanol, diphenyl ether, and dichloromethane, will be recycled and reused in the process. This would be the most cost-effective alternative, given that we would avoid dealing with disposal costs of organic solvents.

Biological Waste

Biological waste will include any cell debris recovered after the fermentations. A main concern that needs to be accounted for when disposing of biological waste is the inactivation of any microorganisms before they are placed in a clearly labeled biological waste container [32].
13.0 Conclusions and Recommendations

This report suggests that the proposed process be considered for implementation. Operating costs are somewhat high, but not a roadblock to financial success. Cell culture media dominates the operating costs, and this is considering a continuous process, which uses much less media than the equivalent batch mode.

The authors recommend the following courses of action. During research, several genetically modified versions of *Candida tropicalis* engineered by J.H. Kim *et al.* were considered. They boast a range of useful properties like the ability to ferment arabinose (the second most plentiful sugar in BSG hemicellulose) into xylitol, and increased xylose to xylitol efficiency. These organisms could possibly increase production without increasing operating cost. However, the full reports on these organisms could not be obtained within the timeframe of this project, so they had to be excluded from consideration. Further research into their metabolic parameters could be fruitful.

Secondly, if pre-made media is the most prohibitive cost, it may be better to make the necessary media in-house. Cell debris from fermenter effluent can be used as nutrients to grow up the next batch of culture. Further research would have to be done on obtaining the remaining raw ingredients and costing the mixing and storage vessels for such large batches of media. However, it presents a possible cost-reducing option.

Lastly, the sensitivity analysis revealed that PLA price has the most significant impact on ROI. If the price were to increase by 10%, we would see a large increase in value for the process. The authors recommend researching the viability of such a process in other cities around the country.
14.0 Acknowledgements

We would like to thank Dr. Bruce Vrana, Dr. Warren Seider and Dr. Len Fabiano for all of the help and guidance that they provided us while we worked through this project. We would also like to thank Dr. Scott Diamond for submitting this project concept and for working with us to make sure that we were approaching the project in an efficient and intelligent manner. We would like to thank all of the industrial consultants that gave us valuable critique and insightful ideas as we moved through the concept, design, and execution phases of the project and dedicated their time towards helping our group. We are grateful for everyone who offered us their help in completing this project and could not have done it without their guidance.
15.0 References

[10] Lactic Acid and Poly Lactic Acid (PLA) Market Analysis By Application (Packaging, Agriculture, Transport, Electronics, Textiles) And Segment Forecasts To 2020


16.0 Appendices
## FLASH DRYER

<table>
<thead>
<tr>
<th>Identification:</th>
<th>Item: PLA Recycle Drier</th>
<th>Date: 7 April 2017</th>
</tr>
</thead>
<tbody>
<tr>
<td>Item No.</td>
<td>E-9</td>
<td>No. Required</td>
</tr>
</tbody>
</table>

By: Group 7

**Function:** Removes water from the stream of wet cellulose solids sent to AAS reactor

**Operation:**

### Materials Handled:

<table>
<thead>
<tr>
<th>Mixed Feed</th>
<th>Water Out</th>
<th>Dry PLA Rec.</th>
<th>Stream 2</th>
<th>Stream 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>52808.1</td>
<td>51772.3</td>
<td>1035.82</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Composition:**

- Ammonium Hydr.
- Ca(OH)\(_2\)
- CaSO\(_4\)
- Cellulose Solid
- CH\(_2\)Cl\(_2\)
- Enzymes
- Diphenyl Ether 0.756717
- Ferment. Sugars 0.00263459
- Lactic Acid
- Methanol
- N\(_2\)
- Other Solids
- Other Solutes
- Polylactic Acid 0.201864
- Sodium Citrate
- Sulfuric Acid
- Water 0.0387842
- Xylitol
- Xylose

**Temperature (°C):**

- Mixed Feed 110
- Water Out 99.8609
- Dry PLA Rec. 99.8609

**Design Data:**

- Shell Material SS304
- Diameter 0.9144 meters
- Height 3.6576 meters
- Volume 2401.932948 liters
- Design Temp 137.7779517
- Operating Temp 110.0001739

**Utilities (kW):**

- 13.51

**Bare Module Cost:** $27,700.00

**Installation Cost:** $171,300.00

**Equipment Weight (lbs):** 1,900.00

**Installed Weight (lbs):** 13,140.00

**Comments and Drawings:**
# HEAT EXCHANGER

**Identification:**
- **Item:** Wet BSG Heater
- **Item No.:** HX-1
- **No. Required:** 1
- **Date:** 7 April 2017
- **By:** Group 7

**Function:**
Heats the input wet BSG stream to 150°C for the acid hydrolysis reactor

**Operation:**

**Materials Handled:**

<table>
<thead>
<tr>
<th>Material</th>
<th>Material In</th>
<th>Material Out</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quantity (kg/day)</td>
<td>516,332.00</td>
<td>516,332.00</td>
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</tbody>
</table>

**Composition:**
- Ammonium Hydr.
- Ca(OH)₂
- CaSO₄
- Cellulose Solid 0.12
- CH₃Cl₂
- Enzymes
- Diphenyl Ether
- Ferment. Sugars 0.00
- Lactic Acid
- Methanol
- N₂
- Other Solids
- Other Solutes
- Polylactic Acid
- Sodium Citrate
- Sulfuric Acid
- Water 0.88
- Xylitol
- Xylose
- Temperature (°C): 140.00, 150.00

**Design Data:**

<table>
<thead>
<tr>
<th>Heat Transfer Area</th>
<th>2.58 square meters</th>
<th>Shell Material</th>
<th>321S</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Shells</td>
<td>0.00</td>
<td>Tube Material</td>
<td>321S</td>
</tr>
<tr>
<td>Tube Design Temp.</td>
<td>202.78°C</td>
<td>Tube Length</td>
<td>6.10 meters</td>
</tr>
<tr>
<td>Tube Op.Temp.</td>
<td>175.00°C</td>
<td>Tube Pitch</td>
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<tr>
<td>Shell Design Temp</td>
<td>177.78°C</td>
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<tr>
<td>Shell Op. Temp</td>
<td>150.00°C</td>
<td>No. Shell Pass</td>
<td>1.00</td>
</tr>
</tbody>
</table>

**Utilities (kW):**
- 131.12

**Bare Module Cost:** $10,300.00
**Installation Cost:** $83,200.00

**Equipment Weight (lbs):** 560.00
**Installed Weight (lbs):** 7,028.00

**Comments:**
**HEAT EXCHANGER**

**Identification:**
- Item: Steam Condenser
- Item No.: HX-2
- No. Required: 1
- Date: 7 April 2017
- By: Group 7

**Function:** Condenses the recycled steam stream so that it can be reused as feed water

**Operation:**

**Materials Handled:**

<table>
<thead>
<tr>
<th>Material In</th>
<th>Material Out</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quantity (kg/day)</td>
<td>152,716.00</td>
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<tr>
<td></td>
<td>152,717.00</td>
</tr>
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**Composition:**
- Ammonium Hydr.
- Ca(OH)₂
- CaSO₄
- Cellulose Solid
- CH₂Cl₂
- Enzymes
- Diphenyl Ether
- Ferment. Sugars
- Lactic Acid
- Methanol
- N₂
- Other Solids: 0.00
- Other Solutes
- Polylactic Acid
- Sodium Citrate
- Sulfuric Acid
- Water: 1.00
- Xylitol
- Xylose
- Temperature (°C): 102.46

**Design Data:**

- Heat Transfer Area: 67.80 square meters
- Number of Shells: 0.00
- Tube Design Temp.: 130.24 °C
- Tube Op.Temp.: 25.00 °C
- Shell Design Temp: 130.24 °C
- Shell Op.Temp.: 102.46 °C
- Tube Material: 321S
- Tube Design Temp.: 6.10 meters
- Tube Pitch: 0.03
- No. Tube Pass: 1.00
- No. Shell Pass: 1.00

**Utilities (kW):** 3622.00

**Bare Module Cost:** $53,700.00

**Installation Cost:** $156,900.00

**Equipment Weight (lbs):** 5,700.00

**Installed Weight (lbs):** 13,432.00

**Comments:**
**HEAT EXCHANGER**

**Identification:**
- Item: Inlet Water HX
- Item No.: HX-3
- No. Required: 1
- Date: 7 April 2017
- By: Group 7

**Function:**
Heats the inlet water to the process using recycled steam

**Operation:**

<table>
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<tr>
<th>Materials Handled</th>
<th>Cold In</th>
<th>Cold Out</th>
<th>Hot In</th>
<th>Hot Out</th>
<th>Stream 3</th>
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</thead>
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<tr>
<td>Composition</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Ammonium Hydr.</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Ca(OH)₂</td>
<td>-</td>
<td>-</td>
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<tr>
<td>CaSO₄</td>
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<td>Cellulose Solid</td>
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<td>CH₂Cl₂</td>
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</tr>
<tr>
<td>Ferment. Sugars</td>
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<tr>
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<tr>
<td>Other Solids</td>
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<td>-</td>
<td>0.00</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>Other Solutes</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Polylactic Acid</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Sodium Citrate</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Sulfuric Acid</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Water</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>Xylitol</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Xylose</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Temperature (°C):</td>
<td>58.83</td>
<td>95.00</td>
<td>145.12</td>
<td>102.46</td>
<td></td>
</tr>
</tbody>
</table>

**Design Data:**

- Heat Transfer Area: 30.91 square meters
- Shell Material: 321S
- Number of Shells: 0.00
- Tube Material: 321S
- Tube Design Temp.: 172.90°C
- Tube Length: 6.10 meters
- Tube Op.Temp.: 95.00°C
- Tube Pitch: 0.03
- Shell Design Temp: 172.90°C
- No. Tube Pass: 1.00
- Shell Op. Temp: 145.12°C
- No. Shell Pass: 1.00

**Utilities (kW):**
- No Utilities

**Bare Module Cost:** $30,900.00
**Installation Cost:** $118,600.00

**Equipment Weight (lbs):** 3,000.00
**Installed Weight (lbs):** 10,886.00

**Comments:**
# HEAT EXCHANGER

**Identification:**

<table>
<thead>
<tr>
<th>Item:</th>
<th>Inlet Sulf. Acid HX</th>
</tr>
</thead>
<tbody>
<tr>
<td>Item No.</td>
<td>HX-4</td>
</tr>
<tr>
<td>No. Required</td>
<td>1</td>
</tr>
</tbody>
</table>

**Date:** 7 April 2017  
**By:** Group 7

**Function:** Heats the inlet sulfuric acid solution using recycled steam

**Operation:**

**Materials Handled:**

<table>
<thead>
<tr>
<th></th>
<th>Cold In</th>
<th>Cold Out</th>
<th>Hot In</th>
<th>Hot Out</th>
<th>Stream 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quantity (kg/day):</td>
<td>355,802.00</td>
<td>355,802.00</td>
<td>152,716.00</td>
<td>152,716.00</td>
<td></td>
</tr>
</tbody>
</table>

**Composition:**

- Ammonium Hydr.
- Ca(OH)₂
- CaSO₄
- Cellulose Solid
- CH₂Cl₂
- Enzymes
- Diphenyl Ether
- Ferment. Sugars
- Lactic Acid
- Methanol
- N₂
- Other Solids
- Other Solutes
- Polylactic Acid
- Sodium Citrate
- Sulfuric Acid
- Water
- Xylitol
- Xylose

**Temperature (°C):**

<table>
<thead>
<tr>
<th></th>
<th>Cold In</th>
<th>Cold Out</th>
<th>Hot In</th>
<th>Hot Out</th>
<th>Stream 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>355,802.00</td>
<td>355,802.00</td>
<td>152,716.00</td>
<td>152,716.00</td>
<td></td>
</tr>
</tbody>
</table>

**Design Data:**

- Heat Transfer Area: 30.91 square meters
- Shell Material: 321S
- Number of Shells: 0.00
- Tube Material: 321S
- Tube Design Temp.: 172.90°C
- Tube Length: 6.10 meters
- Tube Op.Temp.: 95.00°C
- Tube Pitch: 0.03
- Shell Design Temp: 172.90°C
- No. Tube Pass: 1.00
- Shell Op. Temp: 145.12°C
- No. Shell Pass: 1.00

**Utilities (kW):** No Utilities

- Bare Module Cost: $30,900.00
- Equipment Weight (lbs): 3,000.00
- Installation Cost: $118,600.00
- Installed Weight (lbs): 10,886.00

**Comments:**
## HEAT EXCHANGER

**Identification:**
- **Item:** Wet BSG Rec. HX
- **Item No.:** HX-5
- **No. Required:** 4

**Date:** 7 April 2017

**By:** Group 7

**Function:**
Product-to-feed heat exchanger to recycle heat from acid hydrolysis exit stream

**Operation:**

<table>
<thead>
<tr>
<th>Materials Handled:</th>
<th>Cold In</th>
<th>Cold Out</th>
<th>Hot In</th>
<th>Hot Out</th>
<th>Stream 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quantity (kg/day):</td>
<td>2,351.00</td>
<td>2,351.00</td>
<td>152,716.00</td>
<td>152,716.00</td>
<td></td>
</tr>
</tbody>
</table>

**Composition:**

- Ammonium Hydr.
- Ca(OH)$_2$
- CaSO$_4$
- Cellulose Solid
- CH$_2$Cl$_2$
- Enzymes
- Diphenyl Ether
- Ferment. Sugars
- Lactic Acid
- Methanol
- N$_2$
- Other Solids
- Other Solutes
- Polylactic Acid
- Sodium Citrate
- Sulfuric Acid
- Water
- Xylitol
- Xylose

| Temperature (°C): | 25.00 | 92.00 | 102.46 | 102.46 |

**Design Data:**

- **Heat Transfer Area:** 1,672.25 square meters
- **Plate Material:** 321S
- **No. Identical Units:** 4.00
- **Design P:** 4.16 barg
- **Design T:** 177.78 C

**Utilities (kW):**
- No Utilities

<table>
<thead>
<tr>
<th>Utilities (kW)</th>
<th>Bare Module Cost:</th>
<th>$566,000.00</th>
</tr>
</thead>
<tbody>
<tr>
<td>Installation Cost:</td>
<td>$2,417,900.00</td>
<td>Equipment Weight (lbs) 169,600.00</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Installed Weight (lbs) 561,026.00</td>
</tr>
</tbody>
</table>

**Comments:**
HEAT EXCHANGER

Identification: Item: **Lactic Acid Ferm. HX**  
Item No. HX-6  
No. Required 1  
Date: 7 April 2017  
By: Group 7

Function: Heat the fermentable sugar stream to 37°C for the lacte acid fermentation

Operation:

<table>
<thead>
<tr>
<th>Materials Handled</th>
<th>Material In</th>
<th>Material Out</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quantity (kg/day):</td>
<td>368,323.00</td>
<td>368,323.00</td>
</tr>
</tbody>
</table>

Composition:

- *Ammonium Hydr.*
- *Ca(OH)*₂
- *CaSO*₄
- *Cellulose Solid*
- *CH₂Cl₂*
- *Enzymes*
- *Diphenyl Ether*
- *Ferment. Sugars*
- *Lactic Acid*
- *Methanol*
- *N₂*
- *Other Solids*
- *Other Solutes*
- *Polylactic Acid*
- *Sodium Citrate*
- *Sulfuric Acid*
- *Water*
- *Xylitol*
- *Xylose*

Temperature (°C): 25.00 37.00

Design Data:

- Heat Transfer Area: 2.44 square meters
- Shell Material: 321S
- Number of Shells: 0.00
- Tube Material: 321S
- Tube Design Temp.: 152.78 °C
- Tube Length: 6.10 meters
- Tube Op.Temp.: 125.00 °C
- Tube Pitch: 0.03
- Shell Design Temp: 121.11 °C
- No. Tube Pass: 1.00
- Shell Op.Temp: 37.00 °C
- No. Shell Pass: 1.00

Utilities (kW): 242.81

Bare Module Cost:

Installation Cost:

Comments:
## HEAT EXCHANGER

**Identification:** Item: Xylitol Cooling HX  
Item No.: HX-7  
No. Required: 1  
Date: 7 April 2017  
By: Group 7

**Function:** Cools the xylitol stream further so that the xylitol crystallizes out.

**Operation:**

**Materials Handled:**

<table>
<thead>
<tr>
<th>Material</th>
<th>Quantity (kg/day)</th>
<th>Material In</th>
<th>Material Out</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ammonium Hydr.</td>
<td>25,010.30</td>
<td>25,010.30</td>
<td></td>
</tr>
<tr>
<td>Ca(OH)₂</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>CaSO₄</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Cellulose Solid</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>CH₂Cl₂</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Enzymes</td>
<td>0.46</td>
<td>0.46</td>
<td></td>
</tr>
<tr>
<td>Diphenyl Ether</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Ferment. Sugars</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Lactic Acid</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Methanol</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>N₂</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Other Solids</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Other Solutes</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Polylactic Acid</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Sodium Citrate</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Sulfuric Acid</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Water</td>
<td>0.47</td>
<td>0.47</td>
<td></td>
</tr>
<tr>
<td>Xylitol</td>
<td>0.46</td>
<td>0.46</td>
<td></td>
</tr>
<tr>
<td>Xylose</td>
<td>0.07</td>
<td>0.07</td>
<td></td>
</tr>
</tbody>
</table>

**Temperature (°C):**  
Material In: 103.30  
Material Out: 5.00

**Design Data:**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat Transfer Area</td>
<td>6.42 square meters</td>
</tr>
<tr>
<td>Shell Material</td>
<td>321S</td>
</tr>
<tr>
<td>Number of Shells</td>
<td>0.00</td>
</tr>
<tr>
<td>Tube Material</td>
<td>321S</td>
</tr>
<tr>
<td>Tube Design Temp.</td>
<td>131.08 C</td>
</tr>
<tr>
<td>Tube Length</td>
<td>6.10 meters</td>
</tr>
<tr>
<td>Tube Op.Temp.</td>
<td>-24.00 C</td>
</tr>
<tr>
<td>Tube Pitch</td>
<td>0.03</td>
</tr>
<tr>
<td>Shell Design Temp</td>
<td>131.08 C</td>
</tr>
<tr>
<td>No. Tube Pass</td>
<td>1.00</td>
</tr>
<tr>
<td>Shell Op. Temp</td>
<td>103.30 C</td>
</tr>
<tr>
<td>No. Shell Pass</td>
<td>1.00</td>
</tr>
</tbody>
</table>

**Utilities (kW):** -37.19

**Bare Module Cost:** $13,800.00  
**Equipment Weight (lbs):** 1,100.00

**Installation Cost:** $91,000.00  
**Installed Weight (lbs):** 6,985.00

**Comments and Drawings:**
HEAT EXCHANGER

<table>
<thead>
<tr>
<th>Identification:</th>
<th>Item: Xylitol Cool HX</th>
</tr>
</thead>
<tbody>
<tr>
<td>Item No.</td>
<td>HX-21</td>
</tr>
<tr>
<td>No. Required</td>
<td>1</td>
</tr>
<tr>
<td>Date</td>
<td>7 April 2017</td>
</tr>
<tr>
<td>By: Group 7</td>
<td></td>
</tr>
</tbody>
</table>

Function: Uses the recycled xylitol liquor to cool the entering xylitol stream

Operation:

<table>
<thead>
<tr>
<th>Materials Handled:</th>
<th>Cold In</th>
<th>Cold Out</th>
<th>Hot In</th>
<th>Hot Out</th>
<th>Stream 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quantity (kg/day):</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Composition:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ammonium Hydr.</td>
<td>0.14</td>
<td>0.14</td>
<td>0.46</td>
<td>0.46</td>
<td></td>
</tr>
<tr>
<td>Ca(OH)₂</td>
<td>0.14</td>
<td>0.14</td>
<td>0.46</td>
<td>0.46</td>
<td></td>
</tr>
<tr>
<td>CaSO₄</td>
<td>0.14</td>
<td>0.14</td>
<td>0.46</td>
<td>0.46</td>
<td></td>
</tr>
<tr>
<td>Cellulose Solid</td>
<td>0.14</td>
<td>0.14</td>
<td>0.46</td>
<td>0.46</td>
<td></td>
</tr>
<tr>
<td>CH₂Cl₂</td>
<td>0.14</td>
<td>0.14</td>
<td>0.46</td>
<td>0.46</td>
<td></td>
</tr>
<tr>
<td>Enzymes</td>
<td>0.14</td>
<td>0.14</td>
<td>0.46</td>
<td>0.46</td>
<td></td>
</tr>
<tr>
<td>Diphenyl Ether</td>
<td>0.14</td>
<td>0.14</td>
<td>0.46</td>
<td>0.46</td>
<td></td>
</tr>
<tr>
<td>Ferment. Sugars</td>
<td>0.14</td>
<td>0.14</td>
<td>0.46</td>
<td>0.46</td>
<td></td>
</tr>
<tr>
<td>Lactic Acid</td>
<td>0.14</td>
<td>0.14</td>
<td>0.46</td>
<td>0.46</td>
<td></td>
</tr>
<tr>
<td>Methanol</td>
<td>0.14</td>
<td>0.14</td>
<td>0.46</td>
<td>0.46</td>
<td></td>
</tr>
<tr>
<td>N₂</td>
<td>0.14</td>
<td>0.14</td>
<td>0.46</td>
<td>0.46</td>
<td></td>
</tr>
<tr>
<td>Other Solids</td>
<td>0.14</td>
<td>0.14</td>
<td>0.46</td>
<td>0.46</td>
<td></td>
</tr>
<tr>
<td>Other Solutes</td>
<td>0.14</td>
<td>0.14</td>
<td>0.46</td>
<td>0.46</td>
<td></td>
</tr>
<tr>
<td>Polylactic Acid</td>
<td>0.14</td>
<td>0.14</td>
<td>0.46</td>
<td>0.46</td>
<td></td>
</tr>
<tr>
<td>Sodium Citrate</td>
<td>0.14</td>
<td>0.14</td>
<td>0.46</td>
<td>0.46</td>
<td></td>
</tr>
<tr>
<td>Sulfuric Acid</td>
<td>0.14</td>
<td>0.14</td>
<td>0.46</td>
<td>0.46</td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td>0.73</td>
<td>0.73</td>
<td>0.47</td>
<td>0.47</td>
<td></td>
</tr>
<tr>
<td>Xylitol</td>
<td>0.14</td>
<td>0.14</td>
<td>0.46</td>
<td>0.46</td>
<td></td>
</tr>
<tr>
<td>Xylose</td>
<td>0.14</td>
<td>0.14</td>
<td>0.07</td>
<td>0.07</td>
<td></td>
</tr>
<tr>
<td>Temperature (°C):</td>
<td>5.00</td>
<td>95.00</td>
<td>103.30</td>
<td>45.92</td>
<td></td>
</tr>
</tbody>
</table>

Design Data:

<table>
<thead>
<tr>
<th>Heat Transfer Area</th>
<th>3.05 square meters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shell Material</td>
<td>321S</td>
</tr>
<tr>
<td>Tube Material</td>
<td>321S</td>
</tr>
<tr>
<td>Tube Design Temp.</td>
<td>131.08 C</td>
</tr>
<tr>
<td>Tube Length</td>
<td>6.10 meters</td>
</tr>
<tr>
<td>Tube Op.Temp.</td>
<td>95.00 C</td>
</tr>
<tr>
<td>Tube Pitch</td>
<td>0.03</td>
</tr>
<tr>
<td>Shell Design Temp.</td>
<td>131.08 C</td>
</tr>
<tr>
<td>No. Tube Pass</td>
<td>1.00</td>
</tr>
<tr>
<td>Shell Op. Temp.</td>
<td>103.30 C</td>
</tr>
<tr>
<td>No. Shell Pass</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Utilities (kW):

| Bare Module Cost: | $8,600.00 |
| Installation Cost: | $62,500.00 |

Comments:

Utilities Weight (lbs): 590.00
Installed Weight (lbs): 7,690.00
HEAT EXCHANGER

Identification: Item: Lactic Poly. Reac. HX
Item No. HX-8
No. Required 1
Date: 7 April 2017
By: Group 7

Function: Heats the lactic acid stream to 170°C for introduction to the PLA reactor

Operation:

<table>
<thead>
<tr>
<th>Material Handled</th>
<th>Material In</th>
<th>Material Out</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quantity (kg/day)</td>
<td>53,847.70</td>
<td>53,847.70</td>
</tr>
</tbody>
</table>

Composition:
- Ammonium Hydr.
- Ca(OH)₂
- CaSO₄
- Cellulose Solid
- CH₂Cl₂
- Enzymes
- Diphenyl Ether 0.74
- Ferment. Sugars 0.00
- Lactic Acid 0.25
- Methanol
- N₂
- Other Solids
- Other Solutes
- Polylactic Acid
- Sodium Citrate
- Sulfuric Acid
- Water 0.01
- Xylitol
- Xylose

Temperature (°C): 93.20 170.00

Design Data:

- Heat Transfer Area 18.57 square meters
- Shell Material 321S
- Number of Shells 0.00
- Tube Material 321S
- Tube Design Temp. 202.78°C
- Tube Length 6.10 meters
- Tube Op.Temp. 175.00°C
- Tube Pitch 0.03
- Shell Design Temp. 197.78°C
- No. Tube Pass 1.00
- Shell Op. Temp. 170.00°C
- No. Shell Pass 1.00

Utilities (kW) 94.42
Bare Module Cost: $22,800.00
Installation Cost: $112,200.00

Comments and Drawings:
# HEAT EXCHANGER

<table>
<thead>
<tr>
<th>Identification:</th>
<th>Item: PLA Ether Flash HX</th>
<th>Date: 7 April 2017</th>
</tr>
</thead>
<tbody>
<tr>
<td>Item No.</td>
<td>HX-9</td>
<td></td>
</tr>
<tr>
<td>No. Required</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>By:</td>
<td>Group 7</td>
<td></td>
</tr>
</tbody>
</table>

**Function:** Heats the diphenyl ether and PLA mixture in order to flash off the ether

**Operation:**

<table>
<thead>
<tr>
<th>Materials Handled:</th>
<th>Material In</th>
<th>Material Out</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quantity (kg/day):</td>
<td>52,808.10</td>
<td>52,808.10</td>
</tr>
</tbody>
</table>

**Composition:**

- *Ammonium Hydr.*
- *Ca(OH)₂*
- *CaSO₄*
- *Cellulose Solid*
- *CH₂Cl₂*
- *Enzymes*
- *Diphenyl Ether* 0.76
- *Ferment. Sugars* 0.00
- *Lactic Acid* -
- *Methanol* -
- *N₂* -
- *Other Solids* -
- *Other Solutes* -
- *Polylactic Acid* 0.20
- *Sodium Citrate* -
- *Sulfuric Acid* -
- *Water* 0.04
- *Xylitol* -
- *Xylose* -

**Temperature (°C):**

<table>
<thead>
<tr>
<th>Material In</th>
<th>Material Out</th>
</tr>
</thead>
<tbody>
<tr>
<td>237.48</td>
<td>288.00</td>
</tr>
</tbody>
</table>

**Design Data:**

- **Heat Transfer Area**: 4.72 square meters
- **Shell Material**: 321S
- **Number of Shells**: 0.00
- **Tube Material**: 321S
- **Tube Design Temp.**: 400.00°C
- **Tube Length**: 6.10 meters
- **Tube Op.Temp.**: 350.00°C
- **Tube Pitch**: 0.03
- **Shell Design Temp.**: 315.78°C
- **No. Tube Pass**: 1.00
- **Shell Op. Temp**: 288.00°C
- **No. Shell Pass**: 1.00

**Utilities (kW)**

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Bare Module Cost</strong>:</td>
<td>$12,900.00</td>
</tr>
<tr>
<td><strong>Installation Cost</strong></td>
<td>$89,800.00</td>
</tr>
<tr>
<td><strong>Equipment Weight (lbs)</strong></td>
<td>1,000.00</td>
</tr>
<tr>
<td><strong>Installed Weight (lbs)</strong></td>
<td>8,996.00</td>
</tr>
</tbody>
</table>

**Comments:**
# HEAT EXCHANGER

## Identification
- **Item:** Polymer: Feed HX
- **Item No.:** HX-10
- **No. Required:** 1
- **Date:** 7 April 2017
- **By:** Group 7

## Function
Uses the steam generated in the PLA process to heat the lactic acid reactor feed

## Operation

### Materials Handled:

<table>
<thead>
<tr>
<th></th>
<th>Cold In</th>
<th>Cold Out</th>
<th>Hot In</th>
<th>Hot Out</th>
<th>Stream 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quantity (kg/day):</td>
<td>53847.7</td>
<td>53847.7</td>
<td>3775.64</td>
<td>3775.64</td>
<td></td>
</tr>
</tbody>
</table>

### Composition:

- Ammonium Hydr.
- Ca(OH)$_2$
- CaSO$_4$
- Cellulose Solid
- CH$_2$Cl$_2$
- Enzymes
- Diphenyl Ether 0.742835
- Ferment. Sugars 0.00258372
- Lactic Acid 0.247453
- Methanol
- N$_2$
- Other Solids
- Other Solutes
- Polylactic Acid
- Sodium Citrate
- Sulfuric Acid
- Water 0.00712846
- Xylitol
- Xylose

### Temperature (°C):
- Cold In 53847.7
- Cold Out 53847.7
- Hot In 3775.64
- Hot Out 3775.64
- Stream 3 93.2006

## Design Data:

- **Heat Transfer Area:** 1.58451301 square meters
- **Shell Material:** 0
- **Number of Shells:** 0
- **Tube Material:** 321S
- **Tube Design Temp.:** 168.6173839°C
- **Tube Length:** 6.096 meters
- **Tube Op.Temp.:** 140.837°C
- **Tube Pitch:** 0.03175
- **Shell Design Temp:** 121.1111111°C
- **No. Tube Pass:** 1
- **Shell Op. Temp.:** 93.19806222°C
- **No. Shell Pass:** 1

### Utilities (kW)
- **No Utilities**

### Costs:
- **Bare Module Cost:** $9,500.00
- **Installation Cost:** $81,800.00

### Equipment and Installed Weights (lbs)
- **Equipment Weight:** 490.00
- **Installed Weight:** 6,605.00
### HEAT EXCHANGER

**Identification:** Item: *Feed Ether HX*
- Item No.: HX-11
- No. Required: 1
- Date: 7 April 2017
- By: Group 7

**Function:** Distillate-to-feed exchanger that heats ether and PLA feed for ether flash

**Operation:**

<table>
<thead>
<tr>
<th>Materials Handled</th>
<th>Cold In</th>
<th>Cold Out</th>
<th>Hot In</th>
<th>Hot Out</th>
<th>Stream 3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Composition:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Ammonium Hydr.</em></td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><em>Ca(OH)₂</em></td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><em>CaSO₄</em></td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><em>Cellulose Solid</em></td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><em>CH₂Cl₂</em></td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><em>Enzymes</em></td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><em>Diphenyl Ether</em></td>
<td>0.756717</td>
<td>0.756717</td>
<td>0.948094</td>
<td>0.948094</td>
<td></td>
</tr>
<tr>
<td><em>Ferment. Sugars</em></td>
<td>0.00263459</td>
<td>0.00263459</td>
<td>0.00329987</td>
<td>0.00329987</td>
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<tr>
<td><em>Lactic Acid</em></td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><em>Methanol</em></td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<tr>
<td><em>N₂</em></td>
<td>-</td>
<td>-</td>
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<td>-</td>
<td>-</td>
</tr>
<tr>
<td><em>Other Solids</em></td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><em>Other Solutes</em></td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><em>Polylactic Acid</em></td>
<td>0.201864</td>
<td>0.201864</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><em>Sodium Citrate</em></td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><em>Sulfuric Acid</em></td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><em>Water</em></td>
<td>0.0387842</td>
<td>0.0387842</td>
<td>0.0486057</td>
<td>0.0486057</td>
<td></td>
</tr>
<tr>
<td><em>Xylitol</em></td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><em>Xylose</em></td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Temperature (°C):</strong></td>
<td>110</td>
<td>237.482</td>
<td>288</td>
<td>180</td>
<td></td>
</tr>
</tbody>
</table>

**Design Data:**

<table>
<thead>
<tr>
<th>Heat Transfer Area</th>
<th>8.631770001 square meters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Shells</td>
<td>0</td>
</tr>
<tr>
<td>Tube Design Temp.</td>
<td>315.7777778 C</td>
</tr>
<tr>
<td>Tube Op.Temp.</td>
<td>288 C</td>
</tr>
<tr>
<td>Shell Design Temp.</td>
<td>265.2563217 C</td>
</tr>
<tr>
<td>Shell Op. Temp.</td>
<td>237.4785439 C</td>
</tr>
<tr>
<td>Tube Length</td>
<td>6.096 meters</td>
</tr>
<tr>
<td>Tube Pitch</td>
<td>0.03175</td>
</tr>
<tr>
<td>No. Tube Pass</td>
<td>1</td>
</tr>
<tr>
<td>No. Shell Pass</td>
<td>1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Utilities (kW)</th>
<th>No Utilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bare Module Cost:</td>
<td>$ 16,100.00</td>
</tr>
<tr>
<td>Installation Cost:</td>
<td>$ 91,400.00</td>
</tr>
</tbody>
</table>

| Equipment Weight (lbs) | 1,300.00 |
| Installed Weight (lbs) | 8,803.00 |
# HEAT EXCHANGER

**Identification:** Item: Xylose Heating HX  
Item No.: HX-20  
No. Required: 1  
Date: 7 April 2017  
By: Group 7

**Function:** Heats the xylose sugar solution to 32°C for the xylitol fermentation

**Operation:**

## Materials Handled:

<table>
<thead>
<tr>
<th>Material In</th>
<th>Material Out</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quantity (kg/day):</td>
<td></td>
</tr>
<tr>
<td>168,700.00</td>
<td>175,104.00</td>
</tr>
</tbody>
</table>

**Composition:**

- Ammonium Hydr.
- Ca(OH)₂
- CaSO₄
- Cellulose Solid
- CH₂Cl₂
- Enzymes
- Diphenyl Ether
- Ferment. Sugars
- Lactic Acid
- Methanol
- N₂
- Other Solids
- Other Solutes
- Polylactic Acid
- Sodium Citrate
- Sulfuric Acid
- Water
- Xylitol
- Xylose

**Temperature (°C):**

<table>
<thead>
<tr>
<th>Material</th>
<th>Temperature In</th>
<th>Temperature Out</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>25.00</td>
<td>32.00</td>
</tr>
</tbody>
</table>

**Design Data:**

- Heat Transfer Area: 0.43 square meters  
- Shell Material: 321S  
- Number of Shells: 0.00  
- Tube Material: 321S  
- Tube Design Temp.: 152.78°C  
- Tube Length: 6.10 meters  
- Tube Op.Temp.: 125.00°C  
- Tube Pitch: 0.03 meters  
- Shell Design Temp.: 121.11°C  
- No. Tube Pass: 1.00  
- Shell Op. Temp.: 32.00°C  
- No. Shell Pass: 1.00

**Utilities (kW):**

| Utilities | 43.59 |

**Bare Module Cost:** $8,400.00  
**Installation Cost:** $54,100.00

**Equipment Weight (lbs):** 270.00  
**Installed Weight (lbs):** 3,337.00

**Comments:** 
# HEAT EXCHANGER

**Identification:**

<table>
<thead>
<tr>
<th>Item:</th>
<th>PLA Steam HX</th>
</tr>
</thead>
<tbody>
<tr>
<td>Item No.:</td>
<td>HX-16</td>
</tr>
<tr>
<td>No. Required:</td>
<td>1</td>
</tr>
<tr>
<td>Date:</td>
<td>7 April 2017</td>
</tr>
</tbody>
</table>

**By:** Group 7

**Function:**

Uses the PLA reactor effluent to heat steam produced in the xylitol process.

**Operation:**

**Materials Handled:**

<table>
<thead>
<tr>
<th>Stream 3</th>
<th>Cold In</th>
<th>Cold Out</th>
<th>Hot In</th>
<th>Hot Out</th>
<th>Quantity (kg/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>118,953.00</td>
<td>118,953.00</td>
<td>105,620.00</td>
<td>105,620.00</td>
<td></td>
</tr>
</tbody>
</table>

**Composition:**

- Ammonium Hydr.
- Ca(OH)₂
- CaSO₄
- Cellulose Solid
- CH₂Cl₂
- Enzymes
- Diphenyl Ether
- Ferment. Sugars
- Lactic Acid
- Methanol
- N₂
- Other Solids
- Other Solutes
- Polylactic Acid
- Sodium Citrate
- Sulfuric Acid
- Water
- Xylitol
- Xylose

**Temperature (°C):**

<table>
<thead>
<tr>
<th>Stream 3</th>
<th>Cold In</th>
<th>Cold Out</th>
<th>Hot In</th>
<th>Hot Out</th>
<th>Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>103.30</td>
<td>118,953.00</td>
<td>118,953.00</td>
<td>110.00</td>
<td></td>
</tr>
</tbody>
</table>

**Design Data:**

- Heat Transfer Area: 15.76 square meters
- Shell Material: 321S
- Number of Shells: 0.00
- Tube Material: 321S
- Tube Design Temp.: 197.78 C
- Tube Length: 6.10 meters
- Tube Op.Temp.: 155.20 C
- Tube Pitch: 0.03
- Shell Design Temp: 197.78 C
- No. Tube Pass: 1.00
- Shell Op. Temp: 170.00 C
- No. Shell Pass: 1.00

**Utilities (kW):**

- No Utilities

**Bare Module Cost:** $19,400.00

**Installation Cost:** $107,500.00

**Equipment Weight (lbs):** 1,600.00

**Installed Weight (lbs):** 9,957.00

**Comments:**
# SCRUBBING COLUMN

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Item No.</td>
<td>S-22</td>
<td>No. Required</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Date</td>
<td>7 April 2017</td>
<td></td>
</tr>
<tr>
<td>By:</td>
<td>Group 7</td>
<td></td>
</tr>
</tbody>
</table>

**Function:** Uses feed water to scrub CO2 and cell debris out of fermenter gas

**Operation:** Z

**Materials Handled:**

<table>
<thead>
<tr>
<th>Quantity (kg/day)</th>
<th>Water Feed</th>
<th>Ferm. Gas In</th>
<th>Water Out</th>
<th>Gas Out</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>355871</td>
<td>~100</td>
<td>~384216</td>
<td>~99</td>
</tr>
</tbody>
</table>

**Composition:**

- Ammonium Hydr.
- Ca(OH)\(_2\)
- CaSO\(_4\)
- Cellulose Solid
- CH\(_2\)Cl\(_2\)
- Enzymes
- Diphenyl Ether
- Ferment. Sugars
- Lactic Acid
- Methanol
- N\(_2\)

**Other Solids** 0.000196296

**Other Solutes**

- Polylactic Acid
- Sodium Citrate
- Sulfuric Acid

**Water** 0.999802

**Temperature (°C):** 58.831 36 58.831 36

**Design Data:**

- Shell Material 0
- Diameter 0.9144 meters
- Height 3.6576 meters
- Volume 2401.932948 liters
- Design Temp 121.1111111
- Operating Temp 58.83099778

**Utilities (kW):** No Utilities

**Bare Module Cost:** $15,400.00

**Installation Cost:** $110,100.00

**Equipment Weight (lbs):** 2,600.00

**Installed Weight (lbs):** 11,524.00

**Comments:**
# ROTARY DRUM FILTER

## Identification:

<table>
<thead>
<tr>
<th>Item:</th>
<th>Item No.</th>
<th>Date: 7 April 2017</th>
</tr>
</thead>
<tbody>
<tr>
<td>Xylitol Crystal Filter</td>
<td>S-3</td>
<td></td>
</tr>
<tr>
<td>No. Required</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>By:</td>
<td>Group 7</td>
<td></td>
</tr>
</tbody>
</table>

## Function:
Separates the precipitated xylitol crystals from carrier solution

## Operation:

### Materials Handled:

<table>
<thead>
<tr>
<th>Composition</th>
<th>Feed</th>
<th>Liquid Stream</th>
<th>Solid Stream</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ammonium Hydr.</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Ca(OH)₂</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>CaSO₄</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Cellulose Solid</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>CH₂Cl₂</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Enzymes</td>
<td>0.464588</td>
<td>0.136083</td>
<td>0.809385</td>
</tr>
<tr>
<td>Diphenyl Ether</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Ferment. Sugars</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Lactic Acid</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Methanol</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>N₂</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Other Solids</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Other Solutes</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Polylactic Acid</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Sodium Citrate</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Sulfuric Acid</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Water</td>
<td>0.465008</td>
<td>0.726436</td>
<td>0.190615</td>
</tr>
<tr>
<td>Xylitol</td>
<td>0.464588</td>
<td>0.136083</td>
<td>0.809385</td>
</tr>
<tr>
<td>Xylose</td>
<td>0.0704042</td>
<td>0.137481</td>
<td>-</td>
</tr>
</tbody>
</table>

## Design Data:

Material 0
Application 0
Solid Flow 12202.5 kg/day
Liquid Flow 12808 kg/day

## Utilities (kW):

- No Utilities

<table>
<thead>
<tr>
<th>Utilities</th>
<th>Bare Module Cost:</th>
<th>$78,800.00</th>
</tr>
</thead>
<tbody>
<tr>
<td>Installation Cost:</td>
<td>$86,300.00</td>
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<table>
<thead>
<tr>
<th>Comments:</th>
<th>Equipment Weight (lbs):</th>
<th>-</th>
</tr>
</thead>
<tbody>
<tr>
<td>Installed Weight (lbs):</td>
<td>1,348.00</td>
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</tr>
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</table>
## ROTARY DRUM FILTER

**Identification:** Item: Xylitol Crystal Filter  
Item No. S-3  
No. Required 1  
Date: 7 April 2017  
By: Group 7

**Function:** Separates the precipitated xylitol crystals from carrier solution

**Operation:**

### Materials Handled:

<table>
<thead>
<tr>
<th>Composition</th>
<th>Feed</th>
<th>Liquid Stream</th>
<th>Solid Stream</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ammonium Hydr.</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Ca(OH)₂</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>CaSO₄</td>
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<td>-</td>
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</tr>
<tr>
<td>Cellulose Solid</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>CH₂Cl₂</td>
<td>-</td>
<td>-</td>
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</tr>
<tr>
<td>Enzymes</td>
<td>0.464588</td>
<td>0.136083</td>
<td>0.809385</td>
</tr>
<tr>
<td>Diphenyl Ether</td>
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<td>-</td>
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</tr>
<tr>
<td>Ferment. Sugars</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Lactic Acid</td>
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<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Methanol</td>
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<td>-</td>
<td>-</td>
</tr>
<tr>
<td>N₂</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Other Solids</td>
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</tr>
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<td>Other Solutes</td>
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</tr>
<tr>
<td>Polylactic Acid</td>
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</tr>
<tr>
<td>Sodium Citrate</td>
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</tr>
<tr>
<td>Sulfuric Acid</td>
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</tr>
<tr>
<td>Water</td>
<td>0.465008</td>
<td>0.726436</td>
<td>0.190615</td>
</tr>
<tr>
<td>Xylitol</td>
<td>0.464588</td>
<td>0.136083</td>
<td>0.809385</td>
</tr>
<tr>
<td>Xylose</td>
<td>0.0704042</td>
<td>0.137481</td>
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</tr>
</tbody>
</table>

**Temperature (°C):**  
Feed 5  
Liquid 5  
Solid 5

### Design Data:

- Material #N/A  
- Application #N/A  
- Solid Flow 1220.5 kg/day  
- Liquid Flow 12808 kg/day

### Utilities (kW)

- No Utilities

### Cost:

- **Bare Module Cost:** $219,100.00  
- **Installation Cost:** $271,400.00

### Weight:

- **Equipment Weight (lbs):** -  
- **Installed Weight (lbs):** 903.00

### Comments:
**ROTARY DRUM FILTER**

**Identification:** Item: *Pretreatment Filter*
- Item No.: S-1
- No. Required: 1
- Date: 7 April 2017
- By: Group 7

**Function:** Separates the BSG stream to be sent to xylitol and lactic acid fermentation paths

**Operation:**

**Materials Handled:**

<table>
<thead>
<tr>
<th>Material</th>
<th>Feed (kg/day)</th>
<th>Liquid Stream (kg/day)</th>
<th>Solid Stream (kg/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ammonium Hydr.</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Ca(OH)₂</td>
<td>-</td>
<td>-</td>
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</tr>
<tr>
<td>CaSO₄</td>
<td>-</td>
<td>-</td>
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</tr>
<tr>
<td>Cellulose Solid</td>
<td>0.0295048</td>
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<tr>
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<td>Enzymes</td>
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</tr>
<tr>
<td>Diphenyl Ether</td>
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<td>Ferment. Sugars</td>
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<tr>
<td>Methanol</td>
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<tr>
<td>Xylose</td>
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<td>Temperature (°C)</td>
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<td>102.776</td>
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</table>

**Design Data:**

- Material SS316
- Application HI RATE
- Solid Flow 352906 kg/day
- Liquid Flow 165777 kg/day

**Utilities (kW):**
- No Utilities

**Costs:**

<table>
<thead>
<tr>
<th>Description</th>
<th>Amount</th>
<th>Notes</th>
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<td>Bare Module Cost:</td>
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<td>Installation Cost:</td>
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<td>Installed Weight (lbs) 12,195.00</td>
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**Comments:**
DISK CENTRIFUGE

Item No. S-10
No. Required 1
Date: 7 April 2017
By: Group 7

Function: Purifies lactic acid fermentation product

Operation:

Materials Handled:

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<tr>
<th></th>
<th>Feed</th>
<th>Supernatent</th>
<th>Solids</th>
<th>Stream 2</th>
<th>Stream 3</th>
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<td>CH₂Cl₂</td>
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<td>Sulfuric Acid</td>
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Design Data:

<table>
<thead>
<tr>
<th>Diameter</th>
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<th>meters</th>
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</thead>
</table>

Utilities (kW):

Utilities (kW) 0.35
Bare Module Cost: $ 39,300.00 Equipment Weight (lbs) 2,900.00
Installation Cost: $ 189,000.00 Installed Weight (lbs) 12,528.00

Comments:
**DISK CENTRIFUGE**

**Identification:**  
Item: *Xylitol Ferm. Centri.*  
Item No. S-4  
No. Required 1  
Date: 7 April 2017  
By: Group 7

**Function:** Purifies xylitol fermentation product

**Operation:**

<table>
<thead>
<tr>
<th>Materials Handled</th>
<th>Feed</th>
<th>Supernatent</th>
<th>Solids</th>
<th>Stream 2</th>
<th>Stream 3</th>
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<tbody>
<tr>
<td>Quantity (kg/day)</td>
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<td>173766</td>
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Composition:

- **Ammonium Hydr.**
- **Ca(OH)₂**
- **CaSO₄**
- **Cellulose Solid**
- **CH₂Cl₂**
- **Enzymes** 0.0663634 0.0668744
- **Diphenyl Ether**
- **Ferment. Sugars**
- **Lactic Acid**
- **Methanol**
- **N₂**
- **Other Solids** 0.00764203
- **Other Solutes** 0.170195 0.171506
- **Polylactic Acid**
- **Sodium Citrate**
- **Sulfuric Acid**
- **Water** 0.745743 0.751485
- **Xylitol** 0.0663634 0.0668744
- **Xylose** 0.0100569 0.0101344

Temperature (°C):

- Feed 32
- Supernatent 32
- Solids 32

**Design Data:**

- Diameter #N/A meters

**Utilities (kW):**  
Bare Module Cost: $31,200.00  
Installation Cost: $175,700.00  
No Utilities  
Equipment Weight (lbs) 2,300.00  
Installed Weight (lbs) 13,538.00  
Comments:
DISK CENTRIFUGE

Identification:  
Item: Sacch. Centrifuge  
Item No. S-6  
No. Required 7  
Date: 7 April 2017  
By: Group 7

Function: Removes solids in the stream exiting saccharification reactor

Operation:

Materials Handled:

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<th>Composition</th>
<th>Feed</th>
<th>Supernatent</th>
<th>Solids</th>
<th>Stream 2</th>
<th>Stream 3</th>
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</thead>
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<tr>
<td>CaSO\textsubscript{4}</td>
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<tr>
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<td>Lactic Acid</td>
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<tr>
<td>Methanol</td>
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<tr>
<td>N\textsubscript{2}</td>
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<tr>
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<tr>
<td>Polylactic Acid</td>
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<tr>
<td>Xylose</td>
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<tr>
<td>Temperature (°C)</td>
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<td>25</td>
<td>25</td>
<td></td>
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</tr>
</tbody>
</table>

Design Data:

Diameter 0.254 meters

Utilities (kW):

| Bare Module Cost: | $1,533,700.00 |
| Installation Cost: | $1,899,700.00 |
| Equipment Weight (lbs): | - |
| Installed Weight (lbs): | 6,320.00 |
**DISK CENTRIFUGE**

**Identification:**
- **Item:** Neutr. Centrifuge
- **Item No.:** S-5
- **No. Required:** 1
- **Date:** 7 April 2017
- **By:** Group 7

**Function:** Removes calcium sulfate precipitated in neutralization reactor

**Operation:**

**Materials Handled:**
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<th></th>
<th>Feed</th>
<th>Supernatent</th>
<th>Solids</th>
<th>Stream 2</th>
<th>Stream 3</th>
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<tbody>
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</tr>
<tr>
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<td>Enzymes</td>
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<tr>
<td>Diphenyl Ether</td>
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<td>N₂</td>
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**Design Data:**
- Diameter 0.254 meters

**Utilities (kW):**
- **Bare Module Cost:** $219,100.00
- **Installation Cost:** $271,400.00
- **Equipment Weight (lbs):** -
- **Installed Weight (lbs):** 903.00

**Comments and Drawings:**
**CRYSTALLIZER**

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<th>Item:</th>
<th>PLA Crystallizer</th>
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**Date:** 7 April 2017

**By:** Group 7

**Function:** Removes water from the PLA recycle stream before it is introduced into reactor

**Operation:**

**Materials Handled:**

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<tr>
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<td>-</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>Sodium Citrate</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Sulfuric Acid</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Water</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Xylitol</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Xylose</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Temperature (°C):</td>
<td>40.1463</td>
<td>55.1613</td>
<td>25.8549</td>
<td>25.8549</td>
</tr>
</tbody>
</table>

**Design Data:**

- **Shell Material SS304**
  - Diameter 1.0668 meters
  - Height 3.6576 meters
  - Volume 3269.297609 liters
  - Design Temp 121.1111111
  - Operating Temp 25.85487722

**Utilities (kW):**

- **No Utilities**

**Bare Module Cost:** $31,200.00

**Installation Cost:** $166,100.00

**Equipment Weight (lbs):** 2,300.00

**Installed Weight (lbs):** 10,478.00

**Comments:**

---

135
**FLASH DRUM**

**Identification:**  
Item: Lactic Acid Dryer  
Item No.: S-14  
No. Required: 1  
Date: 7 April 2017  
By: Group 7

**Function:**

**Operation:**

**Materials Handled:**

<table>
<thead>
<tr>
<th>Mixed Feed</th>
<th>Distillate</th>
<th>Bottoms</th>
<th>Stream 2</th>
<th>Stream 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quantity (kg/day):</td>
<td>143964</td>
<td>118953</td>
<td>25010.3</td>
<td></td>
</tr>
<tr>
<td>Composition:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ammonium Hydr.</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Ca(OH)₂</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>CaSO₄</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Cellulose Solid</td>
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<tr>
<td>CH₂Cl₂</td>
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</tr>
<tr>
<td>Enzymes</td>
<td>0.080718</td>
<td>-</td>
<td>0.464588</td>
<td></td>
</tr>
<tr>
<td>Diphenyl Ether</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Ferment. Sugars</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Lactic Acid</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Methanol</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>N₂</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Other Solids</td>
<td>-</td>
<td>-</td>
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</tr>
<tr>
<td>Other Solutes</td>
<td>-</td>
<td>-</td>
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<td></td>
</tr>
<tr>
<td>Polylactic Acid</td>
<td>-</td>
<td>-</td>
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<tr>
<td>Sodium Citrate</td>
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<td>-</td>
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<tr>
<td>Sulfuric Acid</td>
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<td>-</td>
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<td>Xylose</td>
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<td>Temperature (°C):</td>
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<td>103.304</td>
<td>103.304</td>
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**Design Data:**

<table>
<thead>
<tr>
<th>Shell Material SS304</th>
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</thead>
<tbody>
<tr>
<td>Diameter 1.0668 meters</td>
</tr>
<tr>
<td>Height 3.6576 meters</td>
</tr>
<tr>
<td>Volume 3269.297609 liters</td>
</tr>
<tr>
<td>Design Temp 131.0813639</td>
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<tr>
<td>Operating Temp 103.3035861</td>
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**Utilities (kW):**

- No Utilities

**Bare Module Cost:** $31,200.00  
**Equipment Weight (lbs):** 2,300.00  
**Installation Cost:** $175,700.00  
**Installed Weight (lbs):** 13,538.00  
**Comments:**
# FLASH DRUM

**Identification:**

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<tr>
<th>Item</th>
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</tr>
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</tr>
<tr>
<td>No. Required</td>
<td>1</td>
</tr>
<tr>
<td>Date:</td>
<td>7 April 2017</td>
</tr>
<tr>
<td>By:</td>
<td>Group 7</td>
</tr>
</tbody>
</table>

**Function:**

Removes water from the stream entering lactic acid process

**Operation:**

**Materials Handled:**

<table>
<thead>
<tr>
<th>Mixed Feed</th>
<th>Distillate</th>
<th>Bottoms</th>
<th>Stream 2</th>
<th>Stream 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quantity (kg/day):</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ammonium Hydr.</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Ca(OH)₂</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>CaSO₄</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<tr>
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<td>0.0479523</td>
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<tr>
<td>CH₂Cl₂</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Enzymes</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Diphenyl Ether</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Ferment. Sugars</td>
<td>-</td>
<td>-</td>
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<td>-</td>
</tr>
<tr>
<td>Lactic Acid</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Methanol</td>
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<td>-</td>
</tr>
<tr>
<td>N₂</td>
<td>-</td>
<td>-</td>
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<tr>
<td>Other Solids</td>
<td>0.0110606</td>
<td>0.00206905</td>
<td>0.0120119</td>
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<tr>
<td>Sodium Citrate</td>
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</tr>
<tr>
<td>Sulfuric Acid</td>
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<td>-</td>
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</tr>
<tr>
<td>Water</td>
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<td>Xylitol</td>
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<tr>
<td>Xylose</td>
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</tr>
<tr>
<td>Temperature (°C):</td>
<td>102.776</td>
<td>110</td>
<td>110</td>
<td>-</td>
</tr>
</tbody>
</table>

**Design Data:**

- Shell Material SS304
- Diameter: 1.2192 meters
- Height: 3.81 meters
- Volume: 4448.023966 liters
- Design Temp: 137.7777778
- Operating Temp: 110

**Utilities (kW):**

- No Utilities

**Bare Module Cost:** $33,600.00

**Installation Cost:** $192,900.00

**Equipment Weight (lbs):** 2,600.00

**Installed Weight (lbs):** 15,954.00

**Comments:**
**TRAY DISTILLATION TOWER**

<table>
<thead>
<tr>
<th>Identification:</th>
<th>Item:</th>
<th>PLA Solvent Recover</th>
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</thead>
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<tr>
<td>Item No.</td>
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<tr>
<td>No. Required</td>
<td>1</td>
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</tr>
<tr>
<td>Date</td>
<td>7 April 2017</td>
<td></td>
</tr>
<tr>
<td>By:</td>
<td>Group 7</td>
<td></td>
</tr>
</tbody>
</table>

**Function:** Separates the dichloromethane and methanol used in PLA purification

**Operation:**

**Materials Handled:**

<table>
<thead>
<tr>
<th>Quantity (kg/day)</th>
<th>Mixed Feed</th>
<th>Distillate</th>
<th>Bottoms</th>
<th>Stream 2</th>
<th>Stream 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ammonium Hydr.</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ca(OH)₂</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CaSO₄</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cellulose Solid</td>
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<td>-</td>
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<td></td>
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<tr>
<td>CH₂Cl₂</td>
<td>0.688654</td>
<td>0.999229</td>
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<tr>
<td>Enzymes</td>
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<td>-</td>
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<td>Diphenyl Ether</td>
<td>9.41327E-05</td>
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<td>0.000157868</td>
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<td></td>
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<tr>
<td>Ferment. Sugars</td>
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<td>-</td>
<td>-</td>
<td></td>
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<tr>
<td>Lactic Acid</td>
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<td>Methanol</td>
<td>0.311251</td>
<td>0.000770948</td>
<td>0.52147</td>
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<td>N₂</td>
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<td></td>
</tr>
<tr>
<td>Other Solutes</td>
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<td>-</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Polylactic Acid</td>
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<td>-</td>
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</tr>
<tr>
<td>Sodium Citrate</td>
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</tr>
<tr>
<td>Sulfuric Acid</td>
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<td>-</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water</td>
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<td>-</td>
<td>-</td>
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<td></td>
</tr>
<tr>
<td>Xylitol</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Xylose</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temperature (°C)</td>
<td>25.8549</td>
<td>40.1463</td>
<td>55.1613</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Design Data:**

- Material SS304
- Diameter 1.0668 meters
- Height 10.9728 meters
- Trays 12
- Tray Spacing 0.6096 meters
- Design Temp 121.1111111
- Oper. Temp 63.2666
- Tray Type SIEVE

**Utilities (kW):**

- No Utilities

**Bare Module Cost:** $128,600.00

**Installation Cost:** $286,400.00

**Equipment Weight (lbs):** 10,800.00

**Installed Weight (lbs):** 21,819.00

**Comments:**
LIQUID EXTRACTION COLUMN

Identification: | Item: | Date: 7 April 2017 |
---|---|---|
Item No. | S-7 | |
No. Required | 1 | |
By: Group 7

Function: Transfers lactic acid from fermentation effluent into diphenyl ether solvent

Operation:

<table>
<thead>
<tr>
<th>Materials Handled</th>
<th>Ferm. Product</th>
<th>Solvent Input</th>
<th>Extract</th>
<th>Raffinate</th>
<th>Stream 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quantity (kg/day):</td>
<td>366931</td>
<td>40407.5</td>
<td>53847.7</td>
<td>353084</td>
<td></td>
</tr>
</tbody>
</table>

Composition:
- Ammonium Hydr.
- Ca(OH)₂
- CaSO₄
- Cellulose Solid
- CH₂Cl₂
- Enzymes
- Diphenyl Ether
- Ferment. Sugars
- Lactic Acid
- Methanol
- N₂
- Other Solids
- Other Solutes
- Polylactic Acid
- Sodium Citrate
- Sulfuric Acid
- Water
- Xylitol
- Xylose

Temperature (°C): 37

Design Data:

<table>
<thead>
<tr>
<th>Material</th>
</tr>
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</table>

Utilities (kW):

<table>
<thead>
<tr>
<th>Utilities (kW)</th>
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<tbody>
<tr>
<td>Bare Module Cost:</td>
<td>$299,400.00</td>
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<td>Installation Cost:</td>
<td>$326,800.00</td>
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Equipment Weight (lbs): -
Installed Weight (lbs): 8,088.00
FLASH DRUM

Identification: Ether Recovery Flash
Item No. S-13
No. Required 1
Date: 7 April 2017
By: Group 7

Function: Separates water from diphenyl ether so that ether can be recycled

Operation:

Materials Handled: Mixed Feed Distillate Bottoms Stream 2 Stream 3
Quantity (kg/day): 42137.1 2739.82 39397.2
Composition:
Ammonium Hydr. - - -
Ca(OH) 2 - - -
CaSO 4 - - -
Cellulose Solid - - -
CH 2 Cl 2 - - -
Enzymes - - -
Diphenyl Ether 0.948094 0.348745 0.989775
Ferment. Sugars 0.00329987 - 0.00352872
Lactic Acid - - -
Methanol - - -
N 2 - - -
Other Solids - - -
Other Solutes - - -
Polylactic Acid - - -
Sodium Citrate - - -
Sulfuric Acid - - -
Water 0.0486057 0.651246 0.00669609
Xylitol - - -
Xylose - - -
Temperature (°C): 180 157.48 157.48

Design Data:

Shell Material SS304
Diameter 0.9144 meters
Height 3.6576 meters
Volume 2401.932948 liters
Design Temp 207.7777778
Operating Temp 180

Utilities (kW)
-27.71
Bare Module Cost: $ 27,900.00
Installation Cost: $ 173,500.00
Equipment Weight (lbs) 2,000.00
Installed Weight (lbs) 14,211.00

Comments:
**FLASH DRUM**

**Identification:**
- **Item:** PLA/Ether Flash
- **Item No.:** S-12
- **No. Required:** 1
- **Date:** 7 April 2017
- **By:** Group 7

**Function:** Separates the PLA from diphenyl ether solvent

**Operation:**

<table>
<thead>
<tr>
<th>Materials Handled</th>
<th>Mixed Feed</th>
<th>Distillate</th>
<th>Bottoms</th>
<th>Stream 2</th>
<th>Stream 3</th>
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</thead>
<tbody>
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</tr>
<tr>
<td>Ammonium Hydr.</td>
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</tr>
<tr>
<td>Ca(OH)₂</td>
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</tr>
<tr>
<td>CaSO₄</td>
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<tr>
<td>Cellulose Solid</td>
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<tr>
<td>CH₂Cl₂</td>
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<td>Lactic Acid</td>
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<tr>
<td>Methanol</td>
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<tr>
<td>N₂</td>
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<tr>
<td>Other Solids</td>
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<tr>
<td>Other Solutes</td>
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<tr>
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<tr>
<td>Sulfuric Acid</td>
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<td>Xylose</td>
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<tr>
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<td>288</td>
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<td></td>
</tr>
</tbody>
</table>

**Design Data:**

- Shell Material SS304
- Diameter: 0.9144 meters
- Height: 3.6576 meters
- Volume: 2401.932948 liters
- Design Temp: 315.7777778
- Operating Temp: 288

**Utilities (kW):**
- No Utilities

**Bare Module Cost:** $27,900.00

**Installation Cost:** $185,600.00

**Equipment Weight (lbs):** 2,000.00

**Installed Weight (lbs):** 15,391.00

**Comments:**
DECANTER

Identification: Item: Water/Ether Decant
Item No. S-11
No. Required 1
Date: 7 April 2017
By: Group 7

Function: Separates water and diphenyl ether so that each can be recycled

Operation:

Materials Handled:

<table>
<thead>
<tr>
<th>Material</th>
<th>Mixed Feed</th>
<th>Ether Out</th>
<th>Water Out</th>
<th>Stream 2</th>
<th>Stream 3</th>
</tr>
</thead>
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<tr>
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<tr>
<td>Ammonium Hydr.</td>
<td>-</td>
<td>-</td>
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</tr>
<tr>
<td>Ca(OH)₂</td>
<td>-</td>
<td>-</td>
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</tr>
<tr>
<td>CaSO₄</td>
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<tr>
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<tr>
<td>CH₂Cl₂</td>
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<tr>
<td>Enzymes</td>
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<tr>
<td>Lactic Acid</td>
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<td>-</td>
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<tr>
<td>N₂</td>
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<td>Other Solutes</td>
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<tr>
<td>Polylactic Acid</td>
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<tr>
<td>Sodium Citrate</td>
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<td>0.737564</td>
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<td>-</td>
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</tr>
<tr>
<td>Xylose</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temperature (°C):</td>
<td>90</td>
<td>90</td>
<td>90</td>
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Design Data:

- Shell Material SS304
- Diameter 0.9144 m
- Height 3.6576 m
- Volume 2401.932948 liters
- Design Temp 121.111111
- Operating Temp 90

Utilities (kW): 8.5805
Bare Module Cost: $27,700.00
Installation Cost: $170,800.00
Comments:
# AGITATED REACTOR

<table>
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<tr>
<th>Identification:</th>
<th>Item: Acid Hydrolysis</th>
<th>Date: 7 April 2017</th>
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</thead>
<tbody>
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<td>Item No.</td>
<td>R-7</td>
<td>No. Required: 1</td>
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<tr>
<td>By: Group 7</td>
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**Function:** Performs acid hydrolysis to break down hemicellulose in the BSG

**Operation:**

**Materials Handled:**

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<th>BSG Feed</th>
<th>Acid Feed</th>
<th>Exit Stream</th>
<th>Stream 2</th>
<th>Stream 3</th>
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</thead>
<tbody>
<tr>
<td>Quantity (kg/day):</td>
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<td>2351</td>
<td>518683</td>
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<tr>
<td>Ammonium Hydr.</td>
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<td>-</td>
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<td></td>
</tr>
<tr>
<td>Ca(OH)₂</td>
<td>-</td>
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<td></td>
</tr>
<tr>
<td>CaSO₄</td>
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<td>-</td>
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<tr>
<td>Cellulose Solid</td>
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<td>0.0295048</td>
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<td>CH₂Cl₂</td>
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<tr>
<td>Enzymes</td>
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<tr>
<td>Diphenyl Ether</td>
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<tr>
<td>Ferment. Sugars</td>
<td>3.51194E-05</td>
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<tr>
<td>Methanol</td>
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<tr>
<td>N₂</td>
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<td>-</td>
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<tr>
<td>Xylose</td>
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<td>-</td>
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<tr>
<td>Temperature (°C):</td>
<td>150</td>
<td>25</td>
<td>150</td>
<td></td>
</tr>
</tbody>
</table>

**Design Data:**

| Residence Time | 1.5 hours |
| Shell Material | SS304 |
| Diameter | 2.1336 meters |
| Height | 7.9248 meters |
| Volume | 28333.91261 liters |

**Utilities (kW):**

| Bare Module Cost: | $378,500.00 |
| Installation Cost: | $620,000.00 |

**Comments and Drawings:** Design temperature of 178°C
### AGITATED REACTOR

**Identification:**
- **Item:** Sacchar. Reactor
- **Item No.:** R-4
- **No. Required:** 1
- **Date:** 7 April 2017
- **By:** Group 7

**Function:**
Uses enzymes to convert the cellulose in BSG to glucose for lactic acid process

**Operation:**

**Materials Handled:**

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<tr>
<th></th>
<th>Solids Feed</th>
<th>Na Citr. Feed</th>
<th>Enzyme Feed</th>
<th>Exit Stream</th>
<th>Stream 3</th>
</tr>
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<tbody>
<tr>
<td>Quantity (kg/day):</td>
<td>399133</td>
<td>5201</td>
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<td>Ca(OH)₂</td>
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</tr>
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<td>CaSO₄</td>
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<td></td>
</tr>
<tr>
<td>Cellulose Solid</td>
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<td>-</td>
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</tr>
<tr>
<td>CH₂Cl₂</td>
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<td>0.0373114</td>
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</tr>
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</tr>
<tr>
<td>N₂</td>
<td>-</td>
<td>-</td>
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<tr>
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<td>-</td>
<td>-</td>
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</tr>
<tr>
<td>Temperature (°C):</td>
<td>64.7913</td>
<td>25</td>
<td>25</td>
<td>25</td>
<td></td>
</tr>
</tbody>
</table>

**Design Data:**
- Residence Time 1.5 hours
- Shell Material SS304
- Diameter 1.0668 meters
- Height 4.1148 meters
- Volume 3677.959802 liters

**Utilities (kW):**
- No Utilities

**Bare Module Cost:** $115,100.00
**Installation Cost:** $290,900.00

**Equipment Weight (lbs):** 9,400.00
**Installed Weight (lbs):** 24,684.00

**Comments:**
**AGITATED REACTOR**

<table>
<thead>
<tr>
<th>Identification:</th>
<th>Item:</th>
<th><strong>AAS Reactor</strong></th>
<th>Date: 7 April 2017</th>
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<tbody>
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<td>Item No.</td>
<td>R-3</td>
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<tr>
<td>No. Required</td>
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</tr>
<tr>
<td>By:</td>
<td>Group 7</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Function:** Treats the cellulose solids in BSG so that they can be broken down by enzymes

**Operation:**

<table>
<thead>
<tr>
<th>Materials Handled:</th>
<th>Cell. Feed</th>
<th>Ammonia Feed</th>
<th>Exit Stream</th>
<th>Stream 2</th>
<th>Stream 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quantity (kg/day):</td>
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<td>29990</td>
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<td>CaSO₄</td>
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<tr>
<td>Diphenyl Ether</td>
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<tr>
<td>Ferment. Sugars</td>
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<td>Methanol</td>
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<td>N₂</td>
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<td>Sulfuric Acid</td>
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<td>70</td>
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</table>

**Design Data:**

- Residence Time 1.5 hours
- Shell Material SS304
- Diameter 2.286 meters
- Height 8.5344 meters
- Volume 35028.18866 liters

**Utilities (kW):**

- 1988.8

**Bare Module Cost:** $408,300.00

**Equipment Weight (lbs):** 57,800.00

**Installation Cost:** $649,600.00

**Installed Weight (lbs):** 84,050.00

**Comments:** Design temperature of 178°C
## AGITATED REACTOR

<table>
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<tbody>
<tr>
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<td>R-1</td>
<td>No. Required 1</td>
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</table>

**Function:** Neutralizes the sulfuric acid introduced in acid hydrolysis to raise pH to 2.5

**Operation:**

<table>
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<th>CaOH2 Feed</th>
<th>Exit Stream</th>
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<th>Stream 3</th>
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<tbody>
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</tr>
<tr>
<td>CH(_2)Cl(_2)</td>
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</tr>
<tr>
<td>Enzymes</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
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</tr>
<tr>
<td>Diphenyl Ether</td>
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<tr>
<td>Other Solutes</td>
<td>0.17977</td>
<td>-</td>
<td>0.1721</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Polylactic Acid</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sodium Citrate</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sulfuric Acid</td>
<td>0.00814949</td>
<td>-</td>
<td>0.000447262</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td>0.733856</td>
<td>0.862935</td>
<td>0.742066</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Xylitol</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Xylose</td>
<td>0.0781123</td>
<td>-</td>
<td>0.0747794</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Temperature (°C): | 102.776 | 25 | 25 |

**Design Data:**

- Residence Time: 1.5 hours
- Shell Material: SS304
- Diameter: 0.762 meters
- Height: 3.5052 meters
- Volume: 1598.50861 liters

**Utilities (kW):** -745.51

- Bare Module Cost: $98,700.00 Equipment Weight (lbs): 6,000.00
- Installation Cost: $270,800.00 Installed Weight (lbs): 20,352.00

**Comments:** Design temperature of 178 C
1. PRODUCT AND COMPANY IDENTIFICATION

1.1 Product identifiers

Product name: Calcium hydroxide

Product Number: 31219
Brand: Sigma-Aldrich

CAS-No.: 1305-62-0

1.2 Relevant identified uses of the substance or mixture and uses advised against

Identified uses: Laboratory chemicals, Synthesis of substances

1.3 Details of the supplier of the safety data sheet

Company: Sigma-Aldrich
3050 Spruce Street
SAINT LOUIS MO 63103 USA

Telephone: +1 800-325-5832
Fax: +1 800-325-5052

1.4 Emergency telephone number

Emergency Phone #: +1-703-527-3887 ( CHEMTREC)

2. HAZARDS IDENTIFICATION

2.1 Classification of the substance or mixture

GHS Classification in accordance with 29 CFR 1910 (OSHA HCS)
Skin irritation (Category 2), H315
Serious eye damage (Category 1), H318
Specific target organ toxicity - single exposure (Category 3), Respiratory system, H335
Acute aquatic toxicity (Category 3), H402

For the full text of the H-Statements mentioned in this Section, see Section 16.

2.2 GHS Label elements, including precautionary statements

Pictogram

Signal word: Danger
Hazard statement(s)
H315 Causes skin irritation.
H318 Causes serious eye damage.
H335 May cause respiratory irritation.
H402 Harmful to aquatic life.

Precautionary statement(s)
P261 Avoid breathing dust/ fume/ gas/ mist/ vapours/ spray.
P264 Wash skin thoroughly after handling.
P271 Use only outdoors or in a well-ventilated area.
P273 Avoid release to the environment.
P280 Wear eye protection/ face protection.
P280 Wear protective gloves.
P302 + P352 IF ON SKIN: Wash with plenty of soap and water.
P304 + P340 + P312 IF INHALED: Remove victim to fresh air and keep at rest in a position comfortable for breathing. Call a POISON CENTER or doctor/ physician if you feel unwell.
P305 + P351 + P338 + P310 IF IN EYES: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing. Immediately call a POISON CENTER/doctor.
P332 + P313 If skin irritation occurs: Get medical advice/ attention.
P362 Take off contaminated clothing and wash before reuse.
P403 + P233 Store in a well-ventilated place. Keep container tightly closed.
P405 Store locked up.
P501 Dispose of contents/ container to an approved waste disposal plant.

2.3 Hazards not otherwise classified (HNOC) or not covered by GHS - none

3. COMPOSITION/INFORMATION ON INGREDIENTS

3.1 Substances

<table>
<thead>
<tr>
<th>Formula</th>
<th>H₂CaO₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>Molecular weight</td>
<td>74.09 g/mol</td>
</tr>
<tr>
<td>CAS-No.</td>
<td>1305-62-0</td>
</tr>
<tr>
<td>EC-No.</td>
<td>215-137-3</td>
</tr>
</tbody>
</table>

Hazardous components

<table>
<thead>
<tr>
<th>Component</th>
<th>Classification</th>
<th>Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcium dihydroxide</td>
<td>Skin Irrit. 2; Eye Dam. 1; STOT SE 3; Aquatic Acute 3; H315, H318, H335, H402</td>
<td>&lt;= 100 %</td>
</tr>
</tbody>
</table>

For the full text of the H-Statements mentioned in this Section, see Section 16.

4. FIRST AID MEASURES

4.1 Description of first aid measures

General advice
Consult a physician. Show this safety data sheet to the doctor in attendance. Move out of dangerous area.

If inhaled
If breathed in, move person into fresh air. If not breathing, give artificial respiration. Consult a physician.

In case of skin contact
Wash off with soap and plenty of water. Consult a physician.

In case of eye contact
Rinse thoroughly with plenty of water for at least 15 minutes and consult a physician.

If swallowed
Never give anything by mouth to an unconscious person. Rinse mouth with water. Consult a physician.
4.2 Most important symptoms and effects, both acute and delayed
The most important known symptoms and effects are described in the labelling (see section 2.2) and/or in section 11.

4.3 Indication of any immediate medical attention and special treatment needed
No data available

5. FIREFIGHTING MEASURES
5.1 Extinguishing media Suitable

- Extinguishing media
  Use water spray, alcohol-resistant foam, dry chemical or carbon dioxide.

5.2 Special hazards arising from the substance or mixture
No data available

5.3 Advice for firefighters
Wear self-contained breathing apparatus for firefighting if necessary.

5.4 Further information
No data available

6. ACCIDENTAL RELEASE MEASURES
6.1 Personal precautions, protective equipment and emergency procedures
Use personal protective equipment. Avoid dust formation. Avoid breathing vapours, mist or gas. Ensure adequate ventilation. Evacuate personnel to safe areas. Avoid breathing dust. For personal protection see section 8.

6.2 Environmental precautions
Prevent further leakage or spillage if safe to do so. Do not let product enter drains. Discharge into the environment must be avoided.

6.3 Methods and materials for containment and cleaning up
Pick up and arrange disposal without creating dust. Sweep up and shovel. Keep in suitable, closed containers for disposal.

6.4 Reference to other sections
For disposal see section 13.

7. HANDLING AND STORAGE
7.1 Precautions for safe handling
Avoid contact with skin and eyes. Avoid formation of dust and aerosols. Further processing of solid materials may result in the formation of combustible dusts. The potential for combustible dust formation should be taken into consideration before additional processing occurs. Provide appropriate exhaust ventilation at places where dust is formed. For precautions see section 2.2.

7.2 Conditions for safe storage, including any incompatibilities
Keep container tightly closed in a dry and well-ventilated place.

- Air and moisture sensitive. Keep in a dry place.
- Storage class (TRGS 510): Non Combustible Solids

7.3 Specific end use(s)
Apart from the uses mentioned in section 1.2 no other specific uses are stipulated

8. EXPOSURE CONTROLS/PERSONAL PROTECTION
8.1 Control parameters
Components with workplace control parameters
<table>
<thead>
<tr>
<th>Component</th>
<th>CAS-No.</th>
<th>Value</th>
<th>Control parameters</th>
<th>Basis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcium dihydroxide</td>
<td>1305-62-0</td>
<td>TWA</td>
<td>5 mg/m³</td>
<td>USA. ACGIH Threshold Limit Values (TLV)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Remarks</td>
<td>Upper Respiratory Tract irritation Eye irritation</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>TWA</td>
<td>5.000000 mg/m³</td>
<td>USA. ACGIH Threshold Limit Values (TLV)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Upper Respiratory Tract irritation Eye irritation</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>TWA</td>
<td>15.000000 mg/m³</td>
<td>USA. Occupational Exposure Limits (OSHA) - Table Z-1 Limits for Air Contaminants</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>USA. NIOSH Recommended Exposure Limits</td>
</tr>
<tr>
<td></td>
<td></td>
<td>PEL</td>
<td>5 mg/m³</td>
<td>California permissible exposure limits for chemical contaminants (Title 8, Article 107)</td>
</tr>
</tbody>
</table>

### 8.2 Exposure controls

**Appropriate engineering controls**  
Handle in accordance with good industrial hygiene and safety practice. Wash hands before breaks and at the end of workday.

**Personal protective equipment**  
**Eye/face protection**  
Face shield and safety glasses. Use equipment for eye protection tested and approved under appropriate government standards such as NIOSH (US) or EN 166(EU).

**Skin protection**  
Handle with gloves. Gloves must be inspected prior to use. Use proper glove removal technique (without touching glove's outer surface) to avoid skin contact with this product. Dispose of contaminated gloves after use in accordance with applicable laws and good laboratory practices. Wash and dry hands.

**Full contact**  
*Material:* Nitrile rubber  
Minimum layer thickness: 0.11 mm  
Break through time: 480 min  
Material tested: Dermatril® (KCL 740 / Aldrich Z677272, Size M)

**Splash contact**  
*Material:* Nitrile rubber  
Minimum layer thickness: 0.11 mm  
Break through time: 480 min  
Material tested: Dermatril® (KCL 740 / Aldrich Z677272, Size M)

data source: KCL GmbH, D-36124 Eichenzell, phone +49 (0)6659 87300, e-mail sales@kcl.de, test method: EN374  
If used in solution, or mixed with other substances, and under conditions which differ from EN 374, contact the supplier of the CE approved gloves. This recommendation is advisory only and must be evaluated by an industrial hygienist and safety officer familiar with the specific situation of anticipated use by our customers. It should not be construed as offering an approval for any specific use scenario.

**Body Protection**  
Complete suit protecting against chemicals. The type of protective equipment must be selected according to
the concentration and amount of the dangerous substance at the specific workplace.

**Respiratory protection**
Where risk assessment shows air-purifying respirators are appropriate use a full-face particle respirator type N100 (US) or type P3 (EN 143) respirator cartridges as a backup to engineering controls. If the respirator is the sole means of protection, use a full-face supplied air respirator. Use respirators and components tested and approved under appropriate government standards such as NIOSH (US) or CEN (EU).

**Control of environmental exposure**
Prevent further leakage or spillage if safe to do so. Do not let product enter drains. Discharge into the environment must be avoided.

### 9. PHYSICAL AND CHEMICAL PROPERTIES

#### 9.1 Information on basic physical and chemical properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) Appearance</td>
<td>Form: powder</td>
</tr>
<tr>
<td></td>
<td>Colour: beige</td>
</tr>
<tr>
<td>b) Odour</td>
<td>No data available</td>
</tr>
<tr>
<td>c) Odour Threshold</td>
<td>No data available</td>
</tr>
<tr>
<td>d) pH</td>
<td>12.4 - 12.6 at 20 °C (68 °F)</td>
</tr>
<tr>
<td>e) Melting point/freezing point</td>
<td>&gt;= 450 °C (&gt;= 842 °F)</td>
</tr>
<tr>
<td>f) Initial boiling point and boiling range</td>
<td>No data available</td>
</tr>
<tr>
<td>g) Flash point</td>
<td>Not applicable</td>
</tr>
<tr>
<td>h) Evaporation rate</td>
<td>No data available</td>
</tr>
<tr>
<td>i) Flammability (solid, gas)</td>
<td>The product is not flammable.</td>
</tr>
<tr>
<td>j) Upper/lower flammability or explosive limits</td>
<td>No data available</td>
</tr>
<tr>
<td>k) Vapour pressure</td>
<td>No data available</td>
</tr>
<tr>
<td>l) Vapour density</td>
<td>No data available</td>
</tr>
<tr>
<td>m) Relative density</td>
<td>2.24 g/cm3 at 25 °C (77 °F)</td>
</tr>
<tr>
<td>n) Water solubility</td>
<td>0.99 g/l at 20 °C (68 °F)</td>
</tr>
<tr>
<td>o) Partition coefficient: n-octanol/water</td>
<td>No data available</td>
</tr>
<tr>
<td>p) Auto-ignition temperature</td>
<td>No data available</td>
</tr>
<tr>
<td>q) Decomposition temperature</td>
<td>No data available</td>
</tr>
</tbody>
</table>
r) Viscosity No data available
s) Explosive properties No data available
t) Oxidizing properties The substance or mixture is not classified as oxidizing.

9.2 Other safety information

Bulk density 200 - 800 kg/m³

10. STABILITY AND REACTIVITY

10.1 Reactivity
No data available

10.2 Chemical stability
Stable under recommended storage conditions.

10.3 Possibility of hazardous reactions
No data available

10.4 Conditions to avoid
No data available

10.5 Incompatible materials
Strong acids

10.6 Hazardous decomposition products
Hazardous decomposition products formed under fire conditions. - Calcium oxide
Other decomposition products - No data available
In the event of fire: see section 5

11. TOXICOLOGICAL INFORMATION

11.1 Information on toxicological effects

Acute toxicity
LD₅₀ Oral - Rat - 7,340 mg/kg
Inhalation: No data available
No data available

Skin corrosion/irritation
Skin - Rabbit
Result: Irritating to skin.
(OECD Test Guideline 404)

Serious eye damage/eye irritation
Eyes - Rabbit
Result: Severe eye irritation
(OECD Test Guideline 405)

Respiratory or skin sensitisation
No data available

Germ cell mutagenicity
No data available

Carcinogenicity

IARC: No component of this product present at levels greater than or equal to 0.1% is identified as probable, possible or confirmed human carcinogen by IARC.

NTP: No component of this product present at levels greater than or equal to 0.1% is identified as a known or anticipated carcinogen by NTP.
OSHA: No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by OSHA.

Reproductive toxicity
No data available

Specific target organ toxicity - single exposure
Inhalation - May cause respiratory irritation.

Specific target organ toxicity - repeated exposure
No data available

Aspiration hazard
No data available

Additional Information
RTECS: EW2800000

12. ECOLOGICAL INFORMATION

12.1 Toxicity
Toxicity to fish
LC50 - Clarias gariepinus - 33.884 mg/l - 96 h

Toxicity to daphnia and other aquatic invertebrates
EC50 - Daphnia magna (Water flea) - 49.1 mg/l - 48 h
(OECD Test Guideline 202)
12.2 Persistence and degradability
The methods for determining biodegradability are not applicable to inorganic substances.

12.3 Bioaccumulative potential
Does not bioaccumulate.

12.4 Mobility in soil
No data available

12.5 Results of PBT and vPvB assessment
PBT/vPvB assessment not available as chemical safety assessment not required/not conducted

12.6 Other adverse effects
An environmental hazard cannot be excluded in the event of unprofessional handling or disposal. Harmful to aquatic life.
No data available

13. DISPOSAL CONSIDERATIONS

13.1 Waste treatment methods
Product
Offer surplus and non-recyclable solutions to a licensed disposal company. Contact a licensed professional waste disposal service to dispose of this material.

Contaminated packaging
Dispose of as unused product.

14. TRANSPORT INFORMATION

DOT (US)
Not dangerous goods

IMDG
Not dangerous goods

IATA
Not dangerous goods

15. REGULATORY INFORMATION

SARA 302 Components
No chemicals in this material are subject to the reporting requirements of SARA Title III, Section 302.

SARA 313 Components
This material does not contain any chemical components with known CAS numbers that exceed the threshold (De Minimis) reporting levels established by SARA Title III, Section 313.

SARA 311/312 Hazards
Acute Health Hazard

Massachusetts Right To Know Components
Calcium dihydroxide

Pennsylvania Right To Know Components
Calcium dihydroxide

New Jersey Right To Know Components
Calcium dihydroxide

California Prop. 65 Components
<table>
<thead>
<tr>
<th>CAS-No. 1305-62-0</th>
<th>Revision Date</th>
<th>94-04-01</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAS-No. 1305-62-0</td>
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<td></td>
</tr>
<tr>
<td>CAS-No. 1305-62-0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
This product does not contain any chemicals known to State of California to cause cancer, birth defects, or any other reproductive harm.

16. OTHER INFORMATION

Full text of H-Statements referred to under sections 2 and 3.

Aquatic Acute: Acute aquatic toxicity
Eye Dam.: Serious eye damage
H315: Causes skin irritation.
H318: Causes serious eye damage.
H335: May cause respiratory irritation.
H402: Harmful to aquatic life.
Skin Irrit.: Skin irritation
STOT SE: Specific target organ toxicity - single exposure

HMIS Rating

<table>
<thead>
<tr>
<th>Category</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Health hazard:</td>
<td>2</td>
</tr>
<tr>
<td>Chronic Health Hazard:</td>
<td>0</td>
</tr>
<tr>
<td>Flammability:</td>
<td>0</td>
</tr>
<tr>
<td>Physical Hazard:</td>
<td>0</td>
</tr>
</tbody>
</table>

NFPA Rating

<table>
<thead>
<tr>
<th>Category</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Health hazard:</td>
<td>2</td>
</tr>
<tr>
<td>Fire Hazard:</td>
<td>0</td>
</tr>
<tr>
<td>Reactivity Hazard:</td>
<td>0</td>
</tr>
</tbody>
</table>

Further information

Copyright 2016 Sigma-Aldrich Co. LLC. License granted to make unlimited paper copies for internal use only. The above information is believed to be correct but does not purport to be all inclusive and shall be used only as a guide. The information in this document is based on the present state of our knowledge and is applicable to the product with regard to appropriate safety precautions. It does not represent any guarantee of the properties of the product. Sigma-Aldrich Corporation and its Affiliates shall not be held liable for any damage resulting from handling or from contact with the above product. See www.sigma-aldrich.com and/or the reverse side of invoice or packing slip for additional terms and conditions of sale.

Preparation Information

Sigma-Aldrich Corporation
Product Safety – Americas Region
1-800-521-8956

Version: 4.9 Revision Date: 05/27/2016 Print Date: 03/19/2017
1. PRODUCT AND COMPANY IDENTIFICATION

1.1 Product identifiers
Product name: Calcium hydroxide
Product Number: 31219
Brand: Sigma-Aldrich
CAS-No.: 1305-62-0

1.2 Relevant identified uses of the substance or mixture and uses advised against
Identified uses: Laboratory chemicals, Synthesis of substances

1.3 Details of the supplier of the safety data sheet
Company: Sigma-Aldrich
3050 Spruce Street
SAINT LOUIS MO 63103
USA
Telephone: +1 800-325-5832
Fax: +1 800-325-5052

1.4 Emergency telephone number
Emergency Phone #: +1-703-527-3887 (CHEMTREC)

2. HAZARDS IDENTIFICATION

2.1 Classification of the substance or mixture
GHS Classification in accordance with 29 CFR 1910 (OSHA HCS)
Skin irritation (Category 2), H315
Serious eye damage (Category 1), H318
Specific target organ toxicity - single exposure (Category 3), Respiratory system, H335
Acute aquatic toxicity (Category 3), H402

For the full text of the H-Statements mentioned in this Section, see Section 16.

2.2 GHS Label elements, including precautionary statements
Pictogram

Signal word: Danger
Hazard statement(s):
H315 Causes skin irritation.
H318 Causes serious eye damage.
H335 May cause respiratory irritation.
H402 Harmful to aquatic life.

Precautionary statement(s)

P261 Avoid breathing dust/ fume/ gas/ mist/ vapours/ spray.
P264 Wash skin thoroughly after handling.
P271 Use only outdoors or in a well-ventilated area.
P273 Avoid release to the environment.
P280 Wear eye protection/ face protection.
P280 Wear protective gloves.
P302 + P352 IF ON SKIN: Wash with plenty of soap and water.
P304 + P340 + P312 IF INHALED: Remove victim to fresh air and keep at rest in a position comfortable for breathing. Call a POISON CENTER or doctor/ physician if you feel unwell.
P305 + P351 + P338 + P310 IF IN EYES: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing. Immediately call a POISON CENTER/doctor.
P332 + P313 If skin irritation occurs: Get medical advice/ attention.
P362 Take off contaminated clothing and wash before reuse.
P403 + P233 Store in a well-ventilated place. Keep container tightly closed.
P405 Store locked up.
P501 Dispose of contents/ container to an approved waste disposal plant.

2.3 Hazards not otherwise classified (HNOC) or not covered by GHS - none

3. COMPOSITION/INFORMATION ON INGREDIENTS

3.1 Substances

Formula: \( \text{H}_2\text{CaO}_2 \)

Molecular weight: 74.09 g/mol

CAS-No.: 1305-62-0

EC-No.: 215-137-3

Hazardous components

<table>
<thead>
<tr>
<th>Component</th>
<th>Classification</th>
<th>Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcium dihydroxide</td>
<td>Skin Irrit. 2; Eye Dam. 1; STOT SE 3; Aquatic Acute 3; H315, H318, H335, H402</td>
<td>&lt;= 100 %</td>
</tr>
</tbody>
</table>

For the full text of the H-Statements mentioned in this Section, see Section 16.

4. FIRST AID MEASURES

4.1 Description of first aid measures

General advice
Consult a physician. Show this safety data sheet to the doctor in attendance. Move out of dangerous area.

If inhaled
If breathed in, move person into fresh air. If not breathing, give artificial respiration. Consult a physician.

In case of skin contact
Wash off with soap and plenty of water. Consult a physician.

In case of eye contact
Rinse thoroughly with plenty of water for at least 15 minutes and consult a physician.

If swallowed
Never give anything by mouth to an unconscious person. Rinse mouth with water. Consult a physician.

4.2 Most important symptoms and effects, both acute and delayed
The most important known symptoms and effects are described in the labelling (see section 2.2) and/or in section 11
4.3 Indication of any immediate medical attention and special treatment needed
No data available

5. FIREFIGHTING MEASURES

5.1 Extinguishing media Suitable
Extinguishing media
Use water spray, alcohol-resistant foam, dry chemical or carbon dioxide.

5.2 Special hazards arising from the substance or mixture
No data available

5.3 Advice for firefighters
Wear self-contained breathing apparatus for firefighting if necessary.

5.4 Further information
No data available

6. ACCIDENTAL RELEASE MEASURES

6.1 Personal precautions, protective equipment and emergency procedures
Use personal protective equipment. Avoid dust formation. Avoid breathing vapours, mist or gas. Ensure adequate ventilation. Evacuate personnel to safe areas. Avoid breathing dust. For personal protection see section 8.

6.2 Environmental precautions
Prevent further leakage or spillage if safe to do so. Do not let product enter drains. Discharge into the environment must be avoided.

6.3 Methods and materials for containment and cleaning up
Pick up and arrange disposal without creating dust. Sweep up and shovel. Keep in suitable, closed containers for disposal.

6.4 Reference to other sections
For disposal see section 13.

7. HANDLING AND STORAGE

7.1 Precautions for safe handling
Avoid contact with skin and eyes. Avoid formation of dust and aerosols. Further processing of solid materials may result in the formation of combustible dusts. The potential for combustible dust formation should be taken into consideration before additional processing occurs. Provide appropriate exhaust ventilation at places where dust is formed. For precautions see section 2.2.

7.2 Conditions for safe storage, including any incompatibilities
Keep container tightly closed in a dry and well-ventilated place.
Air and moisture sensitive. Keep in a dry place.
Storage class (TRGS 510): Non Combustible Solids

7.3 Specific end use(s)
Apart from the uses mentioned in section 1.2 no other specific uses are stipulated

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

8.1 Control parameters
Components with workplace control parameters

<table>
<thead>
<tr>
<th>Component</th>
<th>CAS-No.</th>
<th>Value</th>
<th>Control parameters</th>
<th>Basis</th>
</tr>
</thead>
</table>

159
Calcium dihydroxide  1305-62-0  TWA  5 mg/m³  USA. ACGIH Threshold Limit Values (TLV)

Remarks  Upper Respiratory Tract irritation  Eye irritation  Skin irritation

TWA  5.000000 mg/m³  USA. ACGIH Threshold Limit Values (TLV)

Upper Respiratory Tract irritation  Eye irritation  Skin irritation

TWA  15.000000 mg/m³  USA. Occupational Exposure Limits (OSHA) - Table Z-1 Limits for Air Contaminants

TWA  5.000000 mg/m³  USA. Occupational Exposure Limits (OSHA) - Table Z-1 Limits for Air Contaminants

TWA  5.000000 mg/m³  USA. NIOSH Recommended Exposure Limits

PEL  5 mg/m³  California permissible exposure limits for chemical contaminants (Title 8, Article 107)

8.2 Exposure controls

Appropriate engineering controls
Handle in accordance with good industrial hygiene and safety practice. Wash hands before breaks and at the end of workday.

Personal protective equipment
Eye/face protection
Face shield and safety glasses Use equipment for eye protection tested and approved under appropriate government standards such as NIOSH (US) or EN 166(EU).

Skin protection
Handle with gloves. Gloves must be inspected prior to use. Use proper glove removal technique (without touching glove's outer surface) to avoid skin contact with this product. Dispose of contaminated gloves after use in accordance with applicable laws and good laboratory practices. Wash and dry hands.

Full contact
Material: Nitrile rubber
Minimum layer thickness: 0.11 mm
Break through time: 480 min
Material tested: Dermatril® (KCL 740 / Aldrich Z677272, Size M)

Splash contact
Material: Nitrile rubber
Minimum layer thickness: 0.11 mm
Break through time: 480 min
Material tested: Dermatril® (KCL 740 / Aldrich Z677272, Size M)

data source: KCL GmbH, D-36124 Eichenzell, phone +49 (0)6659 87300, e-mail sales@kcl.de, test method: EN374

If used in solution, or mixed with other substances, and under conditions which differ from EN 374, contact the supplier of the CE approved gloves. This recommendation is advisory only and must be evaluated by an industrial hygienist and safety officer familiar with the specific situation of anticipated use by our customers. It should not be construed as offering an approval for any specific use scenario.

Body Protection
Complete suit protecting against chemicals, The type of protective equipment must be selected according to the concentration and amount of the dangerous substance at the specific workplace.
Respiratory protection
Where risk assessment shows air-purifying respirators are appropriate use a full-face particle respirator type N100 (US) or type P3 (EN 143) respirator cartridges as a backup to engineering controls. If the respirator is the sole means of protection, use a full-face supplied air respirator. Use respirators and components tested and approved under appropriate government standards such as NIOSH (US) or CEN (EU).

Control of environmental exposure
Prevent further leakage or spillage if safe to do so. Do not let product enter drains. Discharge into the environment must be avoided.

9. PHYSICAL AND CHEMICAL PROPERTIES

9.1 Information on basic physical and chemical properties

a) Appearance  
   Form: powder  
   Colour: beige

b) Odour  
   No data available

c) Odour Threshold  
   No data available

d) pH  
   12.4 - 12.6 at 20 °C (68 °F)

e) Melting point/freezing point  
   >= 450 °C (>= 842 °F)

f) Initial boiling point and boiling range  
   No data available

g) Flash point  
   Not applicable

h) Evaporation rate  
   No data available

i) Flammability (solid, gas)  
   The product is not flammable.

j) Upper/lower flammability or explosive limits  
   No data available

k) Vapour pressure  
   No data available

l) Vapour density  
   No data available

m) Relative density  
   2.24 g/cm³ at 25 °C (77 °F)

n) Water solubility  
   0.99 g/l at 20 °C (68 °F)

o) Partition coefficient: n-octanol/water  
   No data available

p) Auto-ignition temperature  
   No data available

q) Decomposition temperature  
   No data available
r) Viscosity No data available
s) Explosive properties No data available
t) Oxidizing properties The substance or mixture is not classified as oxidizing.

9.2 Other safety information

Bulk density 200-800 kg/m³

10. STABILITY AND REACTIVITY

10.1 Reactivity
No data available

10.2 Chemical stability
Stable under recommended storage conditions.

10.3 Possibility of hazardous reactions
No data available

10.4 Conditions to avoid
No data available

10.5 Incompatible materials
Strong acids

10.6 Hazardous decomposition products
Hazardous decomposition products formed under fire conditions.
Calcium oxide
No data available
In the event of fire: see section 5

11. TOXICOLOGICAL INFORMATION

11.1 Information on toxicological effects

Acute toxicity
LD₅₀ Oral - Rat - 7,340 mg/kg
Inhalation: No data available

Skin corrosion/irritation
Skin - Rabbit
Result: Irritating to skin.
(OECD Test Guideline 404)

Serious eye damage/eye irritation
Eyes - Rabbit
Result: Severe eye irritation
(OECD Test Guideline 405)

Respiratory or skin sensitisation
No data available

Germ cell mutagenicity
No data available

Carcinogenicity
IARC: No component of this product present at levels greater than or equal to 0.1% is identified as probable, possible or confirmed human carcinogen by IARC.
NTP: No component of this product present at levels greater than or equal to 0.1% is identified as a known or anticipated carcinogen by NTP.
OSHA: No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by OSHA.

Reproductive toxicity
No data available

Specific target organ toxicity - single exposure
Inhalation - May cause respiratory irritation.

Specific target organ toxicity - repeated exposure
No data available

Aspiration hazard
No data available

Additional Information
RTECS: EW2800000

12. ECOLOGICAL INFORMATION

12.1 Toxicity

Toxicity to fish
LC50 - Clarias gariepinus - 33.884 mg/l - 96 h

Toxicity to daphnia and other aquatic invertebrates
EC50 - Daphnia magna (Water flea) - 49.1 mg/l - 48 h (OECD Test Guideline 202)
Toxicity to algae: EC50 - Pseudokirchneriella subcapitata (green algae) - 184.6 mg/l - 72 h (OECD Test Guideline 201)

12.2 Persistence and degradability
The methods for determining biodegradability are not applicable to inorganic substances.

12.3 Bioaccumulative potential
Does not bioaccumulate.

12.4 Mobility in soil
No data available

12.5 Results of PBT and vPvB assessment
PBT/vPvB assessment not available as chemical safety assessment not required/not conducted

12.6 Other adverse effects
An environmental hazard cannot be excluded in the event of unprofessional handling or disposal. Harmful to aquatic life.
No data available

13. DISPOSAL CONSIDERATIONS

13.1 Waste treatment methods

Product
Offer surplus and non-recyclable solutions to a licensed disposal company. Contact a licensed professional waste disposal service to dispose of this material.

Contaminated packaging
Dispose of as unused product.

14. TRANSPORT INFORMATION

DOT (US)
Not dangerous goods

IMDG
Not dangerous goods

IATA
Not dangerous goods

15. REGULATORY INFORMATION

SARA 302 Components
No chemicals in this material are subject to the reporting requirements of SARA Title III, Section 302.

SARA 313 Components
This material does not contain any chemical components with known CAS numbers that exceed the threshold (De Minimis) reporting levels established by SARA Title III, Section 313.

SARA 311/312 Hazards
Acute Health Hazard

Massachusetts Right To Know Components
Calcium dihydroxide

Pennsylvania Right To Know Components
Calcium dihydroxide

New Jersey Right To Know Components
Calcium dihydroxide

California Prop. 65 Components
Calcium
CAS-No. 1305-62-0

Revision Date 1994-04-01

CAS-No. 1305-62-0

Revision Date 1994-04-01

CAS-No. 1305-62-0

Revision Date 1994-04-01
This product does not contain any chemicals known to State of California to cause cancer, birth defects, or any other reproductive harm.

16. OTHER INFORMATION

Full text of H-Statements referred to under sections 2 and 3.

Aquatic Acute  Acute aquatic toxicity
Eye Dam.  Serious eye damage
H315  Causes skin irritation.
H318  Causes serious eye damage.
H335  May cause respiratory irritation.
H402  Harmful to aquatic life.
Skin Irrit.  Skin irritation
STOT SE  Specific target organ toxicity - single exposure

HMIS Rating

<table>
<thead>
<tr>
<th></th>
<th>2</th>
<th>0</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Health hazard:</td>
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</tr>
<tr>
<td>Chronic Health Hazard:</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Flammability:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Physical Hazard</td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

NFPA Rating

<table>
<thead>
<tr>
<th></th>
<th>2</th>
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<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Health hazard:</td>
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<td></td>
</tr>
<tr>
<td>Fire Hazard:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reactivity Hazard:</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Further information

Copyright 2016 Sigma-Aldrich Co. LLC. License granted to make unlimited paper copies for internal use only. The above information is believed to be correct but does not purport to be all inclusive and shall be used only as a guide. The information in this document is based on the present state of our knowledge and is applicable to the product with regard to appropriate safety precautions. It does not represent any guarantee of the properties of the product. Sigma-Aldrich Corporation and its Affiliates shall not be held liable for any damage resulting from handling or from contact with the above product. See www.sigma-aldrich.com and/or the reverse side of invoice or packing slip for additional terms and conditions of sale.

Preparation Information

Sigma-Aldrich Corporation
Product Safety – Americas Region
1-800-521-8956

Version: 4.9  Revision Date: 05/27/2016  Print Date: 03/23/2017
1. PRODUCT AND COMPANY IDENTIFICATION

1.1 Product identifiers

Product name: Calcium sulfate dihydrate
Product Number: C3771
Brand: Sigma-Aldrich
CAS-No.: 10101-41-4

1.2 Relevant identified uses of the substance or mixture and uses advised against

Identified uses: Laboratory chemicals, Synthesis of substances

1.3 Details of the supplier of the safety data sheet

Company: Sigma-Aldrich
3050 Spruce Street
SAINT LOUIS MO 63103
USA

Telephone: +1 800-325-5832
Fax: +1 800-325-5052

1.4 Emergency telephone number

Emergency Phone #: +1-703-527-3887 (CHEMTREC)

2. HAZARDS IDENTIFICATION

2.1 Classification of the substance or mixture

Not a hazardous substance or mixture.

2.2 GHS Label elements, including precautionary statements

Not a hazardous substance or mixture.

2.3 Hazards not otherwise classified (HNOC) or not covered by GHS - none

3. COMPOSITION/INFORMATION ON INGREDIENTS

3.1 Substances

<table>
<thead>
<tr>
<th>Substance</th>
<th>Formula</th>
<th>Molecular weight</th>
<th>CAS-No.</th>
<th>EC-No.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CaO₄S · 2H₂O</td>
<td>172.17 g/mol</td>
<td>10101-41-4</td>
<td>231-900-3</td>
</tr>
</tbody>
</table>

Hazardous components

<table>
<thead>
<tr>
<th>Component</th>
<th>Classification</th>
<th>Concentration</th>
</tr>
</thead>
</table>
4. FIRST AID MEASURES

4.1 Description of first aid measures If

inhaled
If breathed in, move person into fresh air. If not breathing, give artificial respiration.

In case of skin contact
Wash off with soap and plenty of water.

In case of eye contact
Flush eyes with water as a precaution.

If swallowed
Never give anything by mouth to an unconscious person. Rinse mouth with water.

4.2 Most important symptoms and effects, both acute and delayed
The most important known symptoms and effects are described in the labelling (see section 2.2) and/or in section 11

4.3 Indication of any immediate medical attention and special treatment needed
No data available

5. FIREFIGHTING MEASURES

5.1 Extinguishing media Suitable

extinguishing media
Use water spray, alcohol-resistant foam, dry chemical or carbon dioxide.

5.2 Special hazards arising from the substance or mixture
Sulphur oxides, Calcium oxide

5.3 Advice for firefighters
Wear self-contained breathing apparatus for firefighting if necessary.

5.4 Further information
No data available

6. ACCIDENTAL RELEASE MEASURES

6.1 Personal precautions, protective equipment and emergency procedures
Avoid dust formation. Avoid breathing vapours, mist or gas.
For personal protection see section 8.

6.2 Environmental precautions
Do not let product enter drains.

6.3 Methods and materials for containment and cleaning up
Sweep up and shovel. Keep in suitable, closed containers for disposal.

6.4 Reference to other sections
For disposal see section 13.

7. HANDLING AND STORAGE

7.1 Precautions for safe handling
Provide appropriate exhaust ventilation at places where dust is formed.
For precautions see section 2.2.

7.2 Conditions for safe storage, including any incompatibilities
Keep container tightly closed in a dry and well-ventilated place.
7.3 Specific end use(s)
Apart from the uses mentioned in section 1.2 no other specific uses are stipulated.

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

8.1 Control parameters

Components with workplace control parameters

<table>
<thead>
<tr>
<th>Component</th>
<th>CAS-No.</th>
<th>Value</th>
<th>Control parameters</th>
<th>Basis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcium sulfate</td>
<td>10101-41-4</td>
<td>TWA</td>
<td>15.000000 mg/m³</td>
<td>USA. Occupational Exposure Limits (OSHA) - Table Z-1 Limits for Air Contaminants</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TWA</td>
<td>5.000000 mg/m³</td>
<td>USA. Occupational Exposure Limits (OSHA) - Table Z-1 Limits for Air Contaminants</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TWA</td>
<td>10.000000 mg/m³</td>
<td>USA. ACGIH Threshold Limit Values (TLV)</td>
</tr>
</tbody>
</table>

Remarks
- Nasal symptoms

<table>
<thead>
<tr>
<th>Component</th>
<th>Value</th>
<th>Control parameters</th>
<th>Basis</th>
</tr>
</thead>
<tbody>
<tr>
<td>TWA</td>
<td>5.000000 mg/m³</td>
<td>USA. NIOSH Recommended Exposure Limits</td>
<td></td>
</tr>
</tbody>
</table>

Gypsum is the dihydrate form & Plaster of Paris is the hemihydrate form.

<table>
<thead>
<tr>
<th>Component</th>
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<th>Control parameters</th>
<th>Basis</th>
</tr>
</thead>
<tbody>
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Gypsum is the dihydrate form & Plaster of Paris is the hemihydrate form.

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<th>Basis</th>
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<tbody>
<tr>
<td>TWA</td>
<td>10.000000 mg/m³</td>
<td>USA. ACGIH Threshold Limit Values (TLV)</td>
<td></td>
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</tbody>
</table>

Remarks
- Nasal symptoms

<table>
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<tr>
<th>Component</th>
<th>Value</th>
<th>Control parameters</th>
<th>Basis</th>
</tr>
</thead>
<tbody>
<tr>
<td>TWA</td>
<td>10 mg/m³</td>
<td>USA. ACGIH Threshold Limit Values (TLV)</td>
<td></td>
</tr>
</tbody>
</table>

Remarks
- Nasal symptoms

8.2 Exposure controls

Appropriate engineering controls
General industrial hygiene practice.

Personal protective equipment Eye/face protection
Use equipment for eye protection tested and approved under appropriate government standards such as NIOSH (US) or EN 166(EU).

Skin protection
Handle with gloves. Gloves must be inspected prior to use. Use proper glove removal technique (without touching glove's outer surface) to avoid skin contact with this product. Dispose of contaminated gloves after use in accordance with applicable laws and good laboratory practices. Wash and dry hands.

Full contact
Material: Nitrile rubber
Minimum layer thickness: 0.11 mm
Break through time: 480 min
Material tested:Dermatril® (KCL 740 / Aldrich Z677272, Size M)

Splash contact
Material: Nitrile rubber
Minimum layer thickness: 0.11 mm
Break through time: 480 min
Material tested:Dermatril® (KCL 740 / Aldrich Z677272, Size M)
Body Protection
Choose body protection in relation to its type, to the concentration and amount of dangerous substances, and to the specific workplace. The type of protective equipment must be selected according to the concentration and amount of the dangerous substance at the specific workplace.

Respiratory protection
Respiratory protection is not required. Where protection from nuisance levels of dusts are desired, use type N95 (US) or type P1 (EN 143) dust masks. Use respirators and components tested and approved under appropriate government standards such as NIOSH (US) or CEN (EU).

Control of environmental exposure
Do not let product enter drains.

9. PHYSICAL AND CHEMICAL PROPERTIES

9.1 Information on basic physical and chemical properties

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
</table>
| a) Appearance | Form: powder  
Colour: white |
| b) Odour | No data available |
| c) Odour Threshold | No data available |
| d) pH | No data available |
| e) Melting point/freezing point | No data available |
| f) Initial boiling point and boiling range | No data available |
| g) Flash point | Not applicable |
| h) Evaporation rate | No data available |
| i) Flammability (solid, gas) | No data available |
| j) Upper/lower flammability or explosive limits | No data available |
| k) Vapour pressure | No data available |
| l) Vapour density | No data available |
| m) Relative density | 2.320 g/cm³ |
| n) Water solubility | No data available |
| o) Partition coefficient: n-octanol/water | No data available |
| p) Auto-ignition temperature | No data available |
| q) Decomposition temperature | No data available |
r) Viscosity No data available
s) Explosive properties No data available
t) Oxidizing properties No data available

9.2 Other safety information
No data available

10. STABILITY AND REACTIVITY

10.1 Reactivity
No data available

10.2 Chemical stability
Stable under recommended storage conditions.

10.3 Possibility of hazardous reactions
No data available

10.4 Conditions to avoid
Avoid moisture.

10.5 Incompatible materials
Strong oxidizing agents

10.6 Hazardous decomposition products
Other decomposition products - No data available
In the event of fire: see section 5

11. TOXICOLOGICAL INFORMATION

11.1 Information on toxicological effects
Acute toxicity
No data available
Inhalation: No data available
Dermal: No data available
No data available

Skin corrosion/irritation
No data available

Serious eye damage/eye irritation
No data available

Respiratory or skin sensitisation
No data available

Germ cell mutagenicity
No data available

Carcinogenicity
IARC: No component of this product present at levels greater than or equal to 0.1% is identified as probable, possible or confirmed human carcinogen by IARC.

NTP: No component of this product present at levels greater than or equal to 0.1% is identified as a known or anticipated carcinogen by NTP.

OSHA: No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by OSHA.
Reproductive toxicity
No data available
No data available

Specific target organ toxicity - single exposure
No data available

Specific target organ toxicity - repeated exposure
No data available

Aspiration hazard
No data available

Additional Information
RTECS: EW4150000
To the best of our knowledge, the chemical, physical, and toxicological properties have not been thoroughly investigated.

12. ECOLOGICAL INFORMATION

12.1 Toxicity
No data available

12.2 Persistence and degradability
No data available

12.3 Bioaccumulative potential
No data available

12.4 Mobility in soil
No data available

12.5 Results of PBT and vPvB assessment
PBT/vPvB assessment not available as chemical safety assessment not required/not conducted

12.6 Other adverse effects
No data available

13. DISPOSAL CONSIDERATIONS

13.1 Waste treatment methods
Product
Offer surplus and non-recyclable solutions to a licensed disposal company.

Contaminated packaging
Dispose of as unused product.

14. TRANSPORT INFORMATION

DOT (US)
Not dangerous goods

IMDG
Not dangerous goods

IATA
Not dangerous goods

15. REGULATORY INFORMATION
SARA 302 Components
No chemicals in this material are subject to the reporting requirements of SARA Title III, Section 302.

SARA 313 Components
This material does not contain any chemical components with known CAS numbers that exceed the threshold (De Minimis) reporting levels established by SARA Title III, Section 313.

SARA 311/312 Hazards
No SARA Hazards

Massachusetts Right To Know Components

<table>
<thead>
<tr>
<th>Component</th>
<th>CAS-No.</th>
<th>Revision Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcium sulfate</td>
<td>10101-41-4</td>
<td>1994-04-01</td>
</tr>
</tbody>
</table>

Pennsylvania Right To Know Components

<table>
<thead>
<tr>
<th>Component</th>
<th>CAS-No.</th>
<th>Revision Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcium sulfate</td>
<td>10101-41-4</td>
<td>1994-04-01</td>
</tr>
</tbody>
</table>

New Jersey Right To Know Components

<table>
<thead>
<tr>
<th>Component</th>
<th>CAS-No.</th>
<th>Revision Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcium sulfate</td>
<td>10101-41-4</td>
<td>1994-04-01</td>
</tr>
</tbody>
</table>

California Prop. 65 Components
This product does not contain any chemicals known to State of California to cause cancer, birth defects, or any other reproductive harm.

16. OTHER INFORMATION

HMIS Rating
Health hazard: 0
Chronic Health Hazard: 
Flammability: 0
Physical Hazard 0

NFPA Rating
Health hazard: 0
Fire Hazard: 0
Reactivity Hazard: 0

Further information
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Preparation Information
Sigma-Aldrich Corporation
Product Safety – Americas Region
1-800-521-8956

Version: 3.6 Revision Date: 12/02/2015 Print Date: 03/19/2017
1. PRODUCT AND COMPANY IDENTIFICATION

1.1 Product identifiers
Product name : Diphenyl ether
Product Number : 240834
Brand : Aldrich
CAS-No. : 101-84-8

1.2 Relevant identified uses of the substance or mixture and uses advised against
Identified uses : Laboratory chemicals, Synthesis of substances

1.3 Details of the supplier of the safety data sheet
Company : Sigma-Aldrich
3050 Spruce Street
SAINT LOUIS MO 63103 USA
Telephone : +1 800-325-5832
Fax : +1 800-325-5052

1.4 Emergency telephone number
Emergency Phone # : +1-703-527-3887 (CHEMTREC)

2. HAZARDS IDENTIFICATION

2.1 Classification of the substance or mixture
GHS Classification in accordance with 29 CFR 1910 (OSHA HCS)
Eye irritation (Category 2A), H319
Acute aquatic toxicity (Category 2), H401
Chronic aquatic toxicity (Category 2), H411

For the full text of the H-Statements mentioned in this Section, see Section 16.

2.2 GHS Label elements, including precautionary statements
Pictogram

Signal word : Warning
Hazard statement(s)
H319 Causes serious eye irritation.
H411 Toxic to aquatic life with long lasting effects.
Precautionary statement(s)
2.3 Hazards not otherwise classified (HNOC) or not covered by GHS - none

3. COMPOSITION/INFORMATION ON INGREDIENTS

3.1 Substances
Synonyms: Phenyl ether
Diphenyl oxide

Formula: 
$C_{12}H_{10}O$

Molecular weight: 170.21 g/mol
CAS-No.: 101-84-8
EC-No.: 202-981-2

Hazardous components

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<th>Concentration</th>
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<tr>
<td>Diphenyl ether</td>
<td>Eye Irrit. 2A; Aquatic Acute 2; Aquatic Chronic 2; H319, H411</td>
<td>&lt;= 100 %</td>
</tr>
</tbody>
</table>

For the full text of the H-Statements mentioned in this Section, see Section 16.

4. FIRST AID MEASURES

4.1 Description of first aid measures

General advice
Consult a physician. Show this safety data sheet to the doctor in attendance.

If inhaled
If breathed in, move person into fresh air. If not breathing, give artificial respiration. Consult a physician.

In case of skin contact
Wash off with soap and plenty of water. Consult a physician.

In case of eye contact
Rinse thoroughly with plenty of water for at least 15 minutes and consult a physician.

If swallowed
Never give anything by mouth to an unconscious person. Rinse mouth with water. Consult a physician.

4.2 Most important symptoms and effects, both acute and delayed
The most important known symptoms and effects are described in the labelling (see section 2.2) and/or in section 11

4.3 Indication of any immediate medical attention and special treatment needed
No data available

5. FIREFIGHTING MEASURES

5.1 Extinguishing media Suitable

extinguishing media
Use water spray, alcohol-resistant foam, dry chemical or carbon dioxide.
5.2 Special hazards arising from the substance or mixture
No data available

5.3 Advice for firefighters
Wear self-contained breathing apparatus for firefighting if necessary.

5.4 Further information
No data available

6. ACCIDENTAL RELEASE MEASURES

6.1 Personal precautions, protective equipment and emergency procedures
Use personal protective equipment. Avoid dust formation. Avoid breathing vapours, mist or gas. Ensure adequate ventilation. Avoid breathing dust. For personal protection see section 8.

6.2 Environmental precautions
Prevent further leakage or spillage if safe to do so. Do not let product enter drains. Discharge into the environment must be avoided.

6.3 Methods and materials for containment and cleaning up
Pick up and arrange disposal without creating dust. Sweep up and shovel. Keep in suitable, closed containers for disposal.

6.4 Reference to other sections
For disposal see section 13.

7. HANDLING AND STORAGE

7.1 Precautions for safe handling
Avoid contact with skin and eyes. Avoid formation of dust and aerosols. Further processing of solid materials may result in the formation of combustible dusts. The potential for combustible dust formation should be taken into consideration before additional processing occurs. Provide appropriate exhaust ventilation at places where dust is formed. For precautions see section 2.2.

7.2 Conditions for safe storage, including any incompatibilities
Keep container tightly closed in a dry and well-ventilated place. Storage class (TRGS 510): Non Combustible Solids

7.3 Specific end use(s)
Apart from the uses mentioned in section 1.2 no other specific uses are stipulated

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

8.1 Control parameters

<table>
<thead>
<tr>
<th>Component</th>
<th>CAS-No.</th>
<th>Value</th>
<th>Control parameters</th>
<th>Basis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diphenyl ether</td>
<td>101-84-8</td>
<td>TWA</td>
<td>1.000000 ppm</td>
<td>USA. ACGIH Threshold Limit Values (TLV)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Eye &amp; Upper Respiratory Tract irritation Nausea</td>
</tr>
<tr>
<td></td>
<td></td>
<td>STEL</td>
<td>2.000000 ppm</td>
<td>USA. ACGIH Threshold Limit Values (TLV)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Eye &amp; Upper Respiratory Tract irritation Nausea</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TWA</td>
<td>1.000000 ppm</td>
<td>USA. Occupational Exposure Limits (OSHA) - Table Z-1 Limits for Air Contaminants</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>The value in mg/m3 is approximate.</td>
</tr>
</tbody>
</table>
### USA. NIOSH Recommended Exposure Limits

<table>
<thead>
<tr>
<th>TWA</th>
<th>1.000000 ppm 7.000000 mg/m³</th>
<th>USA, NIOSH Recommended Exposure Limits</th>
</tr>
</thead>
</table>

### USA. Occupational Exposure Limits (OSHA) - Table Z-1 Limits for Air Contaminants

<table>
<thead>
<tr>
<th>TWA</th>
<th>1.000000 ppm 7.000000 mg/m³</th>
<th>USA, Occupational Exposure Limits (OSHA) - Table Z-1 Limits for Air Contaminants</th>
</tr>
</thead>
</table>

The value in mg/m³ is approximate.

### USA. ACGIH Threshold Limit Values (TLV)

<table>
<thead>
<tr>
<th>TWA</th>
<th>1.000000 ppm 7.000000 mg/m³</th>
<th>USA, ACGIH Threshold Limit Values (TLV)</th>
</tr>
</thead>
</table>

#### Upper Respiratory Tract irritation
- Eye irritation
- Nausea

#### Eye irritation
- Eye irritation
- Nausea

### California permissible exposure limits for chemical contaminants (Title 8, Article 107)

<table>
<thead>
<tr>
<th>PEL</th>
<th>1 ppm 7 mg/m³</th>
<th>California permissible exposure limits for chemical contaminants (Title 8, Article 107)</th>
</tr>
</thead>
</table>

---

### 8.2 Exposure controls

#### Appropriate engineering controls
Handle in accordance with good industrial hygiene and safety practice. Wash hands before breaks and at the end of workday.

#### Personal protective equipment

- **Eye/face protection**
  - Safety glasses with side-shields conforming to EN166. Use equipment for eye protection tested and approved under appropriate government standards such as NIOSH (US) or EN 166(EU).

#### Skin protection
Handle with gloves. Gloves must be inspected prior to use. Use proper glove removal technique (without touching glove's outer surface) to avoid skin contact with this product. Dispose of contaminated gloves after use in accordance with applicable laws and good laboratory practices. Wash and dry hands.

- **Full contact**
  - Material: butyl-rubber
  - Minimum layer thickness: 0.3 mm
  - Break through time: 480 min
  - Material tested: Butoject® (KCL 897 / Aldrich Z677647, Size M)

- **Splash contact**
  - Material: butyl-rubber
  - Minimum layer thickness: 0.3 mm
  - Break through time: 480 min
  - Material tested: Butoject® (KCL 897 / Aldrich Z677647, Size M)

- **Data source:** KCL GmbH, D-36124 Eichenzell, phone +49 (0)6659 87300, e-mail sales@kcl.de, test method: EN374

If used in solution, or mixed with other substances, and under conditions which differ from EN 374, contact the supplier of the CE approved gloves. This recommendation is advisory only and must be evaluated by an industrial hygienist and safety officer familiar with the specific situation of anticipated use by our customers. It should not be construed as offering an approval for any specific use scenario.
Body Protection
Impervious clothing, The type of protective equipment must be selected according to the concentration and amount of the dangerous substance at the specific workplace.

Respiratory protection
For nuisance exposures use type P95 (US) or type P1 (EU EN 143) particle respirator. For higher level protection use type OV/AG/P99 (US) or type ABEK-P2 (EU EN 143) respirator cartridges. Use respirators and components tested and approved under appropriate government standards such as NIOSH (US) or CEN (EU).

Control of environmental exposure
Prevent further leakage or spillage if safe to do so. Do not let product enter drains. Discharge into the environment must be avoided.

9. PHYSICAL AND CHEMICAL PROPERTIES

9.1 Information on basic physical and chemical properties

a) Appearance
   Form: crystalline
   Colour: white

b) Odour
   unpleasant

c) Odour Threshold
   No data available

d) pH
   No data available

e) Melting point/freezing point
   Melting point/range: 25 - 27 °C (77 - 81 °F) - lit.

f) Initial boiling point and boiling range
   259 °C (498 °F) - lit.

g) Flash point
   115 °C (239 °F) - closed cup

h) Evaporation rate
   No data available

i) Flammability (solid, gas)
   No data available

j) Upper/lower flammability or explosive limits
   Upper explosion limit: 1.5 %(V)
   Lower explosion limit: 0.8 %(V)

k) Vapour pressure
   1,013 hPa (760 mmHg) at 257.9 °C (496.2 °F)
   < 1 hPa (< 1 mmHg) at 20 °C (68 °F)

l) Vapour density
   No data available

m) Relative density
   1.073 g/mL at 25 °C (77 °F)

n) Water solubility
   No data available

o) Partition coefficient: n-octanol/water
   log Pow: 4.21 at 25 °C (77 °F)

p) Auto-ignition temperature
   No data available

q) Decomposition temperature
   No data available
r) Viscosity
No data available

s) Explosive properties
No data available

t) Oxidizing properties
No data available

10.5 Incompatible materials
Strong oxidizing agents

10.6 Hazardous decomposition products
Hazardous decomposition products formed under fire conditions. Other decomposition products - No data available
In the event of fire: see section 5

9.2 Other safety information

11. TOXICOLOGICAL INFORMATION

11.1 Information on toxicological effects
Acute toxicity
LD₅₀ 3,700 mg/kg
Skin corrosion/irritation
Skin - Rabbit
Result: Mild skin irritation - 24 h

Serious eye damage/eye irritation
Eyes - Rabbit
Result: Irritating to eyes.

Respiratory or skin sensitisation
No data available

Germ cell mutagenicity
No data available

Carcinogenicity
IARC: No component of this product present at levels greater than or equal to 0.1% is identified as probable, possible or confirmed human carcinogen by IARC.

NTP: No component of this product present at levels greater than or equal to 0.1% is identified as a known or anticipated carcinogen by NTP.

OSHA: No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by OSHA.

Reproductive toxicity
No data available
No data available

Specific target organ toxicity - single exposure
No data available

Specific target organ toxicity - repeated exposure
No data available

Aspiration hazard
No data available

Additional Information
RTECS: KN8970000

prolonged or repeated exposure can cause,
Dermatitis, Liver injury may occur.
To the best of our knowledge, the chemical, physical, and toxicological properties have not been thoroughly investigated.

Stomach

12. ECOLOGICAL INFORMATION

12.1 Toxicity

Toxicity to fish
LC50 - Cyprinodon variegatus (sheepshead minnow) - 1.0 - 2.4 mg/l - 96.0 h

Toxicity to daphnia and other aquatic invertebrates

Based on Human Evidence

Stomach - Irregularities - Based on Human Evidence

Based on Human Evidence
LC50 - Leuciscus idus (Goldenorfe) - 3.0 mg/l - 48 h
12.2 Persistence and degradability
Ratio BOD/ThBOD 62 %

12.3 Bioaccumulative potential
Bioaccumulation  Oncorhynchus mykiss (rainbow trout) - 7 d - 16 µg/l

Bioconcentration factor (BCF): 470
Indication of bioaccumulation.

12.4 Mobility in soil
No data available

12.5 Results of PBT and vPvB assessment
PBT/vPvB assessment not available as chemical safety assessment not required/not conducted

12.6 Other adverse effects
An environmental hazard cannot be excluded in the event of unprofessional handling or disposal. Toxic to aquatic life with long lasting effects.

13. DISPOSAL CONSIDERATIONS

13.1 Waste treatment methods

Product
Offer surplus and non-recyclable solutions to a licensed disposal company. Contact a licensed professional waste disposal service to dispose of this material.

Contaminated packaging
Dispose of as unused product.

14. TRANSPORT INFORMATION

DOT (US)
Not dangerous goods

IMDG
UN number: 3077  Class: 9  Packing group: III  EMS-No: F-A, S-F
Proper shipping name: ENVIRONMENTALLY HAZARDOUS SUBSTANCE, SOLID, N.O.S. (Diphenyl ether)
Marine pollutant:yes

IATA
UN number: 3077  Class: 9  Packing group: III
Proper shipping name: Environmentally hazardous substance, solid, n.o.s. (Diphenyl ether)

Further information
EHS-Mark required (ADR 2.2.9.1.10, IMDG code 2.10.3) for single packagings and combination packagings containing inner packagings with Dangerous Goods > 5L for liquids or > 5kg for solids.

15. REGULATORY INFORMATION

SARA 302 Components
No chemicals in this material are subject to the reporting requirements of SARA Title III, Section 302.

SARA 313 Components
This material does not contain any chemical components with known CAS numbers that exceed the threshold (De Minimis) reporting levels established by SARA Title III, Section 313.

SARA 311/312 Hazards
Acute Health Hazard, Chronic Health
Massachusetts Right To Know Components
Diphenyl ether 101-84-8 2007-03-01

**Pennsylvania Right To Know Components**

<table>
<thead>
<tr>
<th>CAS-No.</th>
<th>Revision Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>101-84-8</td>
<td>2007-03-01</td>
</tr>
</tbody>
</table>

**New Jersey Right To Know Components**

<table>
<thead>
<tr>
<th>CAS-No.</th>
<th>Revision Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>101-84-8</td>
<td>2007-03-01</td>
</tr>
</tbody>
</table>

**California Prop. 65 Components**

This product does not contain any chemicals known to State of California to cause cancer, birth defects, or any other reproductive harm.

### 16. OTHER INFORMATION

Full text of H-Statements referred to under sections 2 and 3.

- **Aquatic Acute**
  - Acute aquatic toxicity
- **Aquatic Chronic**
  - Chronic aquatic toxicity
- **Eye Irrit.**
  - Eye irritation
- **H319**
  - Causes serious eye irritation.
- **H401**
  - Toxic to aquatic life.
- **H411**
  - Toxic to aquatic life with long lasting effects.

**HMIS Rating**

- Health hazard: 2
- Chronic Health Hazard: *
- Flammability: 1
- Physical Hazard: 0

**NFPA Rating**

- Health hazard: 2
- Fire Hazard: 1
- Reactivity Hazard: 0

**Further information**

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**Preparation Information**

Sigma-Aldrich Corporation
Product Safety – Americas Region
1-800-521-8956

Version: 4.7  Revision Date: 05/23/2016  Print Date: 03/18/2017
1. PRODUCT AND COMPANY IDENTIFICATION

1.1 Product identifiers

Product name : Furfural
Product Number : 185914
Brand : Sigma-Aldrich
Index-No. : 605-010-00-4
CAS-No. : 98-01-1

1.2 Relevant identified uses of the substance or mixture and uses advised against

Identified uses : Laboratory chemicals, Synthesis of substances

1.3 Details of the supplier of the safety data sheet

Company : Sigma-Aldrich
3050 Spruce Street
SAINT LOUIS MO 63103
USA
Telephone : +1 800-325-5832
Fax : +1 800-325-5052

1.4 Emergency telephone number

Emergency Phone # : +1-703-527-3887 (CHEMTREC)

2. HAZARDS IDENTIFICATION

2.1 Classification of the substance or mixture

GHS Classification in accordance with 29 CFR 1910 (OSHA HCS)
Flammable liquids (Category 4), H227
Acute toxicity, Oral (Category 3), H301
Acute toxicity, Inhalation (Category 2), H330
Acute toxicity, Dermal (Category 4), H312
Eye irritation (Category 2A), H319
Carcinogenicity (Category 2), H351
Acute aquatic toxicity (Category 3), H402

For the full text of the H-Statements mentioned in this Section, see Section 16.

2.2 GHS Label elements, including precautionary statements

Pictogram
Signal word : Danger
Hazard statement(s)
H227 : Combustible liquid.
H301 : Toxic if swallowed.
H312 | Harmful in contact with skin.
H319 | Causes serious eye irritation.
H330 | Fatal if inhaled.
H351 | Suspected of causing cancer.
H402 | Harmful to aquatic life.

Precautionary statement(s)
P201 | Obtain special instructions before use.
P202 | Do not handle until all safety precautions have been read and understood.
P210 | Keep away from heat/sparks/open flames/hot surfaces. No smoking.
P260 | Do not breathe dust/ fume/ gas/ mist/ vapours/ spray.
P264 | Wash skin thoroughly after handling.
P270 | Do not eat, drink or smoke when using this product.
P271 | Use only outdoors or in a well-ventilated area.
P273 | Avoid release to the environment.
P280 | Wear protective gloves/ protective clothing/ eye protection/ face protection.
P284 | Wear respiratory protection.
P301 + P310 + P330 | IF SWALLOWED: Immediately call a POISON CENTER/doctor. Rinse mouth.
P302 + P352 + P312 | IF ON SKIN: Wash with plenty of water. Call a POISON CENTER/doctor if you feel unwell.
P304 + P340 + P310 | IF INHALED: Remove person to fresh air and keep comfortable for breathing. Immediately call a POISON CENTER/doctor.
P305 + P351 + P338 | IF IN EYES: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing.
P308 + P313 | IF exposed or concerned: Get medical advice/ attention.
P337 + P313 | If eye irritation persists: Get medical advice/ attention.
P363 | Wash contaminated clothing before reuse.
P370 + P378 | In case of fire: Use dry sand, dry chemical or alcohol-resistant foam to extinguish.
P403 + P233 | Store in a well-ventilated place. Keep container tightly closed.
P403 + P235 | Store in a well-ventilated place. Keep cool.
P405 | Store locked up.
P501 | Dispose of contents/ container to an approved waste disposal plant.

2.3 Hazards not otherwise classified (HNOC) or not covered by GHS
Photosensitizer.

3. COMPOSITION/INFORMATION ON INGREDIENTS

3.1 Substances
Synonyms: 2-Furaldehyde
Furan-2-carboxaldehyde

Formula: C₅H₄O₂
Molecular weight: 96.08 g/mol
CAS-No.: 98-01-1
EC-No.: 202-827-7
Index-No.: 605-010-00-4

Hazardous components

<table>
<thead>
<tr>
<th>Component</th>
<th>Classification</th>
<th>Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>2-Furaldehyde</strong></td>
<td>Flam. Liq. 4; Acute Tox. 3; Acute Tox. 2; Acute Tox. 4; Eye Irrit. 2A; Carc. 2; Aquatic Acute 3; H227, H301, H312, H319, H330, H351, H402</td>
<td>90 - 100 %</td>
</tr>
</tbody>
</table>

For the full text of the H-Statements mentioned in this Section, see Section 16.
4. FIRST AID MEASURES

4.1 Description of first aid measures

General advice
Consult a physician. Show this safety data sheet to the doctor in attendance. Move out of dangerous area.

If inhaled
If breathed in, move person into fresh air. If not breathing, give artificial respiration. Consult a physician.

In case of skin contact
Wash off with soap and plenty of water. Take victim immediately to hospital. Consult a physician.

In case of eye contact
Rinse thoroughly with plenty of water for at least 15 minutes and consult a physician.

If swallowed
Do NOT induce vomiting. Never give anything by mouth to an unconscious person. Rinse mouth with water. Consult a physician.

4.2 Most important symptoms and effects, both acute and delayed
The most important known symptoms and effects are described in the labelling (see section 2.2) and/or in section 11.

4.3 Indication of any immediate medical attention and special treatment needed
No data available

5. FIREFIGHTING MEASURES

5.1 Extinguishing media
Suitable extinguishing media
Use water spray, alcohol-resistant foam, dry chemical or carbon dioxide.

5.2 Special hazards arising from the substance or mixture
No data available

5.3 Advice for firefighters
Wear self-contained breathing apparatus for firefighting if necessary.

5.4 Further information
Use water spray to cool unopened containers.

6. ACCIDENTAL RELEASE MEASURES

6.1 Personal precautions, protective equipment and emergency procedures
Wear respiratory protection. Avoid breathing vapours, mist or gas. Ensure adequate ventilation. Remove all sources of ignition. Evacuate personnel to safe areas. Beware of vapours accumulating to form explosive concentrations. Vapours can accumulate in low areas.
For personal protection see section 8.

6.2 Environmental precautions
Prevent further leakage or spillage if safe to do so. Do not let product enter drains. Discharge into the environment must be avoided.

6.3 Methods and materials for containment and cleaning up
Contain spillage, and then collect with an electrically protected vacuum cleaner or by wet-brushing and place in container for disposal according to local regulations (see section 13). Keep in suitable, closed containers for disposal.

6.4 Reference to other sections
For disposal see section 13.

7. HANDLING AND STORAGE

7.1 Precautions for safe handling
Avoid contact with skin and eyes. Avoid inhalation of vapour or mist. Keep away from sources of ignition - No smoking. Take measures to prevent the build up of electrostatic charge. For precautions see section 2.2.

7.2 Conditions for safe storage, including any incompatibilities
Keep container tightly closed in a dry and well-ventilated place. Containers which are opened must be carefully resealed and kept upright to prevent leakage.

7.3 Specific end use(s)
Apart from the uses mentioned in section 1.2 no other specific uses are stipulated

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

8.1 Control parameters

<table>
<thead>
<tr>
<th>Component</th>
<th>CAS-No.</th>
<th>Control parameters</th>
<th>Value</th>
<th>Basis</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-Furaldehyde</td>
<td>98-01-1</td>
<td>TWA</td>
<td>2 ppm</td>
<td>USA. ACGIH Threshold Limit Values (TLV)</td>
</tr>
</tbody>
</table>
| Remarks         |          | Upper Respiratory Tract irritation Eye irritation
|                 |          | Substances for which there is a Biological Exposure Index or Indices (see BEI® section) |
|                 |          | Confirmed animal carcinogen with unknown relevance to humans Danger of cutaneous absorption |
| TWA             |          | USA. ACGIH Threshold Limit Values (TLV) |
| 2-Furaldehyde   | 98-01-1  | TWA                | 2.000000 ppm | USA. ACGIH Threshold Limit Values (TLV) |
| Remarks         |          | Upper Respiratory Tract irritation Eye irritation
|                 |          | Substances for which there is a Biological Exposure Index or Indices (see BEI® section) |
|                 |          | Confirmed animal carcinogen with unknown relevance to humans Danger of cutaneous absorption |
| TWA             |          | USA. Occupational Exposure Limits (OSHA) - Table Z-1 Limits for Air Contaminants |
| 2-Furaldehyde   | 98-01-1  | PEL                | 2 ppm     | California permissible exposure limits for chemical contaminants (Title 8, Article 107) |
| 2-Furaldehyde   | 98-01-1  | Furoic acid        | 200.0000 mg/l | In urine ACGIH - Biological Exposure Indices (BEI) |

8.2 Exposure controls

Appropriate engineering controls
Avoid contact with skin, eyes and clothing. Wash hands before breaks and immediately after handling the product.

Personal protective equipment Eye/face protection
Face shield and safety glasses Use equipment for eye protection tested and approved under appropriate government standards such as NIOSH (US) or EN 166(EU).
Skin protection
Handle with gloves. Gloves must be inspected prior to use. Use proper glove removal technique (without touching glove's outer surface) to avoid skin contact with this product. Dispose of contaminated gloves after use in accordance with applicable laws and good laboratory practices. Wash and dry hands.

Full contact
Material: butyl-rubber
Minimum layer thickness: 0.3 mm
Break through time: 480 min
Material tested: Butoject® (KCL 897 / Aldrich Z677647, Size M)

Splash contact
Material: Nitrile rubber
Minimum layer thickness: 0.4 mm
Break through time: 30 min
Material tested: Camatril® (KCL 730 / Aldrich Z677442, Size M)

data source: KCL GmbH, D-36124 Eichenzell, phone +49 (0)6659 87300, e-mail sales@kcl.de, test method: EN374
If used in solution, or mixed with other substances, and under conditions which differ from EN 374, contact the supplier of the CE approved gloves. This recommendation is advisory only and must be evaluated by an industrial hygienist and safety officer familiar with the specific situation of anticipated use by our customers. It should not be construed as offering an approval for any specific use scenario.

Body Protection
Complete suit protecting against chemicals. The type of protective equipment must be selected according to the concentration and amount of the dangerous substance at the specific workplace.

Respiratory protection
Where risk assessment shows air-purifying respirators are appropriate use a full-face respirator with multi-purpose combination (US) or type ABEK (EN 14387) respirator cartridges as a backup to engineering controls. If the respirator is the sole means of protection, use a full-face supplied air respirator. Use respirators and components tested and approved under appropriate government standards such as NIOSH (US) or CEN (EU).

Control of environmental exposure
Prevent further leakage or spillage if safe to do so. Do not let product enter drains. Discharge into the environment must be avoided.

9. PHYSICAL AND CHEMICAL PROPERTIES

9.1 Information on basic physical and chemical properties

a) Appearance
   Form: clear, viscous, liquid
   Colour: light brown
b) Odour
   No data available
c) Odour Threshold
   No data available
d) pH
   No data available
e) Melting point/freezing point
   Melting point/range: -36 °C (-33 °F) - lit.
f) Initial boiling point and boiling range
   162 °C (324 °F) - lit.

g) Flash point
   61.7 °C (143.1 °F) - closed cup
h) Evaporation rate
   No data available
i) Flammability (solid, gas)
   No data available
j) Upper/lower flammability or explosive limits
   Upper explosion limit: 19.3 %(V)
   Lower explosion limit: 2.1 %(V)
k) Vapour pressure
18.0 hPa (13.5 mmHg) at 55 °C (131 °F)

No data available

l) Vapour density
3.32 - (Air = 1.0)
m) Relative density
1.16 g/cm³ at 25 °C (77 °F)
n) Water solubility solublet

No data available

o) Partition coefficient: n-log Pow: 0.41 octanol/water
p) Auto-ignition temperature
q) Decomposition temperature
r) Viscosity
No data available
s) Explosive properties
No data available
t) Oxidizing properties
No data available

9.2 Other safety information
10. STABILITY AND REACTIVITY

10.1 Reactivity
No data available

10.2 Chemical stability
Stable under recommended storage conditions.

10.3 Possibility of hazardous reactions
No data available

10.4 Conditions to avoid
Heat, flames and sparks.

10.5 Incompatible materials
Oxidizing agents, Strong acids

10.6 Hazardous decomposition products
Hazardous decomposition products formed under fire conditions. - Carbon oxides
Other decomposition products - No data available
In the event of fire: see section 5

11. TOXICOLOGICAL INFORMATION

11.1 Information on toxicological effects

Acute toxicity
LD50 Oral - Rat - male - 145 - 204 mg/kg
LD50 Oral - Rat - female - 90 - 119 mg/kg
LC50 Inhalation - Rat - male and female - 4 h - > 0.54 - < 1.63 mg/l
(OECD Test Guideline 403)
LD50 Dermal - Rabbit - > 2,000 mg/kg
(OECD Test Guideline 402)
Remarks: Classified according to Regulation (EU) 1272/2008, Annex VI (Table 3.1/3.2)
No data available

Skin corrosion/irritation
Skin - Rabbit
Result: Mild skin irritation - 24 h
(OECD Test Guideline 404)

Serious eye damage/eye irritation
Eyes - Rabbit
Result: Moderate eye irritation - 24 h
(OECD Test Guideline 405)

Respiratory or skin sensitisation
Maximisation Test - Guinea pig
Did not cause sensitisation on laboratory animals.  
(OECD Test Guideline 406)

**Germ cell mutagenicity**
Mouse
lymphocyte
Mutation in mammalian somatic cells.

Human
HeLa cell
DNA inhibition

Human
lymphocyte
Sister chromatid exchange

**Carcinogenicity**

Carcinogenicity - Rat - Oral
Tumorigenic: Equivocal tumorigenic agent by RTECS criteria. Liver: Tumors.

This product is or contains a component that has been reported to be possibly carcinogenic based on its IARC, ACGIH, NTP, or EPA classification.

Limited evidence of carcinogenicity in animal studies

IARC: No component of this product present at levels greater than or equal to 0.1% is identified as probable, possible or confirmed human carcinogen by IARC.

NTP: No component of this product present at levels greater than or equal to 0.1% is identified as a known or anticipated carcinogen by NTP.

OSHA: No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by OSHA.

**Reproductive toxicity**
No data available

**Specific target organ toxicity - single exposure**
No data available

**Specific target organ toxicity - repeated exposure**
No data available

**Aspiration hazard**
No data available

**Additional Information**

RTECS: LT7000000

Central nervous system depression, Headache, Material is extremely destructive to tissue of the mucous membranes and upper respiratory tract, eyes, and skin., Cough

Stomach - Irregularities - Based on Human Evidence
Stomach - Irregularities - Based on Human Evidence

### 12. ECOLOGICAL INFORMATION

#### 12.1 Toxicty

Toxicity to fish
LC50 - Pimephales promelas (fathead minnow) - 32 mg/l - 96 h

Toxicity to daphnia and other aquatic invertebrates
Toxicity to algae: EC50 - other microorganisms - 570 mg/l - 24 h

**12.2 Persistence and degradability**

Biodegradability: aerobic Biochemical oxygen demand - Exposure time 28 d
Result: 93.5 % - Readily biodegradable.
(OECD Test Guideline 301C)

**12.3 Bioaccumulative potential**
No data available

**12.4 Mobility in soil**
No data available

**12.5 Results of PBT and vPvB assessment**
PBT/vPvB assessment not available as chemical safety assessment not required/not conducted

**12.6 Other adverse effects**
An environmental hazard cannot be excluded in the event of unprofessional handling or disposal.
Harmful to aquatic life.
No data available

**13. DISPOSAL CONSIDERATIONS**

**13.1 Waste treatment methods**

**Product**
This combustible material may be burned in a chemical incinerator equipped with an afterburner and scrubber. Offer surplus and non-recyclable solutions to a licensed disposal company. Contact a licensed professional waste disposal service to dispose of this material.

**Contaminated packaging**
Dispose of as unused product.

**14. TRANSPORT INFORMATION**

**DOT (US)**
UN number: 1199  Class: 6.1 (3)  Packing group: II
Proper shipping name: Furaldehydes
Reportable Quantity (RQ): 5000 lbs
Poison Inhalation Hazard: No

**IMDG**
UN number: 1199  Class: 6.1 (3)  Packing group: II  EMS-No: F-E, S-D
Proper shipping name: FURALDEHYDES

**IATA**
UN number: 1199  Class: 6.1 (3)  Packing group: II
Proper shipping name: Furaldehydes

**15. REGULATORY INFORMATION**

**SARA 302 Components**
No chemicals in this material are subject to the reporting requirements of SARA Title III, Section 302.

**SARA 313 Components**
This material does not contain any chemical components with known CAS numbers that exceed the threshold (De Minimis) reporting levels established by SARA Title III, Section 313.

**SARA 311/312 Hazards**
Fire Hazard, Acute Health Hazard, Chronic Health Hazard
New Jersey Right To Know Components

2-Furaldehyde

California Prop. 65 Components

This product does not contain any chemicals known to State of California to cause cancer, birth defects, or any other reproductive harm.

16. OTHER INFORMATION

Full text of H-Statements referred to under sections 2 and 3.

| Acute Tox. | Acute toxicity |
| Aquatic Acute | Acute aquatic toxicity |
| Carc. | Carcinogenicity |
| Eye Irrit. | Eye irritation |
| Flam. Liq. | Flammable liquids |
| H227 | Combustible liquid. |
| H301 | Toxic if swallowed. |
| H312 | Harmful in contact with skin. |
| H319 | Causes serious eye irritation. |
| H330 | Fatal if inhaled. |
| H351 | Suspected of causing cancer. |
| H402 | Harmful to aquatic life. |

HMIS Rating

- Health hazard: 2
- Chronic Health Hazard: *
- Flammability: 2
- Physical Hazard: 0

NFPA Rating

- Health hazard: 2
- Fire Hazard: 2
- Reactivity Hazard: 0

Further information

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The above information is believed to be correct but does not purport to be all inclusive and shall be used only as a guide. The information in this document is based on the present state of our knowledge and is applicable to the product with regard to appropriate safety precautions. It does not represent any guarantee of the properties of the product. Sigma-Aldrich Corporation and its Affiliates shall not be held liable for any damage resulting from handling or from contact with the above product. See www.sigma-aldrich.com and/or the reverse side of invoice or packing slip for additional terms and conditions of sale.

Preparation Information

Sigma-Aldrich Corporation
Product Safety – Americas Region
1-800-521-8956

Version: 4.10 Revision Date: 02/17/2017 Print Date: 03/18/2017
1. PRODUCT AND COMPANY IDENTIFICATION

1.1 Product identifiers

Product name: Glucose solution
Product Number: 49163
Brand: Sigma

1.2 Relevant identified uses of the substance or mixture and uses advised against

Identified uses: Laboratory chemicals, Synthesis of substances

1.3 Details of the supplier of the safety data sheet

Company: Sigma-Aldrich
3050 Spruce Street
SAINT LOUIS MO 63103
USA
Telephone: +1 800-325-5832
Fax: +1 800-325-5052

1.4 Emergency telephone number

Emergency Phone #: +1-703-527-3887 (CHEMTREC)

2. HAZARDS IDENTIFICATION

2.1 Classification of the substance or mixture

Not a hazardous substance or mixture.

2.2 GHS Label elements, including precautionary statements

Not a hazardous substance or mixture.

2.3 Hazards not otherwise classified (HNOC) or not covered by GHS - none

3. COMPOSITION/INFORMATION ON INGREDIENTS

3.2 Mixtures

Formula: C_{6}H_{12}O_{6}
Molecular weight: 180.16 g/mol

No components need to be disclosed according to the applicable regulations.

4. FIRST AID MEASURES

4.1 Description of first aid measures If
inhaled
If breathed in, move person into fresh air. If not breathing, give artificial respiration.

In case of skin contact
Wash off with soap and plenty of water.

In case of eye contact
Flush eyes with water as a precaution.

If swallowed
Never give anything by mouth to an unconscious person. Rinse mouth with water.

4.2 Most important symptoms and effects, both acute and delayed
The most important known symptoms and effects are described in the labelling (see section 2.2) and/or in section 11.

4.3 Indication of any immediate medical attention and special treatment needed
No data available

5. FIREFIGHTING MEASURES
5.1 Extinguishing media Suitable
extinguishing media
Use water spray, alcohol-resistant foam, dry chemical or carbon dioxide.

5.2 Special hazards arising from the substance or mixture
No data available

5.3 Advice for firefighters
Wear self-contained breathing apparatus for firefighting if necessary.

5.4 Further information
No data available

6. ACCIDENTAL RELEASE MEASURES
6.1 Personal precautions, protective equipment and emergency procedures
Avoid breathing vapours, mist or gas.
For personal protection see section 8.

6.2 Environmental precautions
Do not let product enter drains.

6.3 Methods and materials for containment and cleaning up
Keep in suitable, closed containers for disposal.

6.4 Reference to other sections
For disposal see section 13.

7. HANDLING AND STORAGE
7.1 Precautions for safe handling
For precautions see section 2.2.

7.2 Conditions for safe storage, including any incompatibilities
Keep container tightly closed in a dry and well-ventilated place.

7.3 Specific end use(s)
Apart from the uses mentioned in section 1.2 no other specific uses are stipulated

8. EXPOSURE CONTROLS/PERSONAL PROTECTION
8.1 Control parameters
Components with workplace control parameters
Contains no substances with occupational exposure limit values.

8.2 Exposure controls
Appropriate engineering controls
General industrial hygiene practice.

Personal protective
   equipment Eye/face protection
   Use equipment for eye protection tested and approved under appropriate government standards such as NIOSH (US) or EN 166(EU).

Skin protection
Handle with gloves. Gloves must be inspected prior to use. Use proper glove removal technique (without touching glove’s outer surface) to avoid skin contact with this product. Dispose of contaminated gloves after use in accordance with applicable laws and good laboratory practices. Wash and dry hands.

   Full contact
   Material: Nitrile rubber
   Minimum layer thickness: 0.11 mm
   Break through time: 480 min
   Material tested:Dermatril® (KCL 740 / Aldrich Z677272, Size M)

   Splash contact
   Material: Nitrile rubber
   Minimum layer thickness: 0.11 mm
   Break through time: 480 min
   Material tested:Dermatril® (KCL 740 / Aldrich Z677272, Size M)

data source: KCL GmbH, D-36124 Eichenzell, phone +49 (0)6659 87300, e-mail sales@kcl.de, test method: EN374
If used in solution, or mixed with other substances, and under conditions which differ from EN 374, contact the supplier of the CE approved gloves. This recommendation is advisory only and must be evaluated by an industrial hygienist and safety officer familiar with the specific situation of anticipated use by our customers. It should not be construed as offering an approval for any specific use scenario.

Body Protection
Impervious clothing. The type of protective equipment must be selected according to the concentration and amount of the dangerous substance at the specific workplace.

Respiratory protection
Respiratory protection not required. For nuisance exposures use type OV/AG (US) or type ABEK (EU EN 14387) respirator cartridges. Use respirators and components tested and approved under appropriate government standards such as NIOSH (US) or CEN (EU).

Control of environmental exposure
Do not let product enter drains.

9. PHYSICAL AND CHEMICAL PROPERTIES

9.1 Information on basic physical and chemical properties
a) Appearance Form: liquid
b) Odour No data available
c) Odour Threshold No data available
d) pH 5.0 - 8.0 at 25 °C (77 °F)
e) Melting point/freezing point No data available
f) Initial boiling point and boiling range No data available
g) Partition coefficient: n-octanol/water
   No data available

h) Auto-ignition temperature
   No data available

i) Decomposition temperature
   No data available
9.2 Other safety information
No data available

10. STABILITY AND REACTIVITY

10.1 Reactivity
No data available

10.2 Chemical stability
Stable under recommended storage conditions.

10.3 Possibility of hazardous reactions
No data available

10.4 Conditions to avoid
No data available

10.5 Incompatible materials
Strong oxidizing agents

10.6 Hazardous decomposition products
Hazardous decomposition products formed under fire conditions. - Carbon oxides
Other decomposition products - No data available
In the event of fire: see section 5

11. TOXICOLOGICAL INFORMATION

11.1 Information on toxicological effects

Acute toxicity
No data available
Inhalation: No data available
Dermal: No data available
No data available

Skin corrosion/irritation
No data available

Serious eye damage/eye irritation
No data available

Respiratory or skin sensitisation
No data available

Germ cell mutagenicity
No data available

Carcinogenicity

IARC: No component of this product present at levels greater than or equal to 0.1% is identified as probable, possible or confirmed human carcinogen by IARC.

ACGIH: No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by ACGIH.

NTP: No component of this product present at levels greater than or equal to 0.1% is identified as a known or anticipated carcinogen by NTP.
OSHA: No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by OSHA.

Reproductive toxicity
No data available
No data available

Specific target organ toxicity - single exposure
No data available

Specific target organ toxicity - repeated exposure
No data available

Aspiration hazard
No data available

Additional Information
RTECS: Not available
To the best of our knowledge, the chemical, physical, and toxicological properties have not been thoroughly investigated.

12. ECOLOGICAL INFORMATION

12.1 Toxicity
No data available

12.2 Persistence and degradability
No data available

12.3 Bioaccumulative potential
No data available

12.4 Mobility in soil
No data available

12.5 Results of PBT and vPvB assessment
PBT/vPvB assessment not available as chemical safety assessment not required/not conducted

12.6 Other adverse effects
No data available

13. DISPOSAL CONSIDERATIONS

13.1 Waste treatment methods
Product
Offer surplus and non-recyclable solutions to a licensed disposal company.

Contaminated packaging
Dispose of as unused product.

14. TRANSPORT INFORMATION

DOT (US)
Not dangerous goods

IMDG
Not dangerous goods

IATA
Not dangerous goods
15. REGULATORY INFORMATION

SARA 302 Components
No chemicals in this material are subject to the reporting requirements of SARA Title III, Section 302.

SARA 313 Components
This material does not contain any chemical components with known CAS numbers that exceed the threshold (De Minimis) reporting levels established by SARA Title III, Section 313.

SARA 311/312 Hazards
No SARA Hazards

Massachusetts Right To Know Components
No components are subject to the Massachusetts Right to Know Act.

Pennsylvania Right To Know Components

<table>
<thead>
<tr>
<th>Component</th>
<th>CAS-No.</th>
<th>Revision Date</th>
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</thead>
<tbody>
<tr>
<td>Water</td>
<td>7732-18-5</td>
<td></td>
</tr>
<tr>
<td>Glucose</td>
<td>50-99-7</td>
<td></td>
</tr>
</tbody>
</table>

New Jersey Right To Know Components

<table>
<thead>
<tr>
<th>Component</th>
<th>CAS-No.</th>
<th>Revision Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>7732-18-5</td>
<td></td>
</tr>
</tbody>
</table>
Glucose  50-99-7

California Prop. 65 Components
This product does not contain any chemicals known to State of California to cause cancer, birth defects, or any other reproductive harm.

**16. OTHER**

**INFORMATION**

**HMIS Rating**
Health hazard: 0
Chronic Health Hazard: 0
Flammability: 0
Physical Hazard: 0

**NFPA Rating**
Health hazard: 0
Fire Hazard: 0
Reactivity Hazard: 0

**Further information**
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**Preparation Information**
Sigma-Aldrich Corporation
Product Safety – Americas Region
1-800-521-8956

Version: 5.3Revision Date: 04/06/2016Print Date: 03/18/2017
1. PRODUCT AND COMPANY IDENTIFICATION

1.1 Product identifiers
- Product name: L-(+)-Lactic acid
- Product Number: L1750
- Brand: Sigma
- CAS-No.: 79-33-4

1.2 Relevant identified uses of the substance or mixture and uses advised against
- Identified uses: Laboratory chemicals, Manufacture of substances

1.3 Details of the supplier of the safety data sheet
- Company: Sigma-Aldrich
  3050 Spruce Street
  SAINT LOUIS MO 63103 USA
- Telephone: +1 800-325-5832
- Fax: +1 800-325-5052

1.4 Emergency telephone number
- Emergency Phone #: +1-703-527-3887 (CHEMTREC)

2. HAZARDS IDENTIFICATION

2.1 Classification of the substance or mixture
- GHS Classification in accordance with 29 CFR 1910 (OSHA HCS)
  - Skin irritation (Category 2), H315
  - Serious eye damage (Category 1), H318
- For the full text of the H-Statements mentioned in this Section, see Section 16.

2.2 GHS Label elements, including precautionary statements
- Pictogram
- Signal word: Danger
- Hazard statement(s)
  - H315: Causes skin irritation.
  - H318: Causes serious eye damage.
- Precautionary statement(s)
  - P264: Wash skin thoroughly after handling.
  - P280: Wear eye protection/ face protection.
  - P280: Wear protective gloves.
IF ON SKIN: Wash with plenty of soap and water.

IF IN EYES: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing. Immediately call a POISON CENTER or doctor/physician.

If skin irritation occurs: Get medical advice/attention.

If inhaled: If breathed in, move person into fresh air. If not breathing, give artificial respiration. Consult a physician.

In case of skin contact: Wash off with soap and plenty of water. Consult a physician.

In case of eye contact: Rinse thoroughly with plenty of water for at least 15 minutes and consult a physician.

If swallowed: Never give anything by mouth to an unconscious person. Rinse mouth with water. Consult a physician.

Hazardous components

<table>
<thead>
<tr>
<th>Component</th>
<th>Classification</th>
<th>Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>L-(-)-Lactic acid</td>
<td>Skin Irrit. 2; Eye Dam. 1;</td>
<td>&lt;= 100 %</td>
</tr>
<tr>
<td></td>
<td>H315, H318</td>
<td></td>
</tr>
</tbody>
</table>

For the full text of the H-Statements mentioned in this Section, see Section 16.

3. COMPOSITION/INFORMATION ON INGREDIENTS

3.1 Substances

Synonyms: (S)-2-Hydroxypropionic acid Sarcolactic acid

Formula: \( C_3H_6O_3 \)

Molecular weight: 90.08 g/mol

CAS-No.: 79-33-4

EC-No.: 201-196-2

4. FIRST AID MEASURES

4.1 Description of first aid measures

General advice
Consult a physician. Show this safety data sheet to the doctor in attendance. Move out of dangerous area.

If inhaled
If breathed in, move person into fresh air. If not breathing, give artificial respiration. Consult a physician.

In case of skin contact: Wash off with soap and plenty of water. Consult a physician.

In case of eye contact: Rinse thoroughly with plenty of water for at least 15 minutes and consult a physician.

If swallowed: Never give anything by mouth to an unconscious person. Rinse mouth with water. Consult a physician.

4.2 Most important symptoms and effects, both acute and delayed
The most important known symptoms and effects are described in the labelling (see section 2.2) and/or in section 11

4.3 Indication of any immediate medical attention and special treatment needed
No data available

5. FIREFIGHTING MEASURES

5.1 Extinguishing media Suitable extinguishing media
Use water spray, alcohol-resistant foam, dry chemical or carbon dioxide.

5.2 Special hazards arising from the substance or mixture
Carbon oxides

5.3 Advice for firefighters
Wear self-contained breathing apparatus for firefighting if necessary.
5.4 Further information
No data available

6. ACCIDENTAL RELEASE MEASURES

6.1 Personal precautions, protective equipment and emergency procedures
Use personal protective equipment. Avoid dust formation. Avoid breathing vapours, mist or gas. Ensure adequate ventilation. Evacuate personnel to safe areas. Avoid breathing dust.
For personal protection see section 8.

6.2 Environmental precautions
Do not let product enter drains.

6.3 Methods and materials for containment and cleaning up
Pick up and arrange disposal without creating dust. Sweep up and shovel. Keep in suitable, closed containers for disposal.

6.4 Reference to other sections
For disposal see section 13.

7. HANDLING AND STORAGE

7.1 Precautions for safe handling
Avoid contact with skin and eyes. Avoid formation of dust and aerosols. Further processing of solid materials may result in the formation of combustible dusts. The potential for combustible dust formation should be taken into consideration before additional processing occurs.
Provide appropriate exhaust ventilation at places where dust is formed.
For precautions see section 2.2.

7.2 Conditions for safe storage, including any incompatibilities
Keep container tightly closed in a dry and well-ventilated place.
Recommended storage temperature 2 - 8 °C
hygroscopic
Storage class (TRGS 510): Non Combustible Solids

7.3 Specific end use(s)
Apart from the uses mentioned in section 1.2 no other specific uses are stipulated

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

8.1 Control parameters
Components with workplace control parameters
Contains no substances with occupational exposure limit values.

8.2 Exposure controls
Appropriate engineering controls
Handle in accordance with good industrial hygiene and safety practice. Wash hands before breaks and at the end of workday.
Personal protective equipment Eye/face protection
Face shield and safety glasses Use equipment for eye protection tested and approved under appropriate government standards such as NIOSH (US) or EN 166(EU).

Skin protection
Handle with gloves. Gloves must be inspected prior to use. Use proper glove removal technique (without touching glove's outer surface) to avoid skin contact with this product. Dispose of contaminated gloves after use in accordance with applicable laws and good laboratory practices. Wash and dry hands.

Full contact
Material: Nitrile rubber  
Minimum layer thickness: 0.11 mm  
Break through time: 480 min  
Material tested: Dermatril® (KCL 740 / Aldrich Z677272, Size M)

Splash contact  
Material: Nitrile rubber  
Minimum layer thickness: 0.11 mm  
Break through time: 480 min  
Material tested: Dermatril® (KCL 740 / Aldrich Z677272, Size M)

data source: KCL GmbH, D-36124 Eichenzell, phone +49 (0)6659 87300, e-mail sales@kcl.de, test method: EN374

If used in solution, or mixed with other substances, and under conditions which differ from EN 374, contact the supplier of the CE approved gloves. This recommendation is advisory only and must be evaluated by an industrial hygienist and safety officer familiar with the specific situation of anticipated use by our customers. It should not be construed as offering an approval for any specific use scenario.

**Body Protection**

Complete suit protecting against chemicals. The type of protective equipment must be selected according to the concentration and amount of the dangerous substance at the specific workplace.

**Respiratory protection**

Where risk assessment shows air-purifying respirators are appropriate use a full-face particle respirator type N100 (US) or type P3 (EN 143) respirator cartridges as a backup to engineering controls. If the respirator is the sole means of protection, use a full-face supplied air respirator. Use respirators and components tested and approved under appropriate government standards such as NIOSH (US) or CEN (EU).

**Control of environmental exposure**

Do not let product enter drains.

---

### 9. PHYSICAL AND CHEMICAL PROPERTIES

#### 9.1 Information on basic physical and chemical properties

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>a) Appearance</td>
<td>Form: solid</td>
</tr>
<tr>
<td>b) Odour</td>
<td>No data available</td>
</tr>
<tr>
<td>c) Odour Threshold</td>
<td>No data available</td>
</tr>
<tr>
<td>d) pH</td>
<td>1.2</td>
</tr>
<tr>
<td>e) Melting point/freezing point</td>
<td>Melting point/range: 53 °C (127 °F)</td>
</tr>
<tr>
<td>f) Initial boiling point and boiling range</td>
<td>No data available</td>
</tr>
<tr>
<td>g) Flash point</td>
<td>110.00 °C (230.00 °F) - closed cup</td>
</tr>
<tr>
<td>h) Evaporation rate</td>
<td>No data available</td>
</tr>
<tr>
<td>i) Flammability (solid, gas)</td>
<td>No data available</td>
</tr>
<tr>
<td>j) Upper/lower flammability or explosive limits</td>
<td>No data available</td>
</tr>
<tr>
<td>k) Vapour pressure</td>
<td>No data available</td>
</tr>
<tr>
<td>l) Vapour density</td>
<td>No data available</td>
</tr>
<tr>
<td>m) Relative density</td>
<td>1.200 g/cm³</td>
</tr>
<tr>
<td>n) Water solubility</td>
<td>No data available</td>
</tr>
</tbody>
</table>
9.2 Other safety information
No data available

10. STABILITY AND REACTIVITY

10.1 Reactivity
No data available

10.2 Chemical stability
Stable under recommended storage conditions.

10.3 Possibility of hazardous reactions
No data available

10.4 Conditions to avoid
Avoid moisture.

10.5 Incompatible materials
Strong oxidizing agents

10.6 Hazardous decomposition products
Other decomposition products - No data available
In the event of fire: see section 5

11. TOXICOLOGICAL INFORMATION

11.1 Information on toxicological effects

Acute toxicity
LD50 Oral - Rat - female - 3,543 mg/kg
LC50 Inhalation - Rat - male and female - 4 h - > 7.94 mg/l
(OECD Test Guideline 403)
LD50 Dermal - Rabbit - male and female - > 2,000 mg/kg
No data available

Skin corrosion/irritation
Skin - Rabbit
Result: Irritating to skin. - 24 h

Serious eye damage/eye irritation
No data available

Respiratory or skin sensitisation
Buehler Test - Guinea pig
Result: Does not cause skin sensitisation.

Germ cell mutagenicity
Hamster
ovary
Cytogenetic analysis

Carcinogenicity
IARC: No component of this product present at levels greater than or equal to 0.1% is identified as probable, possible or confirmed human carcinogen by IARC.
ACGIH: No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by ACGIH.
NTP: No component of this product present at levels greater than or equal to 0.1% is identified as a known or anticipated carcinogen by NTP.

OSHA: No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by OSHA.

Reproductive toxicity
No data available
Reproductive toxicity - Mouse - Oral
Maternal Effects: Other effects. Specific Developmental Abnormalities: Musculoskeletal system.
No data available

Specific target organ toxicity - single exposure
No data available

Specific target organ toxicity - repeated exposure
No data available

Aspiration hazard
No data available

Additional Information
RTECS: OD2800000
To the best of our knowledge, the chemical, physical, and toxicological properties have not been thoroughly investigated.

12. ECOLOGICAL INFORMATION

12.1 Toxicity
Toxicity to fish static test LC50 - Oncorhynchus mykiss (rainbow trout) - 130 mg/l - 96 h
Toxicity to daphnia and other aquatic invertebrates static test EC50 - Daphnia magna (Water flea) - 130 mg/l - 48 h (OECD Test Guideline 202)
Toxicity to algae
static test EC50 - Pseudokirchneriella subcapitata (algae) - > 2.8 g/l - 72 h (OECD Test Guideline 201)

Toxicity to bacteria
Respiration inhibition EC50 - Sludge Treatment - > 100 mg/l - 3 h (OECD Test Guideline 209)

12.2 Persistence and degradability
Biodegradability
aerobic - Exposure time 20 d
Result: 67 % - Readily biodegradable
Remarks: The 10 day time window criterion is not fulfilled.

12.3 Bioaccumulative potential
No data available

12.4 Mobility in soil
No data available

12.5 Results of PBT and vPvB assessment
PBT/vPvB assessment not available as chemical safety assessment not required/not conducted

12.6 Other adverse effects
No data available

13. DISPOSAL CONSIDERATIONS

13.1 Waste treatment methods
Product
Offer surplus and non-recyclable solutions to a licensed disposal company. Contact a licensed professional waste disposal service to dispose of this material.

Contaminated packaging
Dispose of as unused product.

14. TRANSPORT INFORMATION

DOT (US)
Not dangerous goods

IMDG
Not dangerous goods

IATA
Not dangerous goods

15. REGULATORY INFORMATION

SARA 302 Components
No chemicals in this material are subject to the reporting requirements of SARA Title III, Section 302.

SARA 313 Components
This material does not contain any chemical components with known CAS numbers that exceed the threshold (De Minimis) reporting levels established by SARA Title III, Section 313.

SARA 311/312 Hazards
Acute Health Hazard

Massachusetts Right To Know Components
No components are subject to the Massachusetts Right to Know Act.

Pennsylvania Right To Know Components
L-(+)-Lactic acid
<table>
<thead>
<tr>
<th>New Jersey Right To Know Components</th>
<th>California Prop. 65 Components</th>
</tr>
</thead>
<tbody>
<tr>
<td>L-(+)-Lactic acid</td>
<td>CAS-No. 79-33-4</td>
</tr>
<tr>
<td></td>
<td>CAS-No. 79-33-4</td>
</tr>
<tr>
<td></td>
<td>Revision Date</td>
</tr>
<tr>
<td></td>
<td>Revision Date</td>
</tr>
</tbody>
</table>
This product does not contain any chemicals known to State of California to cause cancer, birth defects, or any other reproductive harm.

16. OTHER INFORMATION

Full text of H-Statements referred to under sections 2 and 3.

- Eye Dam.: Serious eye damage
- H315: Causes skin irritation.
- H318: Causes serious eye damage.
- Skin Irrit.: Skin irritation

HMIS Rating
- Health hazard: 2
- Chronic Health Hazard:
  - Flammability: 1
  - Physical Hazard: 0
- NFPA Rating
  - Health hazard: 2
  - Fire Hazard: 1
  - Reactivity Hazard: 0

Further information
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Preparation Information
Sigma-Aldrich Corporation
Product Safety – Americas
Region 1-800-521-895

SIGMA-ALDRICH

SAFETY DATA SHEET

1. PRODUCT AND COMPANY IDENTIFICATION

1.1 Product identifiers
- Product name: Sodium citrate dihydrate
- Product Number: W302600
- Brand: Aldrich
- CAS-No.: 6132-04-3

1.2 Relevant identified uses of the substance or mixture and uses advised against
Identified uses: Laboratory chemicals, Manufacture of substances

1.3 Details of the supplier of the safety data sheet
Company: Sigma-Aldrich
3050 Spruce Street
SAINT LOUIS MO 63103 USA
Telephone: +1 800-325-5832
Fax: +1 800-325-5052

1.4 Emergency telephone number
Emergency Phone #: +1-703-527-3887 (CHEMTREC)

2. HAZARDS IDENTIFICATION
2.1 Classification of the substance or mixture
Not a hazardous substance or mixture.

2.2 GHS Label elements, including precautionary statements
Not a hazardous substance or mixture.

2.3 Hazards not otherwise classified (HNOC) or not covered by GHS - none

3. COMPOSITION/INFORMATION ON INGREDIENTS
3.1 Substances
Synonyms:
- Sodium citrate tribasicdihydrate
- Trisodium citratedihydrate
- Citric acidtrisodium saltdehydrate

Formula: $\text{C}_6\text{H}_5\text{Na}_3\text{O}_7 \cdot 2\text{H}_2\text{O}$
Molecular Weight: 294.1 g/mol
CAS-No.: 6132-04-3
EC-No.: 200-675-3

No ingredients are hazardous according to OSHA criteria.
No components need to be disclosed according to the applicable regulations.

4. FIRST AID MEASURES
4.1 Description of first aid measures If inhaled
If breathed in, move person into fresh air. If not breathing, give artificial respiration.

In case of skin contact
Wash off with soap and plenty of water.

In case of eye contact
Flush eyes with water as a precaution.

If swallowed
Never give anything by mouth to an unconscious person. Rinse mouth with water.

4.2 Most important symptoms and effects, both acute and delayed
The most important known symptoms and effects are described in the labelling (see section 2.2) and/or in section 11

4.3 Indication of any immediate medical attention and special treatment needed
No data available
5. FIREFIGHTING MEASURES

5.1 Extinguishing media Suitable
   
   Extinguishing media
   Use water spray, alcohol-resistant foam, dry chemical or carbon dioxide.

5.2 Special hazards arising from the substance or mixture
   
   Carbon oxides, Sodium oxides

5.3 Advice for firefighters
   
   Wear self contained breathing apparatus for fire fighting if necessary.

5.4 Further information
   
   no data available

6. ACCIDENTAL RELEASE MEASURES

6.1 Personal precautions, protective equipment and emergency procedures
   
   Avoid dust formation. Avoid breathing vapours, mist or gas.
   For personal protection see section 8.

6.2 Environmental precautions
   
   Do not let product enter drains.

6.3 Methods and materials for containment and cleaning up
   
   Sweep up and shovel. Keep in suitable, closed containers for disposal.

6.4 Reference to other sections
   
   For disposal see section 13.

7. HANDLING AND STORAGE

7.1 Precautions for safe handling
   
   Provide appropriate exhaust ventilation at places where dust is formed.
   For precautions see section 2.2.

7.2 Conditions for safe storage, including any incompatibilities
   
   Keep container tightly closed in a dry and well-ventilated place.
   
   Keep in a dry place.

7.3 Specific end use(s)
   
   Apart from the uses mentioned in section 1.2 no other specific uses are stipulated

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

8.1 Control parameters
   
   Components with workplace control parameters
   Contains no substances with occupational exposure limit values.

8.2 Exposure controls
   
   Appropriate engineering controls
   General industrial hygiene practice.

   Personal protective equipment

   Eye/face protection
   Use equipment for eye protection tested and approved under appropriate government standards such as NIOSH (US) or EN 166(EU).
Skin protection
Handle with gloves. Gloves must be inspected prior to use. Use proper glove removal technique (without touching glove's outer surface) to avoid skin contact with this product. Dispose of contaminated gloves after use in accordance with applicable laws and good laboratory practices. Wash and dry hands.

Full contact
Material: Nitrile rubber
Minimum layer thickness: 0.11 mm
Break through time: 480 min
Material tested: Dermatri® (KCL 740 / Aldrich Z677272, Size M)

Splash contact
Material: Nitrile rubber
Minimum layer thickness: 0.11 mm
Break through time: 480 min
Material tested: Dermatri® (KCL 740 / Aldrich Z677272, Size M)

data source: KCL GmbH, D-36124 Eichenzell, phone +49 (0)6659 87300, e-mail sales@kcl.de, test method: EN374
If used in solution, or mixed with other substances, and under conditions which differ from EN 374, contact the supplier of the CE approved gloves. This recommendation is advisory only and must be evaluated by an industrial hygienist and safety officer familiar with the specific situation of anticipated use by our customers. It should not be construed as offering an approval for any specific use scenario.

Body Protection
Choose body protection in relation to its type, to the concentration and amount of dangerous substances, and to the specific workplace. The type of protective equipment must be selected according to the concentration and amount of the dangerous substance at the specific workplace.

Respiratory protection
Respiratory protection is not required. Where protection from nuisance levels of dusts are desired, use type N95 (US) or type P1 (EN 143) dust masks. Use respirators and components tested and approved under appropriate government standards such as NIOSH (US) or CEN (EU).

Control of environmental exposure
Do not let product enter drains.

9. PHYSICAL AND CHEMICAL PROPERTIES
no data available

**explosive limits**

**e)** Vapour pressure  no data available  
**f)** Vapour density  no data available  
**g)** Relative density  no data available  
**h)** Water solubility  29.4 g/l at 20 °C (68 °F) - completely soluble  
**i)** Partition coefficient: n-octanol/water  no data available  
**j)** Auto-ignition temperature  no data available  
**k)** Decomposition temperature  no data available
l) Viscosity no data available
m) Explosive properties no data available
n) Oxidizing properties no data available

9.1 Other safety information
no data available

10. STABILITY AND REACTIVITY
10.1 Reactivity
no data available

10.2 Chemical stability
Stable under recommended storage conditions.

10.3 Possibility of hazardous reactions
no data available

10.4 Conditions to avoid
no data available

10.5 Incompatible materials
Strong oxidizing agents

10.6 Hazardous decomposition products
Other decomposition products - no data available
In the event of fire: see section 5

11. TOXICOLOGICAL INFORMATION
11.1 Information on toxicological effects
Acute toxicity
no data available
Inhalation: no data available
Dermal: no data available
no data available

Skin corrosion/irritation
no data available

Serious eye damage/eye irritation
no data available

Respiratory or skin sensitisation
no data available

Germ cell mutagenicity
no data available

Carcinogenicity
IARC: No component of this product present at levels greater than or equal to 0.1% is identified as probable, possible or confirmed human carcinogen by IARC.
ACGIH: No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by ACGIH.
NTP: No component of this product present at levels greater than or equal to 0.1% is identified as a known or anticipated carcinogen by NTP.
OSHA: No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by OSHA.
Reproductive toxicity
no data available
no data available

Specific target organ toxicity - single exposure
no data available

Specific target organ toxicity - repeated exposure
no data available

Aspiration hazard
no data available

Additional Information
RTECS: Not available
To the best of our knowledge, the chemical, physical, and toxicological properties have not been thoroughly investigated.

12. ECOLOGICAL INFORMATION

12.1 Toxicity
no data available

12.2 Persistence and degradability
no data available

12.3 Bioaccumulative potential
no data available

12.4 Mobility in soil
no data available

12.5 Results of PBT and vPvB assessment
PBT/vPvB assessment not available as chemical safety assessment not required/not conducted

12.6 Other adverse effects
no data available

13. DISPOSAL CONSIDERATIONS

13.1 Waste treatment methods
Product
Offer surplus and non-recyclable solutions to a licensed disposal company.

Contaminated packaging
Dispose of as unused product.

14. TRANSPORT INFORMATION

DOT (US)
Not dangerous goods

IMDG
Not dangerous goods

IATA
Not dangerous goods

15. REGULATORY INFORMATION

SARA 302 Components
SARA 302: No chemicals in this material are subject to the reporting requirements of SARA Title III, Section 302.

SARA 313 Components
SARA 313: This material does not contain any chemical components with known CAS numbers that exceed the threshold (De Minimis) reporting levels established by SARA Title III, Section 313.

SARA 311/312 Hazards
No SARA Hazards

Massachusetts Right To Know Components
No components are subject to the Massachusetts Right to Know Act.

Pennsylvania Right To Know Components
Trisodium citrate CAS-No. 6132-04-3

New Jersey Right To Know Components
Trisodium citrate CAS-No. 6132-04-3

California Prop. 65 Components
This product does not contain any chemicals known to State of California to cause cancer, birth defects, or any other reproductive harm.

16. OTHER INFORMATION

HMIS Rating
Health hazard: 0
Chronic Health Hazard: 0
Flammability: 0
Physical Hazard 0

NFPA Rating
Health hazard: 0
Fire Hazard: 0
Reactivity Hazard: 0

Further information
Copyright 2014 Sigma-Aldrich Co. LLC. License granted to make unlimited paper copies for internal use only. The above information is believed to be correct but does not purport to be all inclusive and shall be used only as a guide. The information in this document is based on the present state of our knowledge and is applicable to the product with regard to appropriate safety precautions. It does not represent any guarantee of the properties of the product. Sigma-Aldrich Corporation and its Affiliates shall not be held liable for any damage resulting from handling or from contact with the above product. See www.sigma-aldrich.com and/or the reverse side of invoice or packing slip for additional terms and conditions of sale.

Preparation Information
Sigma-Aldrich Corporation
Product Safety – Americas Region
1. PRODUCT AND COMPANY IDENTIFICATION

1.1 Product identifiers

Product name: Sulfuric acid

Product Number: 339741
Brand: Aldrich
Index-No.: 016-020-00-8
CAS-No.: 7664-93-9

1.2 Relevant identified uses of the substance or mixture and uses advised against

Identified uses: Laboratory chemicals, Synthesis of substances

1.3 Details of the supplier of the safety data sheet

Company: Sigma-Aldrich
3050 Spruce Street
SAINT LOUIS MO 63103
USA

Telephone: +1 800-325-5832
Fax: +1 800-325-5052

1.4 Emergency telephone number

Emergency Phone #: +1-703-527-3887 (CHEMTREC)

2. HAZARDS IDENTIFICATION

2.1 Classification of the substance or mixture

GHS Classification in accordance with 29 CFR 1910 (OSHA HCS)
Corrosive to metals (Category 1), H290
Skin corrosion (Category 1A), H314
Serious eye damage (Category 1), H318

For the full text of the H-Statements mentioned in this Section, see Section 16.

2.2 GHS Label elements, including precautionary statements

Pictogram

Signal word: Danger

Hazard statement(s)
H290: May be corrosive to metals.
H314: Causes severe skin burns and eye damage.
Precautionary statement(s)

P234  Keep only in original container.
P264  Wash skin thoroughly after handling.
P280  Wear protective gloves/ protective clothing/ eye protection/ face protection.
P301 + P330 + P331  IF SWALLOWED: Rinse mouth. Do NOT induce vomiting.
P303 + P361 + P353  IF ON SKIN (or hair): Take off immediately all contaminated clothing. Rinse skin with water/shower.
P304 + P340 + P310  IF INHALED: Remove person to fresh air and keep comfortable for breathing. Immediately call a POISON CENTER/doctor.
P305 + P351 + P338 + P310  IF IN EYES: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing. Immediately call a POISON CENTER/doctor.
P363  Wash contaminated clothing before reuse.
P390  Absorb spillage to prevent material damage.
P405  Store locked up.
P406  Store in corrosive resistant stainless steel container with a resistant inner liner.
P501  Dispose of contents/ container to an approved waste disposal plant.

2.3  Hazards not otherwise classified (HNOC) or not covered by GHS - none

3. COMPOSITION/INFORMATION ON INGREDIENTS

3.1  Substances

<table>
<thead>
<tr>
<th>Formula</th>
<th>H₂O₄S</th>
</tr>
</thead>
<tbody>
<tr>
<td>Molecular weight</td>
<td>98.08 g/mol</td>
</tr>
<tr>
<td>CAS-No.</td>
<td>7664-93-9</td>
</tr>
<tr>
<td>EC-No.</td>
<td>231-639-5</td>
</tr>
<tr>
<td>Index-No.</td>
<td>016-020-00-8</td>
</tr>
<tr>
<td>Registration number</td>
<td>01-2119458838-20-XXXX</td>
</tr>
</tbody>
</table>

Hazardous components

<table>
<thead>
<tr>
<th>Component</th>
<th>Classification</th>
<th>Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sulfuric acid</td>
<td>Met. Corr. 1; Skin Corr. 1A; Eye Dam. 1; H290, H314</td>
<td>&lt;= 100 %</td>
</tr>
</tbody>
</table>

For the full text of the H-Statements mentioned in this Section, see Section 16.

4. FIRST AID MEASURES

4.1  Description of first aid measures

General advice
Consult a physician. Show this safety data sheet to the doctor in attendance. Move out of dangerous area.

If inhaled
If breathed in, move person into fresh air. If not breathing, give artificial respiration. Consult a physician.

In case of skin contact
Take off contaminated clothing and shoes immediately. Wash off with soap and plenty of water. Consult a physician.

In case of eye contact
Rinse thoroughly with plenty of water for at least 15 minutes and consult a physician. Continue rinsing eyes during transport to hospital.

If swallowed
Do NOT induce vomiting. Never give anything by mouth to an unconscious person. Rinse mouth with water. Consult a physician.

4.2  Most important symptoms and effects, both acute and delayed
The most important known symptoms and effects are described in the labelling (see section 2.2) and/or in section 11

4.3 Indication of any immediate medical attention and special treatment needed
No data available

5. FIREFIGHTING MEASURES

5.1 Extinguishing media Suitable extinguishing media
Use water spray, alcohol-resistant foam, dry chemical or carbon dioxide.

5.2 Special hazards arising from the substance or mixture
No data available

5.3 Advice for firefighters
Wear self-contained breathing apparatus for firefighting if necessary.

5.4 Further information
No data available

6. ACCIDENTAL RELEASE MEASURES

6.1 Personal precautions, protective equipment and emergency procedures
Wear respiratory protection. Avoid breathing vapours, mist or gas. Ensure adequate ventilation. Evacuate personnel to safe areas.
For personal protection see section 8.

6.2 Environmental precautions
Do not let product enter drains.

6.3 Methods and materials for containment and cleaning up
Soak up with inert absorbent material and dispose of as hazardous waste. Keep in suitable, closed containers for disposal.

6.4 Reference to other sections
For disposal see section 13.

7. HANDLING AND STORAGE

7.1 Precautions for safe handling
Avoid inhalation of vapour or mist.
For precautions see section 2.2.

7.2 Conditions for safe storage, including any incompatibilities
Keep container tightly closed in a dry and well-ventilated place. Containers which are opened must be carefully resealed and kept upright to prevent leakage.

7.3 Specific end use(s)
Apart from the uses mentioned in section 1.2 no other specific uses are stipulated

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

8.1 Control parameters

<table>
<thead>
<tr>
<th>Component</th>
<th>CAS-No.</th>
<th>Value</th>
<th>Control parameters</th>
<th>Basis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sulfuric acid</td>
<td>7664-93-9</td>
<td>TWA</td>
<td>0.2 mg/m³</td>
<td>USA. ACGIH Threshold Limit Values (TLV)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TWA</td>
<td>1 mg/m³</td>
<td>USA. OSHA - TABLE Z-1 Limits for Air Contaminants - 1910.1000</td>
</tr>
</tbody>
</table>
Derived No Effect Level (DNEL)

<table>
<thead>
<tr>
<th>Application Area</th>
<th>Exposure routes</th>
<th>Health effect</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Workers</td>
<td>Inhalation</td>
<td>Acute local effects</td>
<td>0.1 mg/m³</td>
</tr>
<tr>
<td>Workers</td>
<td>Inhalation</td>
<td>Long-term local effects</td>
<td>0.05 mg/m³</td>
</tr>
</tbody>
</table>

Predicted No Effect Concentration (PNEC)

<table>
<thead>
<tr>
<th>Compartment</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marine water</td>
<td>0.00025 mg/l</td>
</tr>
<tr>
<td>Fresh water</td>
<td>0.0025 mg/l</td>
</tr>
<tr>
<td>Marine sediment</td>
<td>0.002 mg/kg</td>
</tr>
<tr>
<td>Fresh water sediment</td>
<td>0.002 mg/kg</td>
</tr>
<tr>
<td>Onsite sewage treatment plant</td>
<td>8.8 mg/l</td>
</tr>
</tbody>
</table>

8.2 Exposure controls

Appropriate engineering controls
Handle in accordance with good industrial hygiene and safety practice. Wash hands before breaks and at the end of workday.

Personal protective equipment
Eye/face protection
Tightly fitting safety goggles. Faceshield (8-inch minimum). Use equipment for eye protection tested and approved under appropriate government standards such as NIOSH (US) or EN 166(EU).

Skin protection
Handle with gloves. Gloves must be inspected prior to use. Use proper glove removal technique (without touching glove's outer surface) to avoid skin contact with this product. Dispose of contaminated gloves after use in accordance with applicable laws and good laboratory practices. Wash and dry hands.

Full contact
Material: Fluorinated rubber
Minimum layer thickness: 0.7 mm
Break through time: 480 min
Material tested: Vitoject® (KCL 890 / Aldrich Z677698, Size M)

Splash contact
Material: Nitrile rubber
Minimum layer thickness: 0.2 mm
Break through time: 30 min
Material tested: Dermatril® P (KCL 743 / Aldrich Z677388, Size M)

data source: KCL GmbH, D-36124 Eichenzell, phone +49 (0)6659 87300, e-mail sales@kcl.de, test method: EN374

If used in solution, or mixed with other substances, and under conditions which differ from EN 374, contact the supplier of the CE approved gloves. This recommendation is advisory only and must be evaluated by an industrial hygienist and safety officer familiar with the specific situation of anticipated use by our customers. It should not be construed as offering an approval for any specific use scenario.

Body Protection
Complete suit protecting against chemicals. The type of protective equipment must be selected according to the concentration and amount of the dangerous substance at the specific workplace.

Respiratory protection
Where risk assessment shows air-purifying respirators are appropriate use a full-face respirator with multi-purpose combination (US) or type ABEK (EN 14387) respirator cartridges as a backup to engineering controls. If the respirator is the sole means of protection, use a full-face supplied air respirator. Use respirators and
components tested and approved under appropriate government standards such as NIOSH (US) or CEN (EU).

**Control of environmental exposure**
Do not let product enter drains.

---

**9. PHYSICAL AND CHEMICAL PROPERTIES**

**9.1 Information on basic physical and chemical properties**

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) Appearance</td>
<td>Form: clear, liquid</td>
</tr>
<tr>
<td>b) Odour</td>
<td>No data available</td>
</tr>
<tr>
<td>c) Odour Threshold</td>
<td>No data available</td>
</tr>
<tr>
<td>d) pH</td>
<td>1.2 at 5 g/l</td>
</tr>
<tr>
<td>e) Melting point/freezing point</td>
<td>3 °C (37 °F)</td>
</tr>
<tr>
<td>f) Initial boiling point and boiling range</td>
<td>290 °C (554 °F) - lit.</td>
</tr>
<tr>
<td></td>
<td>Description</td>
</tr>
<tr>
<td>---</td>
<td>-----------------------------------------</td>
</tr>
<tr>
<td>g)</td>
<td>Flash point</td>
</tr>
<tr>
<td>h)</td>
<td>Evaporation rate</td>
</tr>
<tr>
<td>i)</td>
<td>Flammability (solid, gas)</td>
</tr>
<tr>
<td>j)</td>
<td>Upper/lower flammability or explosive limits</td>
</tr>
<tr>
<td>k)</td>
<td>Vapour pressure</td>
</tr>
<tr>
<td>l)</td>
<td>Vapour density</td>
</tr>
<tr>
<td>m)</td>
<td>Relative density</td>
</tr>
<tr>
<td>n)</td>
<td>Water solubility</td>
</tr>
<tr>
<td>o)</td>
<td>Partition coefficient: n-octanol/water</td>
</tr>
<tr>
<td>p)</td>
<td>Auto-ignition temperature</td>
</tr>
<tr>
<td>q)</td>
<td>Decomposition temperature</td>
</tr>
</tbody>
</table>
r) Viscosity No data available
s) Explosive properties No data available
t) Oxidizing properties No data available

9.2 Other safety information

- Surface tension: 55.1 mN/m at 20 °C (68 °F)
- Relative vapour density: 3.39 - (Air = 1.0)

10. STABILITY AND REACTIVITY

10.1 Reactivity
No data available

10.2 Chemical stability
Stable under recommended storage conditions.

10.3 Possibility of hazardous reactions
No data available

10.4 Conditions to avoid
No data available

10.5 Incompatible materials
Bases, Halides, Organic materials, Carbides, fulminates, Nitrates, picrates, Cyanides, Chlorates, alkali halides, Zinc salts, permanganates, e.g. potassium permanganate, Hydrogen peroxide, Azides, Perchlorates, Nitromethane, phosphorous, Reacts violently with: cyclopentadiene, cyclopentanone oxime, nitroaryl amines, hexalithium disilicide, phosphorous(III) oxide, Powdered metals.

10.6 Hazardous decomposition products
Hazardous decomposition products formed under fire conditions. - Sulphur oxides
Other decomposition products - No data available
In the event of fire: see section 5

11. TOXICOLOGICAL INFORMATION

11.1 Information on toxicological effects

- Acute toxicity
  - LD50 Oral - Rat: 2,140 mg/kg
  - LC50 Inhalation - Rat: 2 h - 510 mg/m3
  - Dermal: No data available
  - No data available

Skin corrosion/irritation
  - Skin - Rabbit
  - Result: Extremely corrosive and destructive to tissue.

Serious eye damage/eye irritation
  - Eyes - Rabbit
  - Result: Corrosive to eyes

Respiratory or skin sensitisation
  - No data available

Germ cell mutagenicity
  - No data available

Carcinogenicity
  - The International Agency for Research on Cancer (IARC) has determined that occupational exposure to strong-
inorganic-acid mists containing sulfuric acid is carcinogenic to humans (group 1).

IARC: No component of this product present at levels greater than or equal to 0.1% is identified as probable, possible or confirmed human carcinogen by IARC.

NTP: No component of this product present at levels greater than or equal to 0.1% is identified as a known or anticipated carcinogen by NTP.

OSHA: No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by OSHA.

Reproductive toxicity
No data available

Specific target organ toxicity - single exposure
No data available

Specific target organ toxicity - repeated exposure
No data available

Aspiration hazard
No data available

Additional Information
RTECS: WS5600000
Material is extremely destructive to tissue of the mucous membranes and upper respiratory tract, eyes, and skin, spasm, inflammation and edema of the larynx, spasm, inflammation and edema of the bronchi, pneumonitis, pulmonary edema, burning sensation, Cough, wheezing, laryngitis, Shortness of breath, Headache, Nausea, Vomiting, Pulmonary edema. Effects may be delayed., To the best of our knowledge, the chemical, physical, and toxicological properties have not been thoroughly investigated.

Stomach - Irregularities - Based on Human Evidence
Stomach - Irregularities - Based on Human Evidence

12. ECOLOGICAL INFORMATION

12.1 Toxicity

Toxicity to fish LC50 - Gambusia affinis (Mosquito fish) - 42 mg/l - 96 h
Toxicity to daphnia and other aquatic invertebrates EC50 - Daphnia magna (Water flea) - 29 mg/l - 24 h

12.2 Persistence and degradability
The methods for determining the biological degradability are not applicable to inorganic substances.

12.3 Bioaccumulative potential
No data available
12.4 Mobility in soil
No data available

12.5 Results of PBT and vPvB assessment
PBT/vPvB assessment not available as chemical safety assessment not required/not conducted

12.6 Other adverse effects

13. DISPOSAL CONSIDERATIONS

13.1 Waste treatment methods

Product
Offer surplus and non-recyclable solutions to a licensed disposal company. Contact a licensed professional waste disposal service to dispose of this material. Dissolve or mix the material with a combustible solvent and burn in a chemical incinerator equipped with an afterburner and scrubber.

Contaminated packaging
Dispose of as unused product.

14. TRANSPORT INFORMATION

DOT (US)
UN number: 1830  Class: 8  Packing group: II
Proper shipping name: Sulfuric acid
Reportable Quantity (RQ): 1000 lbs
Poison Inhalation Hazard: No

IMDG
UN number: 1830  Class: 8  Packing group: II  EMS-No: F-A, S-B
Proper shipping name: SULPHURIC ACID

IATA
UN number: 1830  Class: 8  Packing group: II
Proper shipping name: Sulphuric acid

15. REGULATORY INFORMATION

SARA 302 Components
The following components are subject to reporting levels established by SARA Title III, Section 302:

<table>
<thead>
<tr>
<th>CAS-No.</th>
<th>Revision Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>7664-93-9</td>
<td>2007-07-01</td>
</tr>
</tbody>
</table>

SARA 313 Components
The following components are subject to reporting levels established by SARA Title III, Section 313:

Sulfuric acid

**SARA 311/312 Hazards**

Acute Health Hazard, Chronic Health Hazard

**Massachusetts Right To Know Components**

<table>
<thead>
<tr>
<th>CAS-No.</th>
<th>Revision Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>7664-93-9</td>
<td>2007-07-01</td>
</tr>
</tbody>
</table>

**Pennsylvania Right To Know Components**

<table>
<thead>
<tr>
<th>CAS-No.</th>
<th>Revision Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>7664-93-9</td>
<td>2007-07-01</td>
</tr>
</tbody>
</table>

**New Jersey Right To Know Components**

<table>
<thead>
<tr>
<th>CAS-No.</th>
<th>Revision Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>7664-93-9</td>
<td>2007-07-01</td>
</tr>
</tbody>
</table>

**California Prop. 65 Components**

WARNING! This product contains a chemical known to the State of California to cause cancer.

<table>
<thead>
<tr>
<th>CAS-No.</th>
<th>Revision Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>7664-93-9</td>
<td>2007-09-28</td>
</tr>
</tbody>
</table>

### 16. OTHER INFORMATION

**Full text of H-Statements referred to under sections 2 and 3.**

- **Eye Dam.**
  - Serious eye damage
- **H290.**
  - May be corrosive to metals.
- **H314.**
  - Causes severe skin burns and eye damage.
- **H318.**
  - Causes serious eye damage.
- **Met. Corr.**
  - Corrosive to metals

**HMIS Rating**

- Health hazard: 3
- Chronic Health Hazard: *
- Flammability: 0
- Physical Hazard: 0

**NFPA Rating**

- Health hazard: 3
- Fire Hazard: 0
- Reactivity Hazard: 0

**Further information**

Copyright 2016 Sigma-Aldrich Co. LLC. License granted to make unlimited paper copies for internal use only. The above information is believed to be correct but does not purport to be all inclusive and shall be used only as a guide. The information in this document is based on the present state of our knowledge and is applicable to the product with regard to appropriate safety precautions. It does not represent any guarantee of the properties of the product. Sigma-Aldrich Corporation and its Affiliates shall not be held liable for any damage resulting from handling or from contact with the above product. See www.sigma-aldrich.com and/or the reverse side of invoice or packing slip for additional terms and conditions of sale.

**Preparation Information**

Sigma-Aldrich Corporation
Product Safety – Americas Region
1-800-521-8956

Version: 5.12 Revision Date: 09/23/2016 Print Date: 03/18/2017
1. PRODUCT AND COMPANY IDENTIFICATION

1.1 Product identifiers
- Product name: Xylitol
- Product Number: X3375
- Brand: Sigma
- CAS-No.: 87-99-0

1.2 Relevant identified uses of the substance or mixture and uses advised against
Identified uses: Laboratory chemicals, Manufacture of substances

1.3 Details of the supplier of the safety data sheet
- Company: Sigma-Aldrich
  3050 Spruce Street
  SAINT LOUIS MO 63103
  USA
- Telephone: +1 800-325-5832
- Fax: +1 800-325-5052

1.4 Emergency telephone number
- Emergency Phone #: +1-703-527-3887 (CHEMTREC)

2. HAZARDS IDENTIFICATION

2.1 Classification of the substance or mixture
- Not a hazardous substance or mixture.

2.2 GHS Label elements, including precautionary statements
- Not a hazardous substance or mixture.

2.3 Hazards not otherwise classified (HNOC) or not covered by GHS - none

3. COMPOSITION/INFORMATION ON INGREDIENTS

3.1 Substances
- Synonyms: Xylite
- Formula: C₅H₁₂O₅
- Molecular weight: 152.15 g/mol
- CAS-No.: 87-99-0
- EC-No.: 201-788-0

No components need to be disclosed according to the applicable regulations.
4. FIRST AID MEASURES

4.1 Description of first aid measures

If inhaled
If breathed in, move person into fresh air. If not breathing, give artificial respiration.

In case of skin contact
Wash off with soap and plenty of water.

In case of eye contact
Flush eyes with water as a precaution.

If swallowed
Never give anything by mouth to an unconscious person. Rinse mouth with water.

4.2 Most important symptoms and effects, both acute and delayed
The most important known symptoms and effects are described in the labelling (see section 2.2) and/or in section 11.

4.3 Indication of any immediate medical attention and special treatment needed
No data available

5. FIREFIGHTING MEASURES

5.1 Extinguishing media
Suitable extinguishing media
Use water spray, alcohol-resistant foam, dry chemical or carbon dioxide.

5.2 Special hazards arising from the substance or mixture
Carbon oxides

5.3 Advice for firefighters
Wear self-contained breathing apparatus for firefighting if necessary.

5.4 Further information
No data available

6. ACCIDENTAL RELEASE MEASURES

6.1 Personal precautions, protective equipment and emergency procedures
Avoid dust formation. Avoid breathing vapours, mist or gas. For personal protection see section 8.

6.2 Environmental precautions
No special environmental precautions required.

6.3 Methods and materials for containment and cleaning up
Sweep up and shovel. Keep in suitable, closed containers for disposal.

6.4 Reference to other sections
For disposal see section 13.

7. HANDLING AND STORAGE

7.1 Precautions for safe handling
Further processing of solid materials may result in the formation of combustible dusts. The potential for combustible dust formation should be taken into consideration before additional processing occurs. Provide appropriate exhaust ventilation at places where dust is formed. For precautions see section 2.2.

7.2 Conditions for safe storage, including any incompatibilities
Keep container tightly closed in a dry and well-ventilated place. Storage class (TRGS 510): Non Combustible Solids
7.3 Specific end use(s)
Apart from the uses mentioned in section 1.2 no other specific uses are stipulated.

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

8.1 Control parameters

Components with workplace control parameters
Contains no substances with occupational exposure limit values.

8.2 Exposure controls

Appropriate engineering controls
General industrial hygiene practice.

Personal protective equipment

Eye/face protection
Use equipment for eye protection tested and approved under appropriate government standards such as NIOSH (US) or EN 166(EU).

Skin protection
Handle with gloves. Gloves must be inspected prior to use. Use proper glove removal technique (without touching glove's outer surface) to avoid skin contact with this product. Dispose of contaminated gloves after use in accordance with applicable laws and good laboratory practices. Wash and dry hands.

Full contact
Material: Nitrile rubber
Minimum layer thickness: 0.11 mm
Break through time: 480 min
Material tested:Dermatril® (KCL 740 / Aldrich Z677272, Size M)

Splash contact
Material: Nitrile rubber
Minimum layer thickness: 0.11 mm
Break through time: 480 min
Material tested:Dermatril® (KCL 740 / Aldrich Z677272, Size M)

data source: KCL GmbH, D-36124 Eichenzell, phone +49 (0)6659 87300, e-mail sales@kcl.de, test method: EN374
If used in solution, or mixed with other substances, and under conditions which differ from EN 374, contact the supplier of the CE approved gloves. This recommendation is advisory only and must be evaluated by an industrial hygienist and safety officer familiar with the specific situation of anticipated use by our customers. It should not be construed as offering an approval for any specific use scenario.

Body Protection
Choose body protection in relation to its type, to the concentration and amount of dangerous substances, and to the specific work-place. The type of protective equipment must be selected according to the concentration and amount of the dangerous substance at the specific workplace.

Respiratory protection
Respiratory protection is not required. Where protection from nuisance levels of dusts are desired, use type N95 (US) or type P1 (EN 143) dust masks. Use respirators and components tested and approved under appropriate government standards such as NIOSH (US) or CEN (EU).

Control of environmental exposure
No special environmental precautions required.

9. PHYSICAL AND CHEMICAL PROPERTIES

9.1 Information on basic physical and chemical properties

a) Appearance
Form: crystalline
Colour: colourless
b) Odour: No data available

c) Odour Threshold: No data available

d) pH: No data available

e) Melting point/freezing point: Melting point/range: 94 - 97 °C (201 - 207 °F)

f) Initial boiling point and boiling range: No data available

g) Flash point: No data available

h) Evaporation rate: No data available

i) Flammability (solid, gas): No data available

j) Upper/lower flammability or: No data available
<table>
<thead>
<tr>
<th></th>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>k)</td>
<td>Vapour pressure</td>
<td>No data available</td>
</tr>
<tr>
<td>l)</td>
<td>Vapour density</td>
<td>No data available</td>
</tr>
<tr>
<td>m)</td>
<td>Relative density</td>
<td>No data available</td>
</tr>
<tr>
<td>n)</td>
<td>Water solubility</td>
<td>No data available</td>
</tr>
<tr>
<td>o)</td>
<td>Partition coefficient: n-octanol/water</td>
<td>No data available</td>
</tr>
<tr>
<td>p)</td>
<td>Auto-ignition temperature</td>
<td>No data available</td>
</tr>
<tr>
<td>q)</td>
<td>Decomposition temperature</td>
<td>No data available</td>
</tr>
</tbody>
</table>
9.2 Other safety information
No data available

10. STABILITY AND REACTIVITY

10.1 Reactivity
No data available

10.2 Chemical stability
Stable under recommended storage conditions.

10.3 Possibility of hazardous reactions
No data available

10.4 Conditions to avoid
No data available

10.5 Incompatible materials
Strong oxidizing agents

10.6 Hazardous decomposition products
Other decomposition products - No data available
In the event of fire: see section 5

11. TOXICOLOGICAL INFORMATION

11.1 Information on toxicological effects

Acute toxicity
LD50 Oral - Rat - 16,500 mg/kg
Inhalation: No data available
Dermal: No data available
No data available

Skin corrosion/irritation
No data available

Serious eye damage/eye irritation
No data available

Respiratory or skin sensitisation
No data available

Germ cell mutagenicity
No data available

Carcinogenicity

IARC: No component of this product present at levels greater than or equal to 0.1% is identified as probable, possible or confirmed human carcinogen by IARC.

ACGIH: No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by ACGIH.

NTP: No component of this product present at levels greater than or equal to 0.1% is identified as a known or anticipated carcinogen by NTP.

OSHA: No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by OSHA.
Reproductive toxicity
No data available
No data available

Specific target organ toxicity - single exposure
No data available

Specific target organ toxicity - repeated exposure
No data available

Aspiration hazard
No data available

Additional Information
RTECS: Not available
To the best of our knowledge, the chemical, physical, and toxicological properties have not been thoroughly investigated.

12. ECOLOGICAL INFORMATION

12.1 Toxicity
No data available

12.2 Persistence and degradability
No data available

12.3 Bioaccumulative potential
No data available

12.4 Mobility in soil
No data available

12.5 Results of PBT and vPvB assessment
PBT/vPvB assessment not available as chemical safety assessment not required/not conducted

12.6 Other adverse effects
No data available

13. DISPOSAL CONSIDERATIONS

13.1 Waste treatment methods
Product
Offer surplus and non-recyclable solutions to a licensed disposal company.

Contaminated packaging
Dispose of as unused product.

14. TRANSPORT INFORMATION

DOT (US)
Not dangerous goods

IMDG
Not dangerous goods

**IATA**
Not dangerous goods

### 15. REGULATORY INFORMATION

**SARA 302 Components**
No chemicals in this material are subject to the reporting requirements of SARA Title III, Section 302.

**SARA 313 Components**
This material does not contain any chemical components with known CAS numbers that exceed the threshold (De Minimis) reporting levels established by SARA Title III, Section 313.

**SARA 311/312 Hazards**
No SARA Hazards

**Massachusetts Right To Know Components**
No components are subject to the Massachusetts Right to Know Act.

**Pennsylvania Right To Know Components**

<table>
<thead>
<tr>
<th>CAS-No.</th>
<th>Revision Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>87-99-0</td>
<td></td>
</tr>
</tbody>
</table>

**New Jersey Right To Know Components**

<table>
<thead>
<tr>
<th>CAS-No.</th>
<th>Revision Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>87-99-0</td>
<td></td>
</tr>
</tbody>
</table>

**Xylitol**

**California Prop. 65 Components**
This product does not contain any chemicals known to State of California to cause cancer, birth defects, or any other reproductive harm.

### 16. OTHER INFORMATION

**HMIS Rating**

<table>
<thead>
<tr>
<th>Health hazard:</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chronic Health Hazard:</td>
<td>0</td>
</tr>
<tr>
<td>Flammability:</td>
<td>0</td>
</tr>
<tr>
<td>Physical Hazard</td>
<td>0</td>
</tr>
</tbody>
</table>

**NFPA Rating**

| Health hazard: | 0 |
| Fire Hazard: | 0 |
| Reactivity Hazard: | 0 |

**Further information**

Copyright 2015 Sigma-Aldrich Co. LLC. License granted to make unlimited paper copies for internal use only. The above information is believed to be correct but does not purport to be all inclusive and shall be used only as a guide. The information in this document is based on the present state of our knowledge and is applicable to the product with regard to appropriate safety precautions. It does not represent any guarantee of the properties of the product. Sigma-Aldrich Corporation and its Affiliates shall not be held liable for any damage resulting from handling or from contact with the above product. See www.sigma-aldrich.com and/or the reverse side of invoice or packing slip for additional terms and conditions of sale.

**Preparation Information**
Sigma-Aldrich Corporation
Product Safety – Americas Region
1. PRODUCT AND COMPANY IDENTIFICATION

1.1 Product identifiers

Product name : D- (+)-Xylose
Product Number : X1500
Brand : Sigma-Aldrich
CAS-No. : 58-86-6

1.2 Relevant identified uses of the substance or mixture and uses advised against

Identified uses : Laboratory chemicals, Manufacture of substances

1.3 Details of the supplier of the safety data sheet

Company : Sigma-Aldrich
3050 Spruce Street
SAINT LOUIS MO 63103 USA
Telephone : +1 800-325-5832
Fax : +1 800-325-5052

1.4 Emergency telephone number

Emergency Phone # : +1-703-527-3887 (CHEMTREC)

2. HAZARDS IDENTIFICATION

2.1 Classification of the substance or mixture

Not a hazardous substance or mixture.

2.2 GHS Label elements, including precautionary statements

Not a hazardous substance or mixture.

2.3 Hazards not otherwise classified (HNOC) or not covered by GHS - none

3. COMPOSITION/INFORMATION ON INGREDIENTS

3.1 Substances

Formula : C₅H₁₀O₅
Molecular weight : 150.13 g/mol
CAS-No. : 58-86-6
EC-No. : 200-400-7

No components need to be disclosed according to the applicable regulations.

4. FIRST AID MEASURES
4.1 Description of first aid measures

If inhaled
If breathed in, move person into fresh air. If not breathing, give artificial respiration.

In case of skin contact
Wash off with soap and plenty of water.

In case of eye contact
Flush eyes with water as a precaution.

If swallowed
Never give anything by mouth to an unconscious person. Rinse mouth with water.

4.2 Most important symptoms and effects, both acute and delayed
The most important known symptoms and effects are described in the labelling (see section 2.2) and/or in section 11

4.3 Indication of any immediate medical attention and special treatment needed
No data available

5. FIREFIGHTING MEASURES

5.1 Extinguishing media
Suitable extinguishing media
Use water spray, alcohol-resistant foam, dry chemical or carbon dioxide.

5.2 Special hazards arising from the substance or mixture
Carbon oxides

5.3 Advice for firefighters
Wear self-contained breathing apparatus for firefighting if necessary.

5.4 Further information
No data available

6. ACCIDENTAL RELEASE MEASURES

6.1 Personal precautions, protective equipment and emergency procedures
Avoid dust formation. Avoid breathing vapours, mist or gas.
For personal protection see section 8.

6.2 Environmental precautions
No special environmental precautions required.

6.3 Methods and materials for containment and cleaning up
Sweep up and shovel. Keep in suitable, closed containers for disposal.

6.4 Reference to other sections
For disposal see section 13.

7. HANDLING AND STORAGE

7.1 Precautions for safe handling
Further processing of solid materials may result in the formation of combustible dusts. The potential for combustible dust formation should be taken into consideration before additional processing occurs.
Provide appropriate exhaust ventilation at places where dust is formed.
For precautions see section 2.2.

7.2 Conditions for safe storage, including any incompatibilities
Keep container tightly closed in a dry and well-ventilated place. Storage class (TRGS 510): Non Combustible Solids

7.3 Specific end use(s)
Apart from the uses mentioned in section 1.2 no other specific uses are stipulated
8. EXPOSURE CONTROLS/PERSONAL PROTECTION

8.1 Control parameters

Components with workplace control parameters
Contains no substances with occupational exposure limit values.

8.2 Exposure controls

Appropriate engineering controls
General industrial hygiene practice.

Personal protective equipment

Eye/face protection
Use equipment for eye protection tested and approved under appropriate government standards such as NIOSH (US) or EN 166(EU).

Skin protection
Handle with gloves. Gloves must be inspected prior to use. Use proper glove removal technique (without touching glove's outer surface) to avoid skin contact with this product. Dispose of contaminated gloves after use in accordance with applicable laws and good laboratory practices. Wash and dry hands.

Full contact
Material: Nitrile rubber
Minimum layer thickness: 0.11 mm
Break through time: 480 min
Material tested:Dermatril® (KCL 740 / Aldrich Z677272, Size M)

Splash contact
Material: Nitrile rubber
Minimum layer thickness: 0.11 mm
Break through time: 480 min
Material tested:Dermatril® (KCL 740 / Aldrich Z677272, Size M)

data source: KCL GmbH, D-36124 Eichenzell, phone +49 (0)6659 87300, e-mail sales@kcl.de, test method: EN374
If used in solution, or mixed with other substances, and under conditions which differ from EN 374, contact the supplier of the CE approved gloves. This recommendation is advisory only and must be evaluated by an industrial hygienist and safety officer familiar with the specific situation of anticipated use by our customers. It should not be construed as offering an approval for any specific use scenario.

Body Protection
Choose body protection in relation to its type, to the concentration and amount of dangerous substances, and to the specific workplace. The type of protective equipment must be selected according to the concentration and amount of the dangerous substance at the specific workplace.

Respiratory protection
Respiratory protection is not required. Where protection from nuisance levels of dusts are desired, use type N95 (US) or type P1 (EN 143) dust masks. Use respirators and components tested and approved under appropriate government standards such as NIOSH (US) or CEN (EU).

Control of environmental exposure
No special environmental precautions required.

9. PHYSICAL AND CHEMICAL PROPERTIES

9.1 Information on basic physical and chemical properties

a) Appearance
Form: crystalline
Colour: white

b) Odour
No data available

c) Odour Threshold
No data available
d) pH  
   4.5 - 6.0

e) Melting point/freezing point  
   Melting point/range: 154 - 158 °C (309 - 316 °F)

f) Initial boiling point and boiling range  
   No data available

g) Flash point  
   No data available

h) Evaporation rate  
   No data available

i) Flammability (solid, gas)  
   The product is not flammable. - Flammability (solids
<table>
<thead>
<tr>
<th>Item</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) Explosive limits</td>
<td>No data available</td>
</tr>
<tr>
<td>b) Vapour pressure</td>
<td>No data available</td>
</tr>
<tr>
<td>c) Vapour density</td>
<td>No data available</td>
</tr>
<tr>
<td>d) Relative density</td>
<td>1.525 g/cm³</td>
</tr>
<tr>
<td>e) Water solubility</td>
<td>150.13 g/l at 20 °C (68 °F)</td>
</tr>
<tr>
<td>f) Partition coefficient: n-octanol/water</td>
<td>No data available</td>
</tr>
<tr>
<td>g) Auto-ignition temperature</td>
<td>No data available</td>
</tr>
<tr>
<td>h) Decomposition temperature</td>
<td>No data available</td>
</tr>
</tbody>
</table>
9.2 Other safety information
No data available

10. STABILITY AND REACTIVITY

10.1 Reactivity
No data available

10.2 Chemical stability
Stable under recommended storage conditions.

10.3 Possibility of hazardous reactions
No data available

10.4 Conditions to avoid
No data available

10.5 Incompatible materials
Strong oxidizing agents

10.6 Hazardous decomposition products
Other decomposition products - No data available
In the event of fire: see section 5

11. TOXICOLOGICAL INFORMATION

11.1 Information on toxicological effects

Acute toxicity
LD50 Oral - Rat - male - > 2,200 mg/kg
LD50 Oral - Rat - female - > 2,500 mg/kg
Inhalation: No data available
Dermal: No data available
LD50 Oral - Rat - males - 2,214 mg/kg
LD50 Oral - Rat - female - 2,513 mg/kg

Skin corrosion/irritation
No data available

Serious eye damage/eye irritation
No data available

Respiratory or skin sensitisation
No data available

Germ cell mutagenicity
No data available

Carcinogenicity
IARC: No component of this product present at levels greater than or equal to 0.1% is identified as probable, possible or confirmed human carcinogen by IARC.
ACGIH: No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by ACGIH.
NTP: No component of this product present at levels greater than or equal to 0.1% is identified as a known or anticipated carcinogen by NTP.
OSHA: No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by OSHA.

Reproductive toxicity
No data available
No data available

Specific target organ toxicity - single exposure
No data available

Specific target organ toxicity - repeated exposure
No data available

Aspiration hazard
No data available

Additional Information
RTECS: Not available
To the best of our knowledge, the chemical, physical, and toxicological properties have not been thoroughly investigated.

12. ECOLOGICAL INFORMATION

12.1 Toxicity
No data available

12.2 Persistence and degradability
Biodegradability aerobic - Exposure time 15 d
Result: 62.9 % - Readily biodegradable

12.3 Bioaccumulative potential
No data available

12.4 Mobility in soil
No data available

12.5 Results of PBT and vPvB assessment
PBT/vPvB assessment not available as chemical safety assessment not required/not conducted

12.6 Other adverse effects
No data available

13. DISPOSAL CONSIDERATIONS

13.1 Waste treatment methods

Product
Offer surplus and non-recyclable solutions to a licensed disposal company.

Contaminated packaging
Dispose of as unused product.
14. TRANSPORT INFORMATION

DOT (US)
Not dangerous goods

IMDG
Not dangerous goods

IATA
Not dangerous goods

15. REGULATORY INFORMATION

SARA 302 Components
No chemicals in this material are subject to the reporting requirements of SARA Title III, Section 302.

SARA 313 Components
This material does not contain any chemical components with known CAS numbers that exceed the threshold (De Minimis) reporting levels established by SARA Title III, Section 313.

SARA 311/312 Hazards
No SARA Hazards

Massachusetts Right To Know Components
No components are subject to the Massachusetts Right to Know Act.

Pennsylvania Right To Know Components

<table>
<thead>
<tr>
<th>Component</th>
<th>CAS-No.</th>
<th>Revision Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Xylose</td>
<td>58-86-6</td>
<td></td>
</tr>
</tbody>
</table>

New Jersey Right To Know Components

<table>
<thead>
<tr>
<th>Component</th>
<th>CAS-No.</th>
<th>Revision Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Xylose</td>
<td>58-86-6</td>
<td></td>
</tr>
</tbody>
</table>

California Prop. 65 Components
This product does not contain any chemicals known to State of California to cause cancer, birth defects, or any other reproductive harm.

16. OTHER INFORMATION

**HMIS Rating**
- Health hazard: 0
- Chronic Health Hazard: 0
- Flammability: 0
- Physical Hazard: 0

**NFPA Rating**
- Health hazard: 0
- Fire Hazard: 0
- Reactivity Hazard: 0

**Further information**

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**Preparation Information**

Sigma-Aldrich Corporation
Product Safety – Americas
Region 1-800-521-8956

Version: 4.5  Revision Date: 07/15/2015  Print Date: 03/18/2017
**FUTERRO POLYLACTIQUE ACIDE**

**WARNING:**

FOR STACKING PALLET, SEE SECTION 7

### 1. Identification of the substance / preparation and of the company / undertaking

<table>
<thead>
<tr>
<th>Trade name</th>
<th>FUTERRO POLYLACTIQUE ACIDE</th>
</tr>
</thead>
<tbody>
<tr>
<td>SDS number</td>
<td>PRUB-PLA01</td>
</tr>
<tr>
<td>Chemical name</td>
<td>Polylactique acide</td>
</tr>
<tr>
<td>MATERIAL USE</td>
<td>raw material , polymer</td>
</tr>
<tr>
<td>RESPONSIBLE FOR PLACING ON THE MARKET</td>
<td>see below this page.</td>
</tr>
</tbody>
</table>

**Trade name of the firm**

Email address: Petrochemicals.felr-sds@total.com (Safety data sheet)

**EMERGENCY NUMBER**

FUTERRO: +32 (0)69 45 22 76

info@futerro.com

The UK National Poisons Emergency number is 0870 600 6266 (Outside the UK: +44 870 600 6266)

NB: these services are only available to health professionals IRL:

The National Poisons Information Centre
PO Box 1297, Beaumont Hospital, Beaumont Road
Dublin 9.

Telephone: +353 (01) 837 9966 / +353 (01) 809 2568
## 2. Hazards identification

<table>
<thead>
<tr>
<th>Main hazards</th>
<th>none to our knowledge</th>
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<tbody>
<tr>
<td></td>
<td>low risk for temperatures below 150 °C</td>
</tr>
<tr>
<td>Symptoms related to use</td>
<td></td>
</tr>
<tr>
<td>Inhalation</td>
<td>fine dust may cause irritation of respiratory system and mucous.</td>
</tr>
<tr>
<td></td>
<td>if heated to more than 150°C, the product may form vapours or fumes which may cause irritation of respiratory tract and cause coughing and sensation of shortness of breath.</td>
</tr>
<tr>
<td>Skin contact</td>
<td>may be irritating</td>
</tr>
<tr>
<td></td>
<td>in contact with hot material, may cause severe thermal burns</td>
</tr>
<tr>
<td>Eye contact</td>
<td>fine dust may cause irritation to ocular mucous.</td>
</tr>
<tr>
<td>Ingestion</td>
<td>in case of ingestion of small quantities, no important effect observed. in case of ingestion of larger amounts: abdominal pain, diarrhoea, ...</td>
</tr>
<tr>
<td>Adverse environmental effects</td>
<td></td>
</tr>
<tr>
<td>Adverse physicochemical effects</td>
<td></td>
</tr>
<tr>
<td></td>
<td>the product is inherently biodegradable</td>
</tr>
<tr>
<td></td>
<td>combustible if exposed to flames</td>
</tr>
<tr>
<td></td>
<td>flowing product can create electrical charge, resulting sparks may ignite dust or cause an explosion in some concentration ranges.</td>
</tr>
</tbody>
</table>

### 3. Composition / information on ingredients

<table>
<thead>
<tr>
<th>chemical name</th>
<th>Polylactique acide</th>
</tr>
</thead>
</table>
FUTERRO POLYLACTIQUE ACIDE

<table>
<thead>
<tr>
<th>Concentration (%)</th>
<th>&gt; 98 %</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAS number</td>
<td>CAS: 9051-89-2</td>
</tr>
<tr>
<td>EINECS or ELINCS number</td>
<td>the product is a polymer, following the European regulation, registration on the EINECS (European Inventory of Existing Commercial Chemical Substances) inventory is not required.</td>
</tr>
</tbody>
</table>

Substances presenting a health hazard: none to our knowledge

### 4. First-aid measures

**IN CASE OF HEAVY OR PERSISTENT DISTURBANCES, CALL A DOCTOR OR SEEK MEDICAL ADVICE URGENTLY**

**Route of exposure**

**Inhalation**

- exposure to spray, fumes and vapours produced by heated or burned product:
  - bring patient into fresh air
  - seek medical advice.

**Skin contact**

- in case of irritation caused by fine dust: wash with copious volumes of water, until the irritation disappears.
- exposure to splashing of hot product:
  - treat the affected part with cold water (by spraying or immersion).
  - no attempt should be made to detach molten product adhering to the skin or to remove clothing attached with molten material, the injured body part would risk being pulled out; usually the layer detaches itself after a few days.
  - in case of severe burns, seek hospital treatment

**Eye contact**

- in case of irritation caused by fine dust: wash with copious volumes of water, until the irritation disappears.
- exposure to splashing of hot product: treat the eyes with cold water.
- Get medical advice (ophthalmologist)
- in case of severe burns, seek hospital treatment

**Ingestion**

- do not induce vomiting.
- seek medical advice immediately.
## 5. Fire - fighting measures

<table>
<thead>
<tr>
<th>Technical measures</th>
<th>stop the fire spreading.</th>
</tr>
</thead>
<tbody>
<tr>
<td>call the fire brigade immediately.</td>
<td></td>
</tr>
<tr>
<td>evacuate non-essential personnel</td>
<td></td>
</tr>
<tr>
<td>Extinguishing media</td>
<td></td>
</tr>
<tr>
<td>Suitable</td>
<td>for minor fires: carbon dioxide (CO2) or powder, water</td>
</tr>
<tr>
<td>for more extensive fires: foam, water spray (mist) to cool the surfaces exposed to the fire.</td>
<td></td>
</tr>
<tr>
<td>Not to be used</td>
<td>do not use water jets (stick jets) for extinguishing fire since they could help to spread the flames</td>
</tr>
<tr>
<td>Special exposure hazards</td>
<td>dust may form an explosive mixture with air, ignited by sparks or sources of ignition.</td>
</tr>
<tr>
<td>Special peril</td>
<td>complete combustion, with an excess of oxygen forms: carbon dioxide (CO2) and water vapour.</td>
</tr>
<tr>
<td>partial combustion, forms also: carbon monoxide (CO), soot and cracked products: aldehydes, ketones</td>
<td></td>
</tr>
</tbody>
</table>
## FUTERRO POLYLACTIQUE ACIDE

| Protective equipment for firefighters | wear suitable breathing equipment, in case of risk of exposure to vapour or fumes. |

### 6. Accidental release measures

Refer to points 8 and 13. After spillage / leakage:

- **on soil**
  - Granules spilled on the floor can cause a risk of slipping on smooth surfaces.
  - Recover the spilled product by sweeping or suction; put it in containers to facilitate its disposal.
  - Dispose safely in accordance with local or national regulations.
  - Prevent the spilled material from spreading.

- **on water**
  - The product has a density > 1000 kg/m³, it sinks in water.
  - Refer to a specialist for waste disposal in a safe manner in accordance with local or national regulations.

### 7. Handling and storage

#### HANDLING

**Technical measures**
- All pneumatic transport equipment must be electrically earthed.
- Avoid dust accumulation by use of filters in the pneumatic transport equipment.

#### STORAGE

**Storage conditions**
- Store at ambient temperature and at atmospheric pressure in original packaging (plastic or cardboard boxes) or in silo made of appropriate material (aluminium, stainless steel, ...).
- Do not store near highly flammable materials.
- Store away from heating source. Avoid static electricity build up with connection to earth.
- Store in dry, well-ventilated area.
- Prolonged storage preferably out of the sun or other sources of radiation.

**Storage of pallets**
- However, when the pictorial warning as shown on the top of the safety data sheet is affixed to the pallet, the pallet must never be placed either on top of or below another pallet.
- N.B.: Here the term pallet includes both the pallet and its load.
- When pallets are stored in racks, it should be checked whether the pallet is fit for stacking in the concerned racks.

**Incompatible materials**
- Avoid contact with strong oxidizing materials, water.

**SPECIFIC USE(S)**
- Refer to point 8
- No information available.
<table>
<thead>
<tr>
<th>8. Exposure controls / personal protection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exposure controls</td>
</tr>
</tbody>
</table>
## FUTERRO POLYLACTIQUE ACIDE

### OCCUPATIONAL EXPOSURE LIMIT

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Respirable dust</td>
<td>3 mg/m³</td>
<td>4 mg/m³*(Respirable Dust)*</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>IRL(2002): OEL (8h): 4 mg/m³ (respirable)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ZA (2006): OEL (8h): 5 mg/m³ (respirable particulate: PNOC)</td>
</tr>
<tr>
<td>Inhalable dust</td>
<td>10 mg/m³</td>
<td>10 mg/m³ (Total Inhalable Dust)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>IRL(2002): OEL (8h): 10 mg/m³ (total inhalable)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ZA (2006): OEL (8h): 10 mg/m³ (inhalable particulate: PNOC)</td>
</tr>
</tbody>
</table>

### EXPOSURE CONTROLS

**Occupational exposure controls**
- **Personal protection**
  - **Respiratory protection**
    - In case of risk of overexposure to dust, vapour or fumes (during product processing), it is recommended that a local exhaust system is placed above the conversion equipment (a fume hood) and the working area must be properly ventilated.
    - Wear a suitable anti-dust respirator
      - Recommended filter type: P1
  - **Skin and body protection**
    - Where exposure is likely, protective clothing must be worn including gloves, eye protection, and safety non-slip shoes in areas where spills or leaks can occur.
    - Shower and eye fountain available.
  - **Other personal protection**
    - Avoid contact with skin and eyes. Do not store near food products.
  - **Industrial health measures**
    - Remove all contaminated clothing and remove protective clothing when the work is completed.

**Environmental exposure controls**
- Unregulated
## 9. Physical and chemical properties

<table>
<thead>
<tr>
<th><strong>GENERAL INFORMATION</strong></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Appearance</td>
<td>pellets from a diameter of 2 to 5 mm</td>
</tr>
<tr>
<td>Physical state at 20°C</td>
<td>solid</td>
</tr>
<tr>
<td>Colour</td>
<td>transparent, translucent, white opaque</td>
</tr>
<tr>
<td>Odour</td>
<td>odourless</td>
</tr>
</tbody>
</table>

### IMPORTANT HEALTH, SAFETY AND ENVIRONMENTAL INFORMATION

<table>
<thead>
<tr>
<th>Change in physical state at 1013 hPa</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Melting range (°C)</td>
<td>from 150 to 180</td>
</tr>
<tr>
<td>Softening point (°C)</td>
<td>55 to 65</td>
</tr>
<tr>
<td>Flash point (ASTM D 1929)(°C)</td>
<td>&gt; 250</td>
</tr>
<tr>
<td>Decomposition point (°C)</td>
<td>&gt; 220</td>
</tr>
</tbody>
</table>

| Auto-ignition temperature (°C) | > 250 |
| Explosion limits (kg/m³) |  |
| Lower | 0.015 (for polymer dust < 63 µm) |

| Vapour pressure at 20°C (hPa) | none |
## Safety data sheet

### FUTERRO POLYLACTIQUE ACIDE

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Density, mass at 20°C (kg/m³)</strong></td>
<td>1200 to 1300</td>
</tr>
<tr>
<td><strong>Solubility in water at 20°C (mg/l)</strong></td>
<td>insoluble</td>
</tr>
<tr>
<td><strong>pH value (concentrated product)</strong></td>
<td>not applicable</td>
</tr>
<tr>
<td><strong>Viscosity (mm²/s)</strong></td>
<td>not applicable</td>
</tr>
<tr>
<td><strong>OTHER INFORMATION</strong></td>
<td>no information available</td>
</tr>
</tbody>
</table>

### 10. Stability and reactivity

**Stability**
- stable under normal operating conditions of storage, handling and use

**Hazardous reactions**
- dust may form an explosive mixture with air, ignited by sparks or sources of ignition.

**CONDITIONS TO AVOID**
- avoid contact with strong oxidizing materials, water
- avoid proximity or contact with flames or sparks
- it is recommended not to heat at a temperature higher than 230 °C

**HAZARDOUS DECOMPOSITION PRODUCTS**
- complete combustion, with an excess of oxygen forms: carbon dioxide (CO₂) and water vapour.
- partial combustion, forms also: carbon monoxide (CO), soot and cracked products: aldehydes, ketones

**Advice to prevent explosion**
- avoid dust accumulation by use of filters in the pneumatic transport equipment.
- thoroughly ventilate the working place.
- all conductive materials must be electrically earthed.

### 11. Toxicological information

**ACUTE TOXICITY**

**Ingestion**
- in case of ingestion of small quantities, no important effect observed. in case of ingestion of larger amounts: abdominal pain, diarrhoea, ...

**LOCAL EFFECT**

**Inhalation**
- dust may cause irritation of respiratory system.
- if heated to more than 150°C, the product may form vapours or fumes which may cause irritation of respiratory tract and cause coughing and sensation of shortness of breath.
- may be irritating

**Skin contact**
- in contact with hot material, may cause severe thermal burns
- thermal decomposition products are produced at elevated temperatures and these may be irritating

**Eye contact**
- fine dust may cause irritation to ocular mucous.
- splashing of molten droplets causes ocular tissue burns.
- thermal decomposition products are produced at elevated temperatures and these may be irritating

**SENSITIZATION**

Skin contact
- following the available information, not regarded as a sensitiser

**SPECIFIC EFFECTS**
- no particular preoccupation for man (According to available experimental data)
### 12. Ecological information

Information on ecological effects

**MOBILITY**

avoid losses to the environment whenever possible.
## Safety data sheet

### FUTERRO POLYLACTIQUE ACIDE

<table>
<thead>
<tr>
<th>Water / Air</th>
<th>Soil and sediments</th>
<th>there is a slow loss by evaporation because of its physico-chemical properties, the product has a low soil mobility</th>
</tr>
</thead>
</table>

### PERSISTENCE AND DEGRADABILITY

- **Biodegradation**
  - the product is inherently biodegradable

### BIOACCUMULATIVE POTENTIAL

- **ECOTOXICITY**
  - potential bioaccumulation of the product in environment is very low
  - because of its structure, the product should not be dangerous for aquatic life
  - 72 hours-IC50-Algae (mg/l) > 1100 mg/l

### 13. Disposal considerations

- **Waste disposal**
  - dispose in a safe manner in accordance with local/national regulations.
  - authorized disposal
  - do not dispose off by means of sinks, drains or into the immediate environment
  - dispose in a safe manner in accordance with local/national regulations.

### 14. Transport information

- **Road (ADR) / Rail (RID)**
  - Not restricted for transport.
  - UN Number: not applicable
  - Marine (IMO)
  - Not restricted for transport.
  - Air transport (ICAO / IATA)
  - Not restricted for transport.

### 15. Regulatory information

- **Labelling and Classification EC**
  - Symbol(s) EC: Not classified according to EEC directives 67/548/EEC (dangerous substances) and 1999/45/EC (dangerous preparations).

- **Germany**
  - Wassergefährdungsklasse
  - Registration: NWG: non-hazardous to waters

- the product is a polymer, following the European regulation, registration on the EINECS (European Inventory of Existing Commercial Chemical Substances) inventory is not required.
- listed on the United States TSCA (Toxic Substances Control Act) inventory
- listed on the Canadian DSL (Domestic Substances List) inventory.
- listed on the Japanese ENCS (Existing & New Chemical Substances) inventory.
- listed on the Korean ECL (Existing Chemical List) inventory.
- listed on the People's Republic of China register: CRC-SEPA (Chemical Registration Center for Chinese State Environmental Protection Administration)
### 16. Other information

<table>
<thead>
<tr>
<th>Training advice</th>
<th>The use of this product requires specific training. The user must receive all product information in order to handle the product safely (personal protection equipment and best practice standards)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recommended uses</td>
<td>Restricted to professional users</td>
</tr>
<tr>
<td>FUTERRO POLYLACTIQUE ACIDE</td>
<td></td>
</tr>
<tr>
<td>-----------------------------</td>
<td></td>
</tr>
<tr>
<td><strong>Further information</strong></td>
<td><strong>no information available</strong></td>
</tr>
</tbody>
</table>

Revised : 25/02/2008

Supersedes : 25/02/2008

This information applies to the PRODUCT AS SUCH and conforming to specifications of FUTERRO. In case of formulations or mixtures, it is necessary to ascertain that a new danger will not appear.

The information contained is based on our knowledge of the product, at the date of publishing and it is given quite sincerely. However the revision of some data is in progress.

Users are advised of possible additional hazards when the product is used in applications for which it was not intended. This sheet shall only be used and reproduced for prevention and security purposes.

The references to legislative, regulatory and codes of practice documents cannot be considered as exhaustive.

It is the responsibility of the person receiving the product to refer to the totality of the official documents concerning the use, the possession and the handling of the product.

It is also the responsibility of the handlers of the product to pass on to any subsequent persons who will come into contact with the product. (usage, storage, cleaning of containers, other processes) the totality of the information contained within this safety data sheet and necessary for safety at work, the protection of health and the protection of environment.

The (*) indicate the changes made with respect to the previous version.
DESCRIPTION

Futerro® PLA injection grade is a thermoplastic resin derived from annually renewable resources and is specifically designed for injection molding applications where the requirements are clarity with heat deflection temperatures lower than 55°C.

Futerro® PLA injection grade is easily processed on conventional injection equipment. The material is stable in the molten state, provided that the drying procedures are followed.

<table>
<thead>
<tr>
<th>PURITY (1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>L-poly-Lactide content</td>
</tr>
<tr>
<td>% w/w</td>
</tr>
<tr>
<td>Min. 99</td>
</tr>
<tr>
<td>Water content</td>
</tr>
<tr>
<td>ppm</td>
</tr>
<tr>
<td>Max. 250</td>
</tr>
<tr>
<td>Free Lactide content</td>
</tr>
<tr>
<td>% w/w</td>
</tr>
<tr>
<td>Max. 0.4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PHYSICAL PROPERTIES PLA POLYMER (1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific Gravity @25°C</td>
</tr>
<tr>
<td>Melt Density @230°C</td>
</tr>
<tr>
<td>Melt Index @190°C/2.16kg</td>
</tr>
<tr>
<td>Melt Index @210°C/2.16kg</td>
</tr>
<tr>
<td>Haze (2 mm)</td>
</tr>
<tr>
<td>Transmittance (2 mm)</td>
</tr>
<tr>
<td>Glass Transition Temperature °C</td>
</tr>
<tr>
<td>Crystalline Melt Temperature °C</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>MECHANICAL PROPERTIES (1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile Strength @ Break</td>
</tr>
<tr>
<td>MPa</td>
</tr>
<tr>
<td>Tensile Yield Strength</td>
</tr>
<tr>
<td>MPa</td>
</tr>
<tr>
<td>Tensile Modulus</td>
</tr>
<tr>
<td>MPa</td>
</tr>
<tr>
<td>Tensile Elongation</td>
</tr>
<tr>
<td>%</td>
</tr>
<tr>
<td>Notched Izod Impact</td>
</tr>
<tr>
<td>kJ/m²</td>
</tr>
<tr>
<td>Flexural Yield Strength</td>
</tr>
<tr>
<td>MPa</td>
</tr>
</tbody>
</table>

(1) Typical properties; not to be construed as specifications.
PROCESSING INFORMATION

Machine Configuration

Futerro® PLA can be processed on conventional injection molding equipment. The material is stable in the molten state, provided that the drying procedures are followed. Mold flow is highly dependent on melt temperature. It is recommended to balance screw speed, back pressure, and process temperature to control melt temperature. Injection speed should be medium to fast.

A general purpose screw designed to minimize residence time and shear works well.

Startup and Shutdown

Futerro® PLA polymer is not compatible with a wide variety of commodity resins, and special purging sequences should be followed:

- 1. Clean machine and bring temperatures to steady state with low-viscosity, general-purpose polystyrene or polypropylene.
- 2. Vacuum out hopper system to avoid contamination.
- 3. Introduce PLA polymer into the machine at the operating conditions used in Step 1.
- 4. Once PLA polymer has purged, reduce barrel temperatures to desired setpoints.
- 5. At shutdown, purge machine with high-viscosity polystyrene or polypropylene.

Drying

In-line drying may be required. A moisture content around 0.025% (250 ppm) is recommended to prevent viscosity degradation. For injection process, it is better to reach 0.010% (100 ppm). Typical drying conditions for crystallized granules are 2 hours at 90ºC or to a dew point of -40ºC, airflow rate of greater than 1.7 m³/kg per hour of resin throughput. Drying time must be increased to 3 hours or more for a 100 ppm residual moisture target. The resin should not be exposed to atmospheric conditions after drying. Keep the package sealed until ready to use and promptly reseal any unused material. Pellets that have been exposed to the atmosphere for extended time periods will require additional drying time. Amorphous regrind must be crystallized prior to drying, to assure efficient and effective drying.

PROCESSING CONDITIONS

<table>
<thead>
<tr>
<th>Melt Temperature</th>
<th>200ºC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feed Throat</td>
<td>20ºC</td>
</tr>
<tr>
<td>Feed Temperature (crystalline pellets)</td>
<td>165ºC</td>
</tr>
<tr>
<td>Feed Temperature (amorphous)</td>
<td>150°C</td>
</tr>
<tr>
<td>-----------------------------</td>
<td>-------</td>
</tr>
<tr>
<td>Compression Section</td>
<td>195°C</td>
</tr>
<tr>
<td>Metering Section</td>
<td>210°C</td>
</tr>
<tr>
<td>Nozzle</td>
<td>210°C</td>
</tr>
<tr>
<td>Mold</td>
<td>25°C</td>
</tr>
<tr>
<td>Screw Speed</td>
<td>100-175 rpm</td>
</tr>
<tr>
<td>Back Pressure</td>
<td>3 – 7 bars</td>
</tr>
<tr>
<td>Mold Shrinkage</td>
<td>0.1 mm/mm. +/-0.01</td>
</tr>
</tbody>
</table>

(2) : These are starting points and may need to be optimized.
Handling and storage

Futerro® PLA should be stored at ambient temperature and at atmospheric pressure in its original packaging bags. The product should be stored in dry, well-ventilated areas, and it is recommended to avoid prolonged storage under extreme temperatures, direct sunlight or other sources of radiation.

It is advisable to convert the product within 12 months after delivery, provided appropriate storage conditions are used.

Please refer to the Safety Data Sheet for further information.

<table>
<thead>
<tr>
<th>CAS number</th>
<th>9051-89-2</th>
</tr>
</thead>
</table>

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Appendix A3 – Aspen Simulation Reports

Input Summary

; Input Summary created by Aspen Plus Rel. 35.0 at 15:44:33 Thu Apr 6, 2017
; Directory S:\AspenTech\Aspen Plus V9.0\BEG Process V9 Compound_1 Filename
C:\Users\ageorg\AppData\Local\Temp\apd349.txt
;

DYNAMICS
DYNAMICS RESULTS=ON
IN-UNITS MET ENTHALPY='J/kg' FLOW='kg/day' MASS-FLOW='kg/day' &
VOLUME-FLOW='l/day' ENTHALPY-FLO=kW &
TEMPERATURE-C DELTA-T=C MOLE-ENTHALP='kJ/mol' &
MASS-ENTHALP='J/kg' HEAT=kJ INVERSE-PRES='1/bar' &
VOL-ENTHALPY='kJ/cum' SHORT-LENGTH=mm

DEF-STREAMS CONVEN ALL
SIM-OPTIONS MASS-BAL-CHE=YES
MODEL-OPTION

MODEL-OPTION

DATABASES ‘APV90 PURE35’ / ‘APV90 SOLIDS’ &
‘APV90 INORGANIC’ / ‘APV90V20 AP-ED’ &

NACIT; NACL / LACTICAC C3H6O3; NITRICE C3H6O3 / N2 /
METHANOL CH4O; “PLA” C12H26

SOLVE
RUN-MODE RUN-SIM

FLOW SHEET
BLOCK CAOH-NEU IN=XYSUGARS CAOH OUT=SUGARSX
BLOCK AAS IN=NH3 4 OUT=AASPROD
BLOCK FILTER IN=PROD OUT=XYSUGARS S5
BLOCK SA-HYDRO IN=METRBSG S11 OUT=PROD-H
BLOCK WASH IN=REG S2 OUT=WETBSG
BLOCK FUGEXYL IN=SUGARSX OUT=XYLSUGAR P_REC
BLOCK WASH2 IN=AASPROG KARNAT OUT=KARNAT
BLOCK PLA-FERM IN=S2I OUT-1
BLOCK XAFTERM IN=S23 OUT-3
BLOCK EVAP IN=S20 OUT-STEAM4 5
BLOCK COOL2 IN=S34 OUT-7
BLOCK FILTER2 IN-7 OUT-8 9
BLOCK WASH3 IN=9 OUT-11 OUT-QUAR XYLITOL
BLOCK EVAP2 IN=S5 OUT-STEAM3 4
BLOCK SPLIT IN=S36 OUT-FUREGE RECYCLE
BLOCK SPLIT2 IN=S9 OUT-S12
BLOCK DRYPLA IN=S9 OUT-STEAM2 PLAREC
BLOCK B1 IN=S16 OUT-WETBSG
BLOCK B2 IN=S1 PURE OUT-STOUT 2
BLOCK B3 IN=STAMS2 STEAM1 OUT-S1
BLOCK POLYBEAT IN-2 OUT-03
BLOCK PLASH PROD IN-24 OUT-ETHPLA PLA
BLOCK UMLIX IN=PLA GDL25N OUT-S7
BLOCK POLYFILAC IN=S3 PLAREC OUT-PLA
BLOCK B4 IN=MEGINH S7 OUT-PLAGUT S8
BLOCK SPLITFLASH IN=S14 OUT-STEAM ETHOUT1
BLOCK B11 IN=ETHPLA S12 OUT-S14 S13
BLOCK WATPUR IN-STOUT OUT-WATER1 ETHOUT2
BLOCK B5 IN=S6 S23 OUT-O1 S2
BLOCK B6 IN=STEAMS STEAM2 OUT-S6
BLOCK B8 IN=S15 SA-IN OUT-S15 S11
BLOCK B10 IN=WATER1 HOBIN S22 OUT-S19
BLOCK B13 IN=S15 OUT-S22
BLOCK B14 IN=ETHIN OUT-ETHIN2
BLOCK B9 IN=1 OUT-S16 S17
BLOCK CHROMA IN=S28 OUT-S18 S20
BLOCK B15 IN=PLASSUGAR OUT-021
BLOCK B16 IN=S25 OUT-023
BLOCK B17 IN=S13 OUT-024
BLOCK B12 IN=3 OUT-S27 S28
BLOCK B18 IN=S8 OUT-X2 X1
BLOCK B7 IN=ETHOUT ETHOUT1 ETHOUTFI
BLOCK B19 IN=PLA1 STEAM4 OUT-S4 STEAMS
BLOCK B20 IN=PROD-H METRBSG OUT=PROD-C S26
BLOCK B21 IN=S19 OUT-S29 S30
BLOCK LLEREK IN=S31 OUT-WASTE S32
BLOCK B25 IN=S32 S33 OUT-WORK
BLOCK B23 IN-XYSUGAR RECYCLE OUT=S25
BLOCK B23 IN-5 OUT=S34 S36
PROPERTIES RK-ASPN
PROPERTIES IDEAL

STRUCTURES
STRUCTURES CAS04 O1 S2 D / S2 O3 S / S2 O4 D / S2 & O5 S

PROP-DATA
PROP-LIST ATOMNO / HOATOM
PVAL CAS04 20 8 16 / 1. 4. 1.

PROP-DATA
PROP-LIST ATOMNO / HOATOM
PVAL PLA 6 1 8 / 3300. 4400. 2200.

ESTIMATE ALL

PROP-DATA AMMONIA
IN-UNITS MET PRESSURE=Mpa TEMPERATURE=C DELTA=T-C PDROP=bar & INVERSE-PRES='1/bar' SHORT-LENGTH=nm
PROP-LIST TCPA / PC / TC
PVAM AMMONIA 132.3 / 11.3 / 132.3

PROP-DATA AMMONIA
IN-UNITS MET PRESSURE=bar TEMPERATURE=C DELTA=T-C PDROP=bar & INVERSE-PRES='1/bar' SHORT-LENGTH=nm
PROP-LIST PCRA / OMEGRA / OMEGA
PVAM AMMONIA 11.3 / 0.293 / 0.293

PROP-DATA CAS04
IN-UNITS MET PRESSURE=bar TEMPERATURE=C DELTA=T-C & MOLE-ENTHALP='kJ/mol' PDROP=bar INVERSE-PRES='1/bar' & SHORT-LENGTH=nm
PROP-LIST DIPORM / DIPORM
PVAM CAS04 -1432.7 / 17.8
PVAM AMMONIA -366.719 / -4.019

PROP-DATA PCES-1
IN-UNITS MET ENTHALPY='kJ/kg' FLOW='kg/day' MASS-FLOW='kg/day' & MOLE-FLOW='mol/hr' VOLUME-FLOW='l/day' ENTHALPY-FLOW='kJ' & TEMPERATURE=C DELTA=T-C MOLE-ENTHALP='kJ/mol' & MOLE-ENTHALP='kJ/mol' FLOW INV-PRES='1/bar' & VOL-ENTHALP='kJ/cum' SHORT-LENGTH=nm
PROP-LIST VC / VC / DHVLB / VB / RTXRA / VLIST
PVAM AMMONIA 68.13756720 / 2.28402160 / 25.69866910 / & 42.12300000 / 0.26767399 / 42.12290000
PROP-LIST VB / RTXRA / VLIST
PVAM CAS04 405.4159630 / -2938596200 / 298.9063450
PROP-LIST RTXRA / VLIST
PVAM CACH2 .2918596200 / 298.9063450
PVAM LACTICAC .2089855090 / 68243.54800

PROP-DATA PLA
IN-UNITS MET ENTHALPY='kJ/kg' FLOW='kg/day' MASS-FLOW='kg/day' & MOLE-FLOW='mol/hr' VOLUME-FLOW='l/day' ENTHALPY-FLOW='kJ' & TEMPERATURE=C DELTA=T-C MOLE-ENTHALP='kJ/mol' & MOLE-ENTHALP='kJ/mol' VOLUME=lit/ol HEAT=kj & INVERSE-PRES='1/bar' VOL-ENTHALP='kJ/cum' SHORT-LENGTH=nm
PROP-LIST TB / TC / PC / VLSTD / TCRCA / PCRA
PVAM PLA 2000 / 3000 / 5 / 1 / 3000 / 5

PROP-DATA DEVIAT-1
IN-UNITS MET ENTHALPY='kJ/kg' FLOW='kg/day' MASS-FLOW='kg/day' & MOLE-FLOW='mol/hr' VOLUME-FLOW='l/day' ENTHALPY-FLOW='kJ' & TEMPERATURE=C DELTA=T-C MOLE-ENTHALP='kJ/mol' & MOLE-ENTHALP='kJ/mol' FLOW INV-PRES='1/bar' & VOL-ENTHALP='kJ/cum' SHORT-LENGTH=nm
PROP-LIST DEVIAT
PVAM AMMONIA 29.32839440 & .5389857650 -79.00000000 .1132839440 & .388957650 -79.00000000
PVAM LACTICAC 50.8247650 238.845000 .380000000 0.0 & 238.845000

PROP-DATA KLDIP-1
IN-UNITS MET ENTHALPY='kJ/kg' FLOW='kg/day' MASS-FLOW='kg/day' & MOLE-FLOW='mol/hr' VOLUME-FLOW='l/day' ENTHALPY-FLOW='kJ' & TEMPERATURE=C DELTA=T-C MOLE-ENTHALP='kJ/mol' & MOLE-ENTHALP='kJ/mol' FLOW INV-PRES='1/bar' & VOL-ENTHALP='kJ/cum' SHORT-LENGTH=nm
PROP-LIST KLDIP
PVAM AMMONIA .1592361920 -5.594856368 / -3.77466738 & 4.96949138E-8 -2.9442358E-10 -2.15500000 128.245000

PROP-DATA MILAND-1
IN-UNITS MET ENTHALPY='kJ/kg' FLOW='kg/day' MASS-FLOW='kg/day' & MOLE-FLOW='mol/hr' VOLUME-FLOW='l/day' ENTHALPY-FLOW='kJ' & TEMPERATURE=C DELTA=T-C MOLE-ENTHALP='kJ/mol' & MOLE-ENTHALP='kJ/mol' FLOW INV-PRES='1/bar' & VOL-ENTHALP='kJ/cum' SHORT-LENGTH=nm
PROP-LIST MILAND
PVAM AMMONIA 87.05270398 -326.836150 -13.60519070 & -2.11000000 128.245000
PVAM CACH2 80.86579488 -12127.32210 -10.25255770 & 1126.850000 1706.850000
PVAM CAS04 81.1698178 -12127.32210 -10.25255770 & 1126.850000 1706.850000

PROP-DATA SIGDIP
IN-UNITS MET ENTHALPY='kJ/kg' FLOW='kg/day' MASS-FLOW='kg/day' & MOLE-FLOW='mol/hr' VOLUME-FLOW='l/day' ENTHALPY-FLOW='kJ' & TEMPERATURE=C DELTA=T-C MOLE-ENTHALP='kJ/mol' & MOLE-ENTHALP='kJ/mol' FLOW INV-PRES='1/bar' & VOL-ENTHALP='kJ/cum' SHORT-LENGTH=nm
PROP-LIST SIGDIP
PVAM AMMONIA 167.8470060 1.22222222 1.7123181E-10 & -1.9123181E-10 1.664593664E-11 -2.15500000 124.191000
PVAM LACTICAC 138.5197808 1.222222220 -5.392945810 & 5.8321013E-10 -2.3134698E-10 238.845000 430.490000

PROP-SET FS-1 TEM KVL GAMMA KVL2 BETA MASSFRAC & SUBSTREAM-MIXED COMPS-METHANOL CRZL2 PHASE-V L1 L2
PROP-SET FP-2 TEM KVL GAMMA KVL2 BETA MASSFRAC & SUBSTREAM-MIXED COMPS-METHANOL CRZL2 PHASE-V L1 L2
PROP-SET FS-3 TEM KVL GAMMA KVL2 BETA MOLEFRAC & SUBSTREAM-MIXED COMPS-PHASE DITER PHASE-V L1 L2
PROP-SET FP-4 TEM KVL GAMMA KVL2 BETA MOLEFRAC & SUBSTREAM-MIXED COMPS-PHASE DITER PHASE-V L1 L2
PROP-SET FP-5 TEM KVL GAMMA KVL2 BETA MOLEFRAC & SUBSTREAM-MIXED COMPS-WATER DITER PHASE-V L1 L2
STREAM AAMAT
SUBSTREAM MIXED TEMP=25.00000000 PRES=1.00000000 MASS-FLOW WATER 50000.

STREAM BSG
SUBSTREAM MIXED TEMP=25.00000000 PRES=1.00000000 MASS-FLOW WATER 98553.99997 / CELULIOS 61957.99999
BLOCK B23 HEATX
PARAM T=COLD=35.
FEEDS HOT= COLD=8
OUTLET= HOT S34
OUTLET= COLD S36
HOT SIDE DPVAPOR=NO
COLD SIDE DPVAPOR=NO
TV=PARAM COV=UES

BLOCK B18 DSTKW
PARAM LIGHTKEY=C2H12 RECOVER=0.5838 HEAVYKEY=ETHANOL &
RECOVER=0.01 PT0=1. PR0=1. NSTATE=10 MAXIT=100 &
FLASH=MIX=100

BLOCK LLE EXTRACT
PARAM NSTAGE=5
FEEDS ETHIZJ 5 / S16 1
PRODUCTS S31 5 L2 / S33 1 L2
P-SPEC 1 1.0000000000 / 2 1.0000000000 / 3 1.0000000000 / &
& 1.0000000000 / 5 1.0000000000
T-SPEC 1 24.5000000000 / 2 21.8000000000 / 3 29.0000000000 / &
& 26.0000000000 / 5 22.7000000000
LI-COMPS WATER
L2-COMPS LACTICAC DIETHER

BLOCK CAOH-NEU RYIELD
PARAM TEMP=25.00000000 PRES=1.0000000000 NPHASE=2
STIO 1 MIXED H2SO4 -1. / CAOH2 -1. / CASO4 1. / &
WATER 2.
CONV 1 MIXED CAOH2 0.95
BLOCK-OPTION FREE-WATER=NO
UTILITY UTILITY-ID=COOLING

BLOCK POLYREAC RYIELD
PARAM TEMP=170. PRES=1. NPHASE=2
STIO 1 MIXED LACTICAC -1100. / WATER 1100. / PL A 1.
CONV 1 MIXED LACTICAC 1.
BLOCK-OPTION FREE-WATER=NO
UTILITY UTILITY-ID=COOLING

BLOCK AAS RYIELD
PARAM TEMP=70.00000000 PRES=1.0000000000
MASS-YIELD MIXED OTHLQUI 1. 
UTILITY UTILITY-ID=COOLING
INERTS WATER / AMMONIA / OTHSOLID

BLOCK PLA-PERM RYIELD
PARAM TEMP=37.00000000 PRES=1.0000000000
MASS-YIELD MIXED LACTICAC 0.99 / GLUCOSE 0.01 / OTHSOLID &
0.1
INERTS WATER / OTHLQUI / "ENZ/XYL" / DIETHER

BLOCK SA-HYDRO RYIELD
PARAM TEMP=150.00000000 PRES=1.0000000000
MASS-YIELD MIXED CELULOS 0.247 / XYLLOSE 0.209 / OTHSOLID &
0.063 / OTHLQUI 0.481
INERTS WATER / H2SO4 / "ENZ/XYL" / DIETHER / GLUCOSE

BLOCK SACCH RYIELD
PARAM TEMP=25.00000000 PRES=1.0000000000
MASS-YIELD MIXED GLUCOSE 1. 
INERTS WATER / AMMONIA / OTHSOLID / "ENZ/XYL" / NACIT

BLOCK XLAFERM RYIELD
PARAM TEMP=32.00000000 PRES=1.0000000000
MASS-YIELD MIXED "ENZ/XYL" 0.8684 / XYLLOSE 0.1316 / &
OTHSOLID 0.1
INERTS WATER / OTHLQUI

STREAM-PRICE
STREAM-PRICE STREAM-ASMAAT VOL-PRICE=7.2647314204 / &
STREAM-BSG MASS-PRICE=0.0 / STREAM-CAH &
MASS-PRICE=1.7680000000 / STREAM-ENZYMES &
MASS-PRICE=0.5700000000 / STREAM-LIQUOR MASS-PRICE=0.0 / &
STREAM-NACIT MASS-PRICE=1.918201681 / STREAM-NH3 &
MASS-PRICE=3.5000000000 / STREAM-PRE-PLA MASS-PRICE=0.0 / &
STREAM-PRE-XYL MASS-PRICE=0.0 / STREAM-PURE &
MASS-PRICE=0.0 / STREAM-SA-IN MASS-PRICE=2.75578277 / &
STREAM-STEAM MASS-PRICE=0.0 / STREAM-STEAM &
MASS-PRICE=0.0 / STREAM-XYLITOL MASS-PRICE=1.433000000

UTILITY AIR GENERAL
DESCRIPTION "Air, Inlet Temp=30 C, Outlet Temp=35 C"
COST ENERGY-PRICE=0. <$/kJ>
PARAM UTILITY-TYPE=GENERAL COOLING-VALO=5. <kJ/kp> TIN=30.
&
TOUT=35. MIN-TAPP=10. HTC=0.0003996 <GJ/hr-sqm>C

UTILITY COOLINGW GENERAL
DESCRIPTION "Cooling Water, Inlet Temp=20 C, Outlet Temp=25 C"
COST ENERGY-PRICE=2.12E-007 <$/kJ>
PARAM UTILITY-TYPE=WATER PRES=1. PRES-OUT=1. TIN=20. &
TOUT=25. TAPP=FLASH MIN-TAPP=5. HTC=0.0135 <GJ/hr-sqm>C

UTILITY ELEC GENERAL
DESCRIPTION "Electrical Utility"
COST ENERGY-PRICE=0.0775 <$/kWhr>
PARAM UTILITY-TYPE-ELECTRICITY CALCUses=YES FACTORSOURCE &
"US-EPA-Rule-E9-5711" FUELSOURCE="Natural_gas" &
CO2FACTOR=2.340000000E-7 EFFICIENCY=0.58

UTILITY FURNACE GENERAL
DESCRIPTION &
"Fixed-Water, Inlet Temp=1000 C, Outlet Temp=400 C"
COST ENERGY-PRICE=4.25E-006 <$/kJ>
PARAM UTILITY-TYPE=GENERAL COOLING-VALO=400. <kJ/kp> &
TIN=1000. TOUT=400. MIN-TAPP=95.CALCUses=YES &
FACTORSOURCE="US-EPA-Rule-E9-5711" FUELSOURCE="Natural_gas" &
CO2FACTOR=2.340000000E-7 EFFICIENCY=0.85 &
HTC=0.0003996 <GJ/hr-sqm>C

UTILITY HPSTEAM GENERAL
DESCRIPTION &
"High Pressure Steam, Inlet Temp=250 C, Outlet Temp=249 C, Presa=572 psi" COST ENERGY-PRICE=2.5E-006 <$/kJ>
PARAM UTILITY-TYPE-STEAM TIN=250. TOUT=249. VFRA=1. &
VFR=O-0. CALP=FLASH MIN-TAPP=10. CALCUses=YES &
FACTORSOURCE="US-EPA-Rule-E9-5711" FUELSOURCE="Natural_gas" &
CO2FACTOR=2.340000000E-7 EFFICIENCY=0.85 &
HTC=0.0126 <GJ/hr-sqm>C

UTILITY LPSTEAM GENERAL
DESCRIPTION &
"Low Pressure Steam, Inlet Temp=125 C, Outlet Temp=124 C"
COST ENERGY-PRICE=1.0E-006 <$/kJ>
PARAM UTILITY-TYPE-STEAM TIN=125. TOUT=124. VFRA=1. &
VFR=O-0. CALP=FLASH MIN-TAPP=10. CALCUses=YES &
FACTORSOURCE="US-EPA-Rule-E9-5711" FUELSOURCE="Natural_gas" &
CO2FACTOR=2.340000000E-7 EFFICIENCY=0.85 &
HTC=0.0126 <GJ/hr-sqm>C

UTILITY MPSTEAM GENERAL
DESCRIPTION &
"Medium Pressure Steam, Inlet Temp=125 C, Outlet Temp=100 C"
COST ENERGY-PRICE=1.0E-006 <$/kJ>
PARAM UTILITY-TYPE-STEAM TIN=125. TOUT=100. VFRA=1. &
VFR=O-0. CALP=FLASH MIN-TAPP=10. CALCUses=YES &
FACTORSOURCE="US-EPA-Rule-E9-5711" FUELSOURCE="Natural_gas" &
CO2FACTOR=2.340000000E-7 EFFICIENCY=0.85 &
HTC=0.0126 <GJ/hr-sqm>C

270
UTILITY NONCONDS GENERAL

DESCRIPTION & "Medium Pressure Steam, Inlet Temp=175 C, Outlet Temp=174 C, Pres=127 psia"
COST ENERGY-PRECE-2.2E-06 <$kJ>
PARAM UTILITY-TYPE=STEAM Tmin=175, TOUT=150. VFRA=1. & VFR-OFT=0. CALO=FLASH MIN-TAPP=10. CALCC2=YES & FACTOR=US-EPA-Rule-E9-5711% FUELSOURCE="Natural_gas" & COF=2.340000E -7 EFFICIENCY=0.85 & HTC=0.0266 <GJ/hr-sqm>-

UTILITY REFRIDGE GENERAL

DESCRIPTION & "Refrigerant 1, Inlet Temp=25 C, Outlet Temp=-24 C"
COST ENERGY-PRECE-2.74E-06 <$kJ>
PARAM UTILITY-TYPE=REFRIGERATO COOLING VALUE=4. <kJ/kg> & TIN=25. TOUT=-24. MIN-TAPP=3. CALCC2=YES FACTOR=US-EPA-Rule-E9-5711% FUELSOURCE="Natural_gas" & COF=2.340000E -7 EFFICIENCY=0.85 & HTC=0.00466 <GJ/hr-sqm>-

DESIGN SPEC CH2CL2
DEFINE CH2CL2STD-VOL FLOW STREAM=87 SUBSTREAM=MIXED & COMPONENT=CH2CL2 UOM="l/day"
DEFINE SOGMASS MASS FLOW STREAM=87 SUBSTREAM=MIXED & COMPONENT=PLA UOM="kg/day"
SPEC C=CH2CL2/SOGMASS TO "7.46" TOL SPEC -0.1 & VARY MASS FLOW STREAM=CH2CL2 IN SUBSTREAM=MIXED & COMPONENT=CH2CL2 UOM="kg/day"
LIMITS "10" "100000" STEP SIZE=1.

DESIGN SPEC DICHLIN
DEFINE DICHLIN MASS FLOW STREAM=88 SUBSTREAM=MIXED & COMPONENT=CH2CL2 UOM="kg/day"
SPEC DICHL 70 "70000" TOL SPEC -0.001 & VARY MASS FLOW STREAM=CH2CL2 IN SUBSTREAM=MIXED & COMPONENT=CH2CL2 UOM="kg/day"
LIMITS "-300" "300" STEP SIZE=1.

DESIGN SPEC ETHIN
DEFINE ETHIN MASS FLOW STREAM=EThIN2 SUBSTREAM=MIXED & COMPONENT=DIOThER UOM="kg/day"
SPEC "ETHIN" TO "40000" TOL SPEC -1 & VARY MASS FLOW STREAM=EThIN SUBSTREAM=MIXED & COMPONENT=DIOThER UOM="kg/day"
LIMITS "0" "400000" STEP SIZE=0.0001

DESIGN SPEC ETHERISPL
DEFINE ETHER MASS FRAC STREAM=EThOUT1 SUBSTREAM=MIXED & COMPONENT=DIOThER
SPEC "ETHER" TO "0.99" TOL SPEC -0.001 & VARY BLOCK VAR BLOCK=EThFAS BLR VARIABLE=TEMP SENTENCE=PARAM & UOM="C"
LIMITS "19" "30" STEP SIZE=0.01

DESIGN SPEC METHANOL
DEFINE METHANOL STD-VOL FLOW STREAM=88 SUBSTREAM=MIXED & COMPONENT=METHANOL UOM="kg/day"
DEFINE CH2CL2 STD-VOL FLOW STREAM=88 SUBSTREAM=MIXED & COMPONENT=CH2CL2 UOM="l/day"
SPEC METHANOL/CH2CL2 TO "0.75" TOL SPEC -0.01 & VARY MASS FLOW STREAM=MEOHIN SUBSTREAM=MIXED & COMPONENT=METHANOL UOM="kg/day"
LIMITS "10" "100000" STEP SIZE=0.5

DESIGN SPEC METHOH
DEFINE METHOH MASS FLOW STREAM=88 SUBSTREAM=MIXED & COMPONENT=METHOH UOM="kg/day"
DEFINE VOL STREAM=VAR STREAM=PLASUGAR SUBSTREAM=MIXED & VARIOUS STD-VOL FLOW UOM="l/day"
SPEC PLAWATER/UL To "0.05" TOL SPEC -0.001 & VARY BLOCK VAR BLOCK=EVAP2 VARIABLE=TEMP SENTENCE=PARAM UOM="C"
LIMITS "50" "200" STEP SIZE=1.

DESIGN SPEC PLASUGAR
DEFINE PLASUGAR MASS FLOW STREAM=PLASUGAR SUBSTREAM=MIXED & COMPONENT=GLUCOSE UOM="kg/day"
DEFINE VOL STREAM=VAR STREAM=PLASUGAR SUBSTREAM=MIXED & VARIOUS STD-VOL FLOW UOM="l/day"
SPEC PLAWATER/UL To "0.05" TOL SPEC -0.001 & VARY MASS FLOW STREAM=MEOHIN SUBSTREAM=MIXED & COMPONENT=METHOH UOM="kg/day"
LIMITS "5711" "100000" STEP SIZE=0.0001

DESIGN SPEC WATERIN
DEFINE PLASUGAR MASS FLOW STREAM=PLASUGAR SUBSTREAM=MIXED & COMPONENT=GLUCOSE UOM="kg/day"
DEFINE VOL STREAM=VAR STREAM=PLASUGAR SUBSTREAM=MIXED & VARIOUS STD-VOL FLOW UOM="l/day"
SPEC PLAWATER/UL To "0.05" TOL SPEC -0.001 & VARY BLOCK VAR BLOCK=EVAP2 VARIABLE=TEMP SENTENCE=PARAM UOM="C"
LIMITS "70" "200" STEP SIZE=1.

DESIGN SPEC WATERIN
DEFINE WATERIN MASS FLOW STREAM=89 SUBSTREAM=MIXED & COMPONENT=WATER UOM="kg/day"
DEFINE VOL FLOW STREAM=89 SUBSTREAM=MIXED & COMPONENT=WATER UOM="l/day"
SPEC WATERFLO TO "355801" TOL SPEC -1 & VARY MASS FLOW STREAM=MEOHIN SUBSTREAM=MIXED & COMPONENT=WATER UOM="kg/day"
LIMITS "20000" "400000" STEP SIZE=0.5

DESIGN SPEC XYFERA
DEFINE XYFERA MASS FLOW STREAM=83 SUBSTREAM=MIXED & COMPONENT=XYLOSE UOM="kg/day"
DEFINE VOL FLOW STREAM=83 SUBSTREAM=MIXED & COMPONENT=XYLOSE UOM="l/day"
SPEC XYLOSE/VO To "0.08" TOL SPEC -0.001 & VARY BLOCK VAR BLOCK=FILTER SENTENCE=FRAC VARIABLE=FRACs & I1-MIXED I2=XYLOSE ELEMENT=1 LIMITS "0.05" "0.9" STEP SIZE=1.

KO-CONNECTIVITY
SENSITIVITY DISTRIL
DEFINE METH FRACTION STREAM=83 SUBSTREAM=MIXED & COMPONENT=METHOH
Sensitivity LLESENS

Define purelact mass-flow stream-pure substream-mixed &
component-1 lacticac uom='kg/day'
Define purewater mass-flow stream-pure substream-mixed &
component-water uom='kg/day'
Define purelac1 mass-flow stream-pure substream-mixed &
component-2 lacticac uom='kg/day'
Define wastelac1 mass-flow stream-waste substream-mixed &
component-1 lacticac uom='kg/day'
Define wastewater mass-flow stream-waste substream-mixed &
component-water uom='kg/day'
Tabulate 1 "purelact"
Tabulate 2 "purewater"
Tabulate 3 "purelac1"
Tabulate 4 "wastelac1"
Tabulate 5 "wastewater"
Vary mass-flow stream-waste substream-mixed &
component-1 lacticac uom='kg/day'
Range opt-list range lower='0.0000000' upper='100.000000' npoint='50'

Conv-Options
Param tear-method broyden tol='0.001'
Weggstein maxit='100'
Broyden maxit='100'

Stream-Report Moleflow

Property-Rep Pces

Prop-Table Binry-1 Flashcurve
In-units ments enthalpy='J/kg' flow='kg/day' mass-flow='kg/day' &
mole-flow='mol/hr' volume-flow='l/day' enthalpy-flow='kJ'
&
temperature=c delta-t=c mole-enthalp='kJ/mol' &
mass-enthalp='kJ' heat-kj inverse-pres='1/bar' &
vol-enthalp='kJ/cum' short-length='mm'
Mass-flow methanol 1 / ch2cl2 1
State vfrac='0.0'
Vary pres
Range list='1.0000000000'
Vary purelac comp=methanol
Range varvalue-range lower='0.0' upper='1.0' npoint='50'
Param npase='3'
Tabulate properties='ps-1'

Prop-Table Binry-2 Flashcurve
In-units ments enthalpy='J/kg' flow='kg/day' mass-flow='kg/day' &
mole-flow='mol/hr' volume-flow='l/day' enthalpy-flow='kJ'
&
temperature=c delta-t=c mole-enthalp='kJ/mol' &
mass-enthalp='kJ' heat-kj inverse-pres='1/bar' &
vol-enthalp='kJ/cum' short-length='mm'
Mass-flow methanol 1 / ch2cl2 1
State vfrac='0.0'
Vary pres
Range list='1.0000000000'
Vary purelac comp=dicholin
Range varvalue-range lower='0.0' upper='1.0' npoint='50'
Param npase='3'
Tabulate properties='ps-5'

Disable SENSITIVITY DISTIL LLESENS LLEWATER
Design-spec ch2cl2 dicholin etherin methin plafewa
Stream Report

STATE VARIABLES:

PHASE:                  LIQUID     LIQUID     LIQUID     LIQUID     LIQUID

SUBSTREAM: MIXED

STREAM COSTS

<table>
<thead>
<tr>
<th>ID</th>
<th>PRICE</th>
<th>COST $/HR</th>
</tr>
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<tbody>
<tr>
<td>AASWAT</td>
<td>7.2647-04  $/L</td>
<td>2.0027</td>
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<tr>
<td>BSG</td>
<td>0.0  $/KG</td>
<td>0.0</td>
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<tr>
<td>CAO</td>
<td>0.1760  $/KG</td>
<td>54.1832</td>
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<td>ENZIMES</td>
<td>0.5070  $/KG</td>
<td>331.0499</td>
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<td>LIQOR</td>
<td>0.0  $/KG</td>
<td>0.0</td>
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<tr>
<td>NACIT</td>
<td>1.9180  $/KG</td>
<td>415.6513</td>
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<tr>
<td>NH3</td>
<td>0.3000  $/KG</td>
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<tr>
<td>NACIT</td>
<td>1.9180  $/KG</td>
<td>415.6513</td>
</tr>
<tr>
<td>NACIT</td>
<td>1.9180  $/KG</td>
<td>415.6513</td>
</tr>
<tr>
<td>PREC-PLA</td>
<td>0.0  $/KG</td>
<td>0.0</td>
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<tr>
<td>PREC-XYL</td>
<td>0.0  $/KG</td>
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<td>SA-IN</td>
<td>0.2756  $/KG</td>
<td>26.9951</td>
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<tr>
<td>STEAM3</td>
<td>0.0  $/KG</td>
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<tr>
<td>STEAM4</td>
<td>0.0  $/KG</td>
<td>0.0</td>
</tr>
<tr>
<td>XYLITOL</td>
<td>1.4330  $/KG</td>
<td>589.7120</td>
</tr>
</tbody>
</table>

STREAM ID | 1 11 2 3 4
FROM : | PLA-FERM WASH3 B2 XLA-HERM EVAP2
TO : | B9 CRYSTAL POLYBEAT B12 AAS

SUBSTREAM: MIXED

PHASE: LIQUID LIQUID LIQUID LIQUID LIQUID

COMPONENTS: MOL/HR

| WATER | 8.1648-05 5379.6749 887.7925 3.0202-05 6.9387+05 |
| GLUCOSE | 32.1773 0.0 32.1773 0.0 0.0 |
| XYLITOL | 0.0 0.0 0.0 0.0 0.0 |
| AMMONIA | 0.0 0.0 0.0 0.0 0.0 |
| ETHYLGLUC | 0.0 0.0 0.0 0.0 0.0 |
| H2SO4 | 0.0 0.0 0.0 0.0 0.0 |
| CAH2 | 0.0 0.0 0.0 0.0 0.0 |
| CAS04 | 0.0 0.0 0.0 0.0 0.0 |
| CASH3 | 0.0 0.0 0.0 0.0 0.0 |
| ETHYLGLUC | 0.0 0.0 0.0 0.0 0.0 |
| CELLULOS | 0.0 0.0 0.0 0.0 3539.4099 |
| ENZ/XYL | 0.0 2704.7653 0.0 3182.3591 0.0888 |
| NACIT | 0.0 0.0 0.0 0.0 0.0 |
| LACTICAC | 6371.1031 0.0 6153.4740 0.0 0.0 |
| DIETHER | 0.0 0.0 9791.7798 0.0 2.7190-09 |
| H2 | 0.0 0.0 0.0 0.0 0.0 |
| METHANOL | 0.0 0.0 0.0 0.0 0.0 |
| C6H12L2 | 0.0 0.0 0.0 0.0 0.0 |
| ETHYL-01 | 0.0 0.0 0.0 0.0 0.0 |
| PLA | 0.0 0.0 0.0 0.0 0.0 |

TOTAL FLOW: MOL/HR

| WATER | 8.1648-05 8084.4402 1.6875+04 3.6933+05 7.0210+05 |
| GLUCOSE | 32.1773 0.0 32.1773 0.0 0.0 |
| XYLITOL | 1.4330 0.0 1.4330 0.0 0.0 |
| NACIT | 1.9180 0.0 1.9180 0.0 0.0 |
| LACTICAC | 6371.1031 0.0 6153.4740 0.0 0.0 |
| DIETHER | 0.0 0.0 9791.7798 0.0 2.7190-09 |
| H2 | 0.0 0.0 0.0 0.0 0.0 |
| METHANOL | 0.0 0.0 0.0 0.0 0.0 |
| C6H12L2 | 0.0 0.0 0.0 0.0 0.0 |
| ETHYL-01 | 0.0 0.0 0.0 0.0 0.0 |
| PLA | 0.0 0.0 0.0 0.0 0.0 |

STATE VARIABLES:

TEMP C | 37.0000 5.0000 93.1981 32.0000 110.0000 |
PREE ATN | 1.0000 1.0000 1.0000 1.0000 1.0000 |
VFRAC | 0.0 0.0 0.0 0.0 0.0 |
LFRAC | 1.0000 1.0000 1.0000 1.0000 1.0000 |
SPFAC | 0.0 0.0 0.0 0.0 0.0 |
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<td>TOTAL FLOW:</td>
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**STATE VARIABLES:**

- **State:** LIQUID
- **Temperature:** 25.0000
- **Pressure:** 150.0000
- **Flux:** 1.0000
- **Density:** 1.0000

**ETHPLA:**

- **Phase:** LIQUID
- **Temperature:** 25.0000
- **Pressure:** 150.0000
- **Flux:** 1.0000
- **Density:** 1.0000

**HOBIN:**

- **Phase:** LIQUID
- **Temperature:** 25.0000
- **Pressure:** 150.0000
- **Flux:** 1.0000
- **Density:** 1.0000

**LIQUOR:**

- **Phase:** LIQUID
- **Temperature:** 25.0000
- **Pressure:** 150.0000
- **Flux:** 1.0000
- **Density:** 1.0000

**MEOHIN:**

- **Phase:** LIQUID
- **Temperature:** 25.0000
- **Pressure:** 150.0000
- **Flux:** 1.0000
- **Density:** 1.0000

**NACIT:**

- **Phase:** LIQUID
- **Temperature:** 25.0000
- **Pressure:** 150.0000
- **Flux:** 1.0000
- **Density:** 1.0000
**Density:**
- **Substream:** Mixed
- **From:** B2
- **To:** B25

**Entropy:**
- **Source:** Cold

**Enthalpy:**
- **Source:** Cold

**Mol/cc:** 6.6736
- **Vfrac:** 0.0 0.0 0.0 1.0000 0.8632
- **Temp:** 22.0031 95.0000 95.0000 140.8396 102.4610

**CH2Cl2:** 0.0 0.0 0.0 0.0 0.0
**Methanol:** 0.0 0.0 0.0 0.0 0.0
**Diether:** 9791.7798 0.0 0.0
**Othsolid:** 0.0 0.0 0.0 0.0 85.5712
**H2SO4:** 0.0 0.0 0.0 0.0 0.0
**Ammonia:** 0.0 0.0 0.0 0.0 0.0
**Xylose:** 0.0 244.3500 244.3500 0.0 2.3098
**Glucose:** 32.1773 0.0 0.0 5.8179 0.0

**GM/cc:** 0.7716 9.3658

**Phase:**
- **Components:** MOL/HR
- **Material:** Water
- **Mol/HR:** 6440.5528
- **G/M:** 9576.52

**Stream ID:**
- **S11:** S12 S13 S14 S15

**Total Flow:**
- **DIETHER:** 0.0 9782.1932 9782.1932 9778.5812 4.7257-05
- **Xylose:** 0.0 0.0 0.0 0.0 0.0
- **Xylose:** 0.0 0.0 0.0 0.0 0.0
- **Methanol:** 0.0 0.0 0.0 0.0 0.0
- **Water:** 0.0 9576.52 0.0 0.0 0.0

**Total Flow:**
- **KJ/MOL:** 2886.7907 1.4557+04 1.4557+04 1.4557+04 3.5313+05
- **KJ/DAY:** 2351.0000 5.2080+04 0.7998+04 0.0000 0.0000

**State Variables:**
- **Temp:** 92.0000 110.0002 237.4785 180.0000 102.4609
- **Pres:** 1.0000 1.0000 1.0000 1.0000 1.0000
- **VFrac:** 0.2038 0.8207 0.3396 0.8618
- **LFrac:** 1.0000 0.7962 0.1193 0.6604 0.1382
- **Enthalpy:** -393.7318 -77.4762 -19.6443 -57.3015 -245.1722
- **Source:** Cold
- **KJ/MOL:** -1.3603-07 -5.1257+05 -1.2996-05 -4.7483+05 -1.3607+05

**Density:**
- **Mol/CC:** 2.3290-02 1.5383-04 2.9668-05 7.8954-05 3.7961-05
- **G/M:** 0.7970 2.3252-02 4.4669+03 9.5280-03 6.8403-04

**Average:**
- **Mol/CC:** 33.9333 151.1517 151.1517 120.6779 18.0192

**Stream ID:**
- **S11:** S16 S17 S18 S19 S20

**Phase:**
- **Components:** MOL/HR
- **Material:** Water
- **Mol/HR:** 6440.5528
- **G/M:** 9576.52

**Total Flow:**
- **DIETHER:** 0.0 9782.1932 9782.1932 9778.5812 4.7257-05
- **Xylose:** 0.0 0.0 0.0 0.0 0.0
- **Xylose:** 0.0 0.0 0.0 0.0 0.0
- **Methanol:** 0.0 0.0 0.0 0.0 0.0
- **Water:** 0.0 9576.52 0.0 0.0 0.0

**State Variables:**
- **Temp:** 92.0000 110.0002 237.4785 180.0000 102.4609
- **Pres:** 1.0000 1.0000 1.0000 1.0000 1.0000
- **VFrac:** 0.2038 0.8207 0.3396 0.8618
- **LFrac:** 1.0000 0.7962 0.1193 0.6604 0.1382
- **Enthalpy:** -393.7318 -77.4762 -19.6443 -57.3015 -245.1722
- **Source:** Cold
- **KJ/MOL:** -1.3603-07 -5.1257+05 -1.2996-05 -4.7483+05 -1.3607+05

**Density:**
- **Mol/CC:** 2.3290-02 1.5383-04 2.9668-05 7.8954-05 3.7961-05
- **G/M:** 0.7970 2.3252-02 4.4669+03 9.5280-03 6.8403-04

**Average:**
- **Mol/CC:** 33.9333 151.1517 151.1517 120.6779 18.0192
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**ENTROPY:**

- CAL/MOL-K: 3.0569+04 2.2485+04 2.9115+04 7.8012+05 3.5313+05
- KG/DAY: 2.5010+04 1.2890+04 1.0562+05 3.5293+05 1.6272+05
- KG/MOL: 1.0000 1.0000 1.0000 3.0211+06 7.8548+06
- AVG MW: 34.0897 23.7331 151.1527 18.8490 18.0152

**STATE VARIABLES:**

- TEMP: 45.9187 95.9972 2312.8515 8.5945+05
- PRES ATM: 1.0000 1.0000 1.0000 1.0000
- VFPAR: 0.0 0.0 0.0 0.0
- ETRHY: 0.0 0.0 0.0 0.0
- ENTHALFY: 0.0 0.0 0.0 0.0

**MEMORY:**

- PK/MOL: -376.6121 -313.6615 -77.4753 -274.5905 -237.7758
- J/KG: -1.1048+07 -1.3216+07 -5.1256+05 -1.4564+07 -1.3196+07
- RW: -3197.9744 -1935.1032 -626.0854 -5.9486+04 -2.3234+04

**DENSITY:**

- MO/CC: 2.7293-02 3.3776-02 1.5383-04 2.2316-04 2.9316-04
- GM/CC: 0.9304 0.8016 2.3522-02 2.3588-03 5.2826-04
- AVG MW: 34.0897 23.7331 151.1527 18.8490 18.0152
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- METHANOL
- ACETIC ACID
- HYDROGEN
- DIETHYL ETHER

**TO:**

- B3
- B6

**SUBSTREAM:**

- MIXED

**PHASE:**

- VAPOR

**COMPONENTS:**

- MOL/HR
- WATER
- GLUCOSE
- AMMONIA
- OXYGEN
- HYDROGEN
- CAO2
- ETHYL ACETATE
- CELLULOSE
- ETHANOL
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- DIETHYL ETHER
- METHANOL
- ACETIC ACID
- DIETHYL ETHER

**TOTAL FLOW:**

- 0.0

**STATE VARIABLES:**

- TEMPERATURE
- PRESSURE
- VAPOR FRAC
- ETHYLALCOHOL
- ETHYL ACETATE
- METHANOL

**ENTROPY:**

- KJ/MOL

**ENTHALPY:**

- MJ/MOL

**TOTAL FLOW:**

- 0.0

**STOUT SUGARSP SUGAR X WASTE WATER**

**STREAM ID**

<table>
<thead>
<tr>
<th>STEAM1</th>
<th>STEAM2</th>
<th>STEAM3</th>
<th>STEAM4</th>
<th>STEAM5</th>
</tr>
</thead>
</table>

**FROM:**

- ETHYLALCOHOL
- METHANOL
- ACETIC ACID
- HYDROGEN
- DIETHYL ETHER

**TO:**

-你好

**SUBSTREAM:**

- MIXED

**PHASE:**

- VAPOR

**COMPONENTS:**

- MOL/HR
- WATER
- GLUCOSE
- AMMONIA
- OXYGEN
- HYDROGEN
- CAO2
- ETHYL ACETATE
- CELLULOSE
- ETHANOL
- ACETIC ACID
- DIETHYL ETHER
- METHANOL
- ACETIC ACID
- DIETHYL ETHER

**TOTAL FLOW:**

- 0.0

**STATE VARIABLES:**

- TEMPERATURE
- PRESSURE
- VAPOR FRAC
- ETHYLALCOHOL
- ETHYL ACETATE
- METHANOL

**ENTROPY:**

- KJ/MOL

**ENTHALPY:**

- MJ/MOL

**TOTAL FLOW:**

- 0.0

**STOUT SUGARSP SUGAR X WASTE WATER**

**STREAM ID**

<table>
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<tr>
<th>STEAM1</th>
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<th>STEAM4</th>
<th>STEAM5</th>
</tr>
</thead>
</table>

**FROM:**

- ETHYLALCOHOL
- METHANOL
- ACETIC ACID
- HYDROGEN
- DIETHYL ETHER

**TO:**

-你好

**SUBSTREAM:**

- MIXED

**PHASE:**

- VAPOR

**COMPONENTS:**

- MOL/HR
- WATER
- GLUCOSE
- AMMONIA
- OXYGEN
- HYDROGEN
- CAO2
- ETHYL ACETATE
- CELLULOSE
- ETHANOL
- ACETIC ACID
- DIETHYL ETHER
- METHANOL
- ACETIC ACID
- DIETHYL ETHER

**TOTAL FLOW:**

- 0.0

**STATE VARIABLES:**

- TEMPERATURE
- PRESSURE
- VAPOR FRAC
- ETHYLALCOHOL
- ETHYL ACETATE
- METHANOL

**ENTROPY:**

- KJ/MOL

**ENTHALPY:**

- MJ/MOL

**TOTAL FLOW:**

- 0.0
### DENSITY:

| Component | MOL/CC | G/M | AVG | AVG
<table>
<thead>
<tr>
<th></th>
<th></th>
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<tbody>
<tr>
<td>WATER</td>
<td>3.6382-04</td>
<td>3.5282-03</td>
<td>3.5564-02</td>
<td>4.1822-02</td>
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<tr>
<td>GLUCOSE</td>
<td>8.5641-03</td>
<td>6.9714-02</td>
<td>0.7855</td>
<td>0.7571</td>
</tr>
</tbody>
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### AVG MN

- 19.7593
- 19.8546
- 18.0136
- 18.0184

### SUBSTREAM: MIXED

#### COMPONENTS: MOL/HR

<table>
<thead>
<tr>
<th>Component</th>
<th>MOL/HR</th>
<th>PHASE:</th>
<th>LIQUID</th>
<th>MIXED</th>
</tr>
</thead>
</table>

#### SUBSTREAM: MIXED TO: B22

- CAOH

#### FROM: FUGEXYL FILTER

- XYLSUGAR
- XYSUGARS

### AVG MW

- ENTR

### DENSITY:

- GM/CC

### ENTROPY:

### TOTAL COST:

- MOL/HR
- LIQUID

### PHASE:

- LIQUID
- MIXED

### COMPONENTS: MOL/HR

| Component | MOL/HR | PHASE: | LIQUID | MIXED |

### ENTHALPY:

| Component | J/KG/MOL |

| Component | J/KG |

### STEAM:

| Component | PRICE |

| Component | COST |

### STREAM ID:

- WETBSGC
- X1
- X2
- XYLITOL

### TOTAL FLOW:

| Component | MOL/HR | PHASE: | LIQUID |

### STATE VARIABLES:

| Component | TEMP | PRESS | VAPOR | LIQUID |

### COST $/HR

| Component | COST |

| Component | COST |

### STREAM COSTS:

| Component | PRICE |

### PRICE:

| Component | PRICE |

### COST $/HR

| Component | COST |

### STREAM ID:

- XYLSUGAR
- XYSUGARS

### FROM:

- FUGEXYL
- FILTER

### TO:

- B22
- CAOH-NEU

### SUBSTREAM: MIXED
### STREAM ID 1

#### FROM : 
PLA-FERM

#### TO : 
B9

**SUBSTREAM: MIXED**

**COMPONENTS: MOL/HR**

- **WATER**: 8.1648+05
- **GLUCOSE**: 32.1773
- **XYLOSE**: 0.0
- **AMMONIA**: 0.0
- **OTHLIQUID**: 0.0
- **H2SO4**: 0.0
- **CAOH2**: 0.0
- **CASO4**: 0.0
- **OTHSOLID**: 1704.2599
- **CELLULOS**: 0.0
- **ENZ/XYL**: 0.0
- **NACIT**: 0.0
- **LACTICAC**: 6371.1031
- **DIETHER**: 0.0
- **N2**: 0.0
- **METHANOL**: 0.0
- **CH2CL2**: 0.0
- **PLA**: 0.0

**TOTAL FLOW:**

- **MOL/HR**: 8.2459+05
- **KG/DAY**: 3.6832+05
- **L/DAY**: 4.8787+05

**STATE VARIABLES:**

- **TEMP**: 37.0000
- **PRES**: 1.0000
- **VFRAC**: 0.0
- **LFRAC**: 1.0000

**ENTHALPY:**

- **KJ/MOL**: -290.6723
- **J/KG**: -1.9700+06
- **KW**: -6.6579+04

**ENTROPY:**

- **CAL/MOL**: -43.6936
- **CAL/GM**: -2.3477

**DENSITY:**

- **MOL/CC**: 4.0564+02
- **GM/CC**: 0.7550
- **AVG MW**: 18.6115

### STREAM COSTS

<table>
<thead>
<tr>
<th>ID</th>
<th>PRICE</th>
<th>COST $/HR</th>
</tr>
</thead>
<tbody>
<tr>
<td>BSG</td>
<td>7.2647-04 $/L</td>
<td>2.0027</td>
</tr>
<tr>
<td>CAOH</td>
<td>0.1760 $/KG</td>
<td>84.1832</td>
</tr>
<tr>
<td>ENZYMES</td>
<td>0.5070 $/KG</td>
<td>331.0499</td>
</tr>
<tr>
<td>LIQUOR</td>
<td>0.0 $/KG</td>
<td>0.0</td>
</tr>
<tr>
<td>NACIT</td>
<td>0.3000 $/KG</td>
<td>374.8750</td>
</tr>
<tr>
<td>PREC-PLA</td>
<td>0.0 $/KG</td>
<td>0.0</td>
</tr>
<tr>
<td>PREC-XYL</td>
<td>0.0 $/KG</td>
<td>0.0</td>
</tr>
<tr>
<td>PURE</td>
<td>0.0 $/KG</td>
<td>0.0</td>
</tr>
<tr>
<td>SA-IN</td>
<td>0.2766 $/KG</td>
<td>26.9951</td>
</tr>
<tr>
<td>STEAM3</td>
<td>0.0 $/KG</td>
<td>0.0</td>
</tr>
<tr>
<td>STEAM4</td>
<td>0.0 $/KG</td>
<td>0.0</td>
</tr>
</tbody>
</table>

### STREAM ID 2

#### FROM : 
POLYHEAT

#### TO : 
B9

**SUBSTREAM: MIXED**

**COMPONENTS: MOL/HR**

- **WATER**: 887.7925
- **GLUCOSE**: 32.1773
- **XYLOSE**: 0.0
- **AMMONIA**: 0.0
- **OTHLIQUID**: 0.0
- **H2SO4**: 0.0
- **CAOH2**: 0.0
- **CASO4**: 0.0
- **OTHSOLID**: 0.0
- **CELLULOS**: 0.0
- **ENZ/XYL**: 0.0
- **NACIT**: 0.0
- **LACTICAC**: 6163.4740
- **DIETHER**: 9791.7798
- **N2**: 0.0
- **METHANOL**: 0.0
- **CH2CL2**: 0.0
- **PLA**: 0.0

**TOTAL FLOW:**

- **MOL/HR**: 1.6875+04
- **KG/DAY**: 5.3848+04
- **L/DAY**: 6.3084+04

**STATE VARIABLES:**

- **TEMP**: 93.1981
- **PRES**: 1.0000
- **VFRAC**: 0.0
- **LFRAC**: 1.0000
- **SFRAC**: 0.0

**ENTHALPY:**

- **KJ/MOL**: -261.9231
- **J/KG**: -1.9700+06
- **KW**: -1227.7808

**ENTROPY:**

- **CAL/MOL**: -259.2704
- **CAL/GM**: -1.9901

**DENSITY:**

- **MOL/CC**: 4.0564+02
- **GM/CC**: 0.7550
- **AVG MW**: 132.9556

### STREAM COSTS

<table>
<thead>
<tr>
<th>ID</th>
<th>PRICE</th>
<th>COST $/HR</th>
</tr>
</thead>
<tbody>
<tr>
<td>AASWAT</td>
<td>7.2647-04 $/L</td>
<td>2.0027</td>
</tr>
<tr>
<td>Component</td>
<td>Price ($/KG)</td>
<td>Cost ($/HR)</td>
</tr>
<tr>
<td>-----------------</td>
<td>--------------</td>
<td>-------------</td>
</tr>
<tr>
<td>Prec-Xyl</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Pure</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Sa-In</td>
<td>0.2756</td>
<td>26.3951</td>
</tr>
<tr>
<td>Steam3</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Steam4</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Xylitol</td>
<td>1.4330</td>
<td>589.7120</td>
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<tr>
<td>Enzymes</td>
<td>0.5070</td>
<td>331.0499</td>
</tr>
<tr>
<td>Liqor</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Nacit</td>
<td>1.9180</td>
<td>415.6513</td>
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<td>Nh3</td>
<td>0.3000</td>
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<td>Prec-Pca</td>
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<td>Prec-Xyl</td>
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<tr>
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<tr>
<td>Xylitol</td>
<td>1.4330</td>
<td>589.7120</td>
</tr>
</tbody>
</table>

**Table 1:** Stream Costs

<table>
<thead>
<tr>
<th>Component</th>
<th>Price ($/KG)</th>
<th>Cost ($/HR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aswat</td>
<td>7.2647</td>
<td>342.7347</td>
</tr>
<tr>
<td>Bsg</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Caoh</td>
<td>0.1760</td>
<td>34.8320</td>
</tr>
<tr>
<td>ID</td>
<td>PRICE</td>
<td>COST $/HR</td>
</tr>
<tr>
<td>---------</td>
<td>-------</td>
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<td>415.6513</td>
</tr>
<tr>
<td>NH3</td>
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</tr>
<tr>
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</tr>
<tr>
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<td>0.0 $/KG</td>
<td>0.0</td>
</tr>
<tr>
<td>XYLITOL</td>
<td>1.4330 $/KG</td>
<td>589.7120</td>
</tr>
</tbody>
</table>

**STREAM COSTS**

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<tr>
<td>XYLITOL</td>
<td>1.4330 $/KG</td>
<td>589.7120</td>
</tr>
</tbody>
</table>

**STATE VARIABLES:**

- **TEMP**: 103.3036 °C
- **PRES**: 1.0000 ATM
- **VFRAC**: 0.0
- **LFRAc**: 1.0000
- **SPFAC**: 0.0

**ENTHALPY:**

- **KJ/MOL**: -370.3653
- **J/KG**: -1.0864+07
- **KW**: -3144.9305

**SELECTED ENTHALPY:**

- **CAL/MOL**
  - -55.297
- **CAL/GM**
  - -1.6221

**DENSITY:**

- **MOL/CC**: 2.6179+02
- **GM/CC**: 0.8924
### CAL/MOL-K
-284

### CAL/GM-K
-1.8511

### DENSITY:
- MOL/CC: 2.7971-02
- GM/CC: 0.9535
- AVG MW: 34.0897

### STREAM COSTS

<table>
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</tr>
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<td>STEAM3</td>
<td>0.0 $/KG</td>
<td>0.0</td>
</tr>
<tr>
<td>STEAM4</td>
<td>0.0 $/KG</td>
<td>0.0</td>
</tr>
<tr>
<td>XYLITOL</td>
<td>1.4330 $/KG</td>
<td>589.7120</td>
</tr>
</tbody>
</table>

### STATE VARIABLES:

- TEMP: 5.0000
- PRES: 284.0000
- VPPAC: 0.0
- LPPAC: 1.0000
- SPFAC: 0.0

### ENTHALPY:
- KJ/MOL: -322.1541
- J/KG: -1.3573+07
- KW: -2012.1472

### ENTHALPY:
- CAL/MOL-K: -49.5701
- CAL/GM-K: -2.0886

### DENSITY:
- MOL/CC: 3.6106-02
- GM/CC: 0.8570
- AVG MW: 322.1541
<table>
<thead>
<tr>
<th>ID</th>
<th>PRICE</th>
<th>COST $/HR</th>
</tr>
</thead>
<tbody>
<tr>
<td>AAASWAT</td>
<td>7.2647e-04 $/L</td>
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<tr>
<td>BSG</td>
<td>0.0 $/KG</td>
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</tr>
<tr>
<td>CAOH</td>
<td>0.1760 $/KG</td>
<td>54.1832</td>
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<td>ENZYMES</td>
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<tr>
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<tr>
<td>PREC-XYL</td>
<td>0.0 $/KG</td>
<td>0.0</td>
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<tr>
<td>PURE</td>
<td>0.0 $/KG</td>
<td>0.0</td>
</tr>
<tr>
<td>SA-IN</td>
<td>0.2756 $/KG</td>
<td>26.9951</td>
</tr>
<tr>
<td>STEAM3</td>
<td>0.0 $/KG</td>
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</tr>
<tr>
<td>STEAM4</td>
<td>0.0 $/KG</td>
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</tr>
<tr>
<td>XYLITOL</td>
<td>1.4330 $/KG</td>
<td>589.7120</td>
</tr>
</tbody>
</table>

**STREAM ID: 11**

**FROM:** WASH3  **TO:** CRYSTALL

**SUBSTREAM: MIXED**

**COMPONENTS: MOL/HR**

- WATER: 5375.6749
- GLUCOSE: 0.0
- XYLITOL: 0.0
- AMMONIA: 0.0
- OTHLQUI: 0.0
- H2SO4: 0.0
- CASO4: 0.0
- OTHSOLID: 0.0
- CELULOS: 0.0
- ENZ/XYL: 2704.7653
- NACIT: 0.0
- LACTICAC: 0.0
- DITER: 0.0
- N2: 0.0
- METHANOL: 0.0
- CH2CL2: 0.0
- ETHYL-01: 0.0
- PLA: 0.0

**STATE VARIABLES:**

- TEMP C: 5.0000
- PRES ATM: 1.0000
- VPFRAC: 0.0
- LPFRAC: 1.0000
- SFPFRAC: 0.0

**STREAM COSTS**

**AVG MW:** 62.8911

**TOTAL FLOW:**

- MOL/L: 8084.4402
- KG/DAY: 1.2203e+04
- L/DAY: 1.1175e+04

**STATE VARIABLES:**

- TEMP C: 5.0000
- PRES ATM: 1.0000
- VPFRAC: 0.0
- LPFRAC: 1.0000
- SFPFRAC: 0.0

**STREAM COSTS**

**AVG MW:** 62.8911
### Total Flow:
- **MOL/HR**: 7.9033 × 10^5
- **KG/DAY**: 3.4913 × 10^5
- **L/DAY**: 9.2381 × 10^6

### State Variables:
- **TEMP (°C)**: 70.0000
- **PRESS (ATM)**: 1.0000
- **VFRAC**: 1.7092
- **LFRAC**: 0.9829
- **SFRAC**: 0.00

### Enthalpy:
- **KJ/MOL**: -285.5104
- **J/KG**: -1.5511 × 10^7
- **KW**: -6.2680 × 10^4

### Entropy:
- **CAL/MOL**: -40.7199
- **CAL/GM**: -2.2123

### Density:
- **MOL/CC**: 2.0532
- **GM/CC**: 3.7793
- **AVG MW**: 18.4065

### Stream Costs

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### Stream ID: AASWAT
- **FROM**: ****
- **TO**: WASH2

### Substream: Mixed
- **Phase**: Liquid
- **Components**: MOL/HR
  - **WATER**: 1.1564 × 10^5
  - **GLUCOSE**: 0.0
  - **XYLOSE**: 0.0
  - **AMMONIA**: 0.0
  - **OTHERS**: 0.0
  - **H2SO4**: 0.0
  - **CAOH2**: 0.0
  - **CASO4**: 0.0
  - **OTHSOLID**: 0.0

### Cellulos
- **PRICE**: 0.0
- **COST $/HR**: 2.0027

### Total Flow:
- **MOL/HR**: 1.1564 × 10^5
- **KG/DAY**: 5.0000 × 10^4
- **L/DAY**: 6.6162 × 10^4

### State Variables:
- **TEMP (°C)**: 25.0000
- **PRESS (ATM)**: 1.0000
- **VFRAC**: 0.00
- **LFRAC**: 1.0000
- **SFRAC**: 0.00

### Enthalpy:
- **KJ/MOL**: -288.8616
- **J/KG**: -1.6034 × 10^7
- **KW**: -9279.0822

### Entropy:
- **CAL/MOL**: -40.8242
- **CAL/GM**: -2.2661

### Density:
- **MOL/CC**: 4.1949
- **GM/CC**: 0.7557
- **AVG MW**: 18.0153

### Stream Costs

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**STATE VARIABLES:**

- **Temp (°C):** 25.0000
- **PRES ATM (kPa):** 1.0000
- **ENTROPY:** 0.0
- **ENTHALPY:** 0.0
- **CAL/MOL-K:** -345.9984
- **CAL/GM-K:** -1.9634
- **DENSITY:** 3.2612-02
- **GM/CC:** 0.9003
- **AVG MW:** 27.6055
- **TOTAL FLOW:** 2.4227+05
- **KG/DAY:** 1.6051+05
- **L/DAY:** 1.7829+05
- **MOL/HR:** 2.4227+05
- **$/HR:** 0.0

**FLOW:**

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**STATE VARIABLES:**

- **Temp (°C):** 25.0000
- **PRES ATM (kPa):** 1.0000
- **ENTROPY:** 0.0
- **ENTHALPY:** 0.0
- **CAL/MOL-K:** -345.9984
- **CAL/GM-K:** -1.9634
- **DENSITY:** 3.2612-02
- **GM/CC:** 0.9003
- **AVG MW:** 27.6055
- **TOTAL FLOW:** 2.4227+05
- **KG/DAY:** 1.6051+05
- **L/DAY:** 1.7829+05
- **MOL/HR:** 2.4227+05
- **$/HR:** 0.0

**FLOW:**

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**FLOW:**

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AMMONIA 0.0
OPTHIQI 0.0
H2SO4 0.0
CAOH2 0.0
CASO4 0.0
OTHSOLID 0.0
CELLULOS 0.0
ENZ/XYL 0.0
NACIT 0.0
LACTICAC 0.0
DIETHER 9791.7798
N2 0.0
METHANOL 0.0
CHEC2L 0.0
ETHYL-01 0.0
PLA 0.0

TOTAL FLOW:
MOL/HR 9791.7798
KG/DAY 4.0000E+04
L/DAY 4.8989E+04

STATE VARIABLES:

TEMP C 141.0000
PRES ATM 1.0000
VFAC 0.0
LFAC 1.0000
SFAC 0.0

ENTHALPY:

kJ/MOL 18.4581
J/KG 1.0844E+05
KW 50.2050

ENTROPY:

CAL/MOL-K -108.6053
CAL/GM-K -0.6381

DENSITY:

MOL/CC 4.7970E-03
GM/CC 0.8165
AVG MW 170.3108

STREAM COSTS

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STREAM ID ETHIN2
FROM : ----
TO : B14

SUBSTREAM: MIXED

PHASE: LIQUID

COMPONENTS: MOL/HR

WATER 0.0
GLUCOSE 0.0
XYLOSE 0.0
AMMONIA 0.0
OPTHIQI 0.0
H2SO4 0.0
CAOH2 0.0
CASO4 0.0
OTHSOLID 0.0
CELLULOS 0.0
ENZ/XYL 0.0
NACIT 0.0
LACTICAC 0.0
DIETHER 9791.7798
N2 0.0
METHANOL 0.0
CHEC2L 0.0
ETHYL-01 0.0
PLA 0.0

TOTAL FLOW:
MOL/HR 9791.7798
KG/DAY 4.0000E+04
L/DAY 4.8989E+04

STATE VARIABLES:

TEMP C 141.0000
PRES ATM 1.0000
VFAC 0.0
LFAC 1.0000
SFAC 0.0

ENTHALPY:

kJ/MOL 18.4581
J/KG 1.0844E+05
KW 50.2050

ENTROPY:

CAL/MOL-K -108.6053
CAL/GM-K -0.6381

DENSITY:

MOL/CC 4.7970E-03
GM/CC 0.8165
AVG MW 170.3108
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**STREAM COSTS**

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**Stream ID: ETHOUT1**

**From:** ETHFLASH

**To:** B7

**SUBSTREAM: MIXED**

**Phase:** LIQUID

**Components:** MOL/HR

- WATER: 610.0397
- GLUCOSE: 32.1350
- XYLOSE: 0.0
- AMMONIA: 0.0
- OTHLIQUI: 0.0
- H2SO4: 0.0
- CAOH2: 0.0
- CASO4: 0.0
- OTHSOLID: 0.0
- ENZ/XYL: 0.0
- NACIT: 0.0
- LACTICAC: 0.0
- CELLULOS: 0.0
- N2: 0.0
- METHANOL: 0.0
- CH2CL2: 0.0
- ETHYL-01: 0.0
- PLA: 0.0

**Total Flow:**

- MOL/HR: 1.0187+04
- KG/DAY: 3.9393+04
- L/DAY: 4.9095+04

**State Variables:**

- TEMP C: 157.4842
- PRES ATM: 1.0000
- VPRAC: 0.0
- LPFRAC: 1.0000
- SFPRAC: 0.0

**Enthalpy:**

- KJ/MOL: 2.7036
- J/KG: 1.6779+04

**State Variables:**

- Temp C: 7.6504
STATE VARIABLES:
- TEMP: 155.7932
- PRES: 1.0000
- VFRAC: 8.8423-04
- LFRAC: 0.9991
- SFRAC: 0.0

STATE VARIABLES:
- TEMP: 155.7932
- PRES: 1.0000
- VFRAC: 8.8423-04
- LFRAC: 0.9991
- SFRAC: 0.0

Density:
- MOL/CC: 5.6800+03
- GM/CC: 0.8315

Average MW:
- 146.3925

Stream Costs:

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ETHPLA

Stream ID: ETHPLA
From: PLAFLASH
To: B11

Substream: Mixed

Phase: Vapor

Components:
- WATER: 4736.6216
- GLUCOSE: 32.1530
- XYLITOL: 0.0
- AMMONIA: 0.0
- OTHLIQUI: 0.0
- H2O4: 0.0
- CAOH2: 0.0
- CASO4: 0.0
- OTHSOLID: 0.0
- CELLULOS: 0.0
- ENZ/XYL: 0.0
- NACIT: 0.0
- LACTICAC: 0.0
- DIETH: 9787.2324
- N2: 0.0
- METHANOL: 0.0
- CH2CL2: 0.0
- ETHYL-01: 0.0

Total Flow:
- MOL/HR: 1.0474+04
- KG/DAY: 4.0404+04
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**State Variables:**

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<td>ETHER-01</td>
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Othsolid 0.0
Cellulos 0.0
Enz-xyl 0.0
Nacit 0.0
Lacticac 0.0
Diether 0.0
N2 0.0
Methanol 0.0
Ch2cl2 0.0
Etyl-01 0.0
Pla 0.0

Cost: $/hr 0.0

Total flow:
- Mol/hr 5379.6749
- Kg/day 2325.9924
- L/day 3036.7727

State variables:
- Temp C 5.0000
- Press atm 1.0000
- Vfrac 0.0
- Lfrac 1.0000
- Sfrac 0.0

Enthalpy:
- Kj/mol -290.6010
- J/kg +1.6131E+07
- Kw -434.2608

Entropy:
- Cal/mol -42.2666
- Cal/kg -2.3462

Density:
- Mol/cc 4.2516
- Gm/cc 0.7659
- Avg mw 18.0153

Stream costs

<table>
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<tr>
<th>ID</th>
<th>Price</th>
<th>Cost $/hr</th>
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<td>7.2647-04 $/L</td>
<td>2.0027</td>
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<tr>
<td>Bsg</td>
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<tr>
<td>Caoh</td>
<td>0.1760 $/kg</td>
<td>54.1832</td>
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<tr>
<td>Enzymes</td>
<td>0.5070 $/kg</td>
<td>331.0499</td>
</tr>
<tr>
<td>Liqor</td>
<td>1.9180 $/kg</td>
<td>415.6513</td>
</tr>
<tr>
<td>Nacit</td>
<td>0.3000 $/kg</td>
<td>374.8750</td>
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<td>Nh3</td>
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<td>Prec-xyl</td>
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<td>Sa-in</td>
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<tr>
<td>Steam3</td>
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<td>Steam4</td>
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<td>Xylitol</td>
<td>1.4330 $/kg</td>
<td>589.7120</td>
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Stream id: mEOHIN
From: ----
To: B4

Substream: Mixed
Phase: Liquid
Components: Mol/hr

Stream costs

<table>
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<tr>
<th>ID</th>
<th>Price</th>
<th>Cost $/hr</th>
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<tbody>
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<tr>
<td>Xylitol</td>
<td>1.4330 $/kg</td>
<td>589.7120</td>
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</table>

MEOHIN

---
TO   :                  SACCH
SUBSTREAM: MIXED
PHASE:                  LIQUID
COMPONENTS: MOL/HR
WATER                  0.0
GLUCOSE                0.0
XYLOSE                 0.0
AMMONIA                0.0
OTHLIQUI               0.0
H2SO4                  0.0
CAOH2                  0.0
CASO4                  0.0
OTHSOLID               0.0
CELLULOS               0.0
ENZ/XYL                0.0
NACIT               3708.0625
LACTICAC               0.0
DIETHER                0.0
N2                     0.0
METHANOL               0.0
CH2CL2                 0.0
ETHYL-01               0.0
PLA                    0.0
COST:
$/HR                 415.6513
TOTAL FLOW:
MOL/HR              3708.0625
KG/Day               5201.0000
L/Day                6233.4334
STATE VARIABLES:
TEMP   C              25.0000
PRES   ATM             1.0000
VFRAC                  0.0
LFRAC                  1.0000
SFRAC                  0.0
ENTHALPY:
KJ/MOL                 445.7720
J/KG                     7.6275E+06
KW                     459.1529
ENTROPY:
CAL/MOL          301.7511
CAL/GM           7.39740
DENSITY:
MOL/CC             1.4277-02
GM/CC                5.4321-03
AVG MW                  58.4425
STREAM COSTS
---------
ID                               PRICE                     COST $/HR
---------
-----------
AASWAT                            7.2647-04             2.0027
BSG                                0.0                    0.0
CASH                              0.1760                 84.1832
ENZYMES                            0.5070                 331.0499
LIQUIOR                            0.0                    0.0
NACIT                              1.9180                 415.6513
NH3                                0.3000                374.8750
PREC-PLA                          0.0                    0.0
PREC-XYL                           0.0                    0.0
PURE                               0.0                    0.0
SA-IN                              0.2766                 26.9951
STEAM3                            0.0                    0.0
STEAM4                            0.0                    0.0
XYLITOL                            1.4330                589.7120

TO   :                  SACCH
SUBSTREAM: MIXED
PHASE:                  LIQUID
COMPONENTS: MOL/HR
WATER               4.9941E+04
GLUCOSE                0.0
XYLOSE                0.0
AMMONIA               9983.5910
OTHLIQUI              0.0
H2SO4                  0.0
CAOH2                  0.0
CASO4                  0.0
OTHSOLID               0.0
CELLULOS               0.0
ENZ/XYL                0.0
NACIT                  0.0
LACTICAC               0.0
DIETHER                 0.0
N2                     0.0
METHANOL               0.0
CH2CL2                 0.0
ETHYL-01               0.0
PLA                    0.0
COST:
$/HR                 374.8750
TOTAL FLOW:
MOL/HR             5.9925E+04
KG/Day                5.9925E+04
L/Day                 5.5321E+06
STATE VARIABLES:
TEMP   C              25.0000
PRES   ATM             1.0000
VFRAC                 0.1705
LFRAC                  0.8295
SFRAC                  0.0
ENTHALPY:
KJ/MOL               301.7511
J/KG                     1.4471E+07
KW                     5022.8586
ENTROPY:
CAL/MOL          82.8665
CAL/GM           3.9739
DENSITY:
MOL/CC             2.5997-04
GM/CC               5.4211-03
AVG MW                  20.8526
STREAM COSTS
---------
ID                               PRICE                     COST $/HR
---------
-----------
AASWAT                            7.2647-04             2.0027
BSG                                0.0                    0.0
CASH                              0.1760                 54.1832
ENZYMES                            0.5070                 331.0499
LIQUIOR                            0.0                    0.0
NACIT                              1.9180                 415.6513
NH3 0.3000 $/KG 374.8750 BSG 0.0 $/KG 0.0
PREC-PLA 0.0 $/KG 0.0 CAOH 0.1760 $/KG 54.1832
PREC-XYL 0.0 $/KG 0.0 ENZYMES 0.5870 $/KG 331.0499
PURE 0.0 $/KG 0.0 LIQUOR 0.0 $/KG 0.0
SA-IN 0.2756 $/KG 26.9951 NACIT 0.0 $/KG 0.0
STEAM3 0.0 $/KG 0.0 NH3 0.3000 $/KG 374.8750
STEAM4 0.0 $/KG 0.0 PREC-PLA 0.0 $/KG 0.0
PURE 0.0 $/KG 0.0 PREC-XYL 0.0 $/KG 0.0
SA-IN 0.2756 $/KG 26.9951 STEAM3 0.0 $/KG 0.0
XYLITOL 1.4330 $/KG 589.7120 STEAM4 0.0 $/KG 0.0
PLA --- STREAM ID PLA
FROM : PLAFLASH TO : CHLMIX
STREAM ID PLA
FROM : PLAFLASH TO : CHLMIX
STREAM COSTS

--- STREAM ID PLA
FROM : PLAFLASH TO : CHLMIX
STREAM COSTS

--- STREAM ID PLA1
FROM : POLYREAC TO : B19
STREAM COSTS

--- STREAM ID PLA1
FROM : POLYREAC TO : B19
STREAM COSTS
### ID | PRICE | COST $/HR
--- | --- | ---
AASWAT | 7.2647-04 S/L | 2.0027
BG | 0.0 | 0.0
CAOH | 0.1760 S/KG | 54.1832
ENZYMES | 0.5070 S/KG | 331.0499
NACIT | 1.9180 S/KG | 415.6513
NH3 | 0.3000 S/KG | 374.8750
PREC-PLA | 0.0 S/KG | 0.0
PREC-XYL | 0.0 S/KG | 0.0
PURE | 0.0 S/KG | 0.0
SA-IN | 0.2756 S/KG | 26.9951
STEAM3 | 0.0 S/KG | 0.0
STEAM4 | 0.0 S/KG | 0.0
XYLITOL | 1.4330 S/KG | 589.7120

### PLAOUT
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STREAM ID | PLAOUT
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FROM : | B4
TO : | ----

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### TOTAL FLOW:
MOL/HR | 1.2234+04
KG/DAY | 5.1772+04
L/DAY | 5.0623+04

### STATE VARIABLES:
TEMP C | 99.8609
PRESS ATM | 1.0000
VFRAc | 0.0
LFRAc | 1.0000
SFRACT | 0.0

### ENTHALPY:
KJ/MOL | -50.9332
J/KG | -2.8887+05
KW | -173.0928

### ENTROPY:
CAL/MOL | -98.0774
CAL/GM | -0.5562

### DENSITY:
MOL/CC | 5.8003-03
GM/CC | 1.0227

### AVG MW | 176.3216

### STREAM COSTS
---
ID | PRICE | COST $/HR
--- | --- | ---
AASWAT | 7.2647-04 S/L | 2.0027
BG | 0.0 | 0.0
CAOH | 0.1760 S/KG | 54.1832
ENZYMES | 0.5070 S/KG | 331.0499
NACIT | 1.9180 S/KG | 415.6513
NH3 | 0.3000 S/KG | 374.8750
PREC-PLA | 0.0 S/KG | 0.0
PREC-XYL | 0.0 S/KG | 0.0
PURE | 0.0 S/KG | 0.0
SA-IN | 0.2756 S/KG | 26.9951
STEAM3 | 0.0 S/KG | 0.0
STEAM4 | 0.0 S/KG | 0.0
XYLITOL | 1.4330 S/KG | 589.7120
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<td>PLA</td>
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</tbody>
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TOTAL FLOW: 6.5652x10^5 MOL/HR
3.6832x10^5 KG/DAY
5.5182x10^6 L/DAY

STATE VARIABLES:

| TEMP C | 25.0000 |
| PRES ATM | 1.0000  |
| VPRAC  | 0.0     |
| DPRAC  | 1.0000  |
| SFRAC  | 0.0     |

| ENTROPY: | | |
| KJ/MOL  | -293.1794 |
| J/KG    | -1.5665x10^7 |
| KW     | -6.6781x10^4 |

| ENTHALPY: | | |
| CAL/MOL-K | -41.8127 |
| CAL/GM-K   | -2.3942  |

| DENSITY: | | |
| MOL/CC  | 4.1228x10^-2 |
| GM/CC   | 0.7716     |
| AVG MW  | 18.7151   |

STREAM COSTS

<table>
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<tr>
<th>ID</th>
<th>PRICE $/L</th>
<th>COST $/HR</th>
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<tr>
<td>BSG</td>
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<td>CAOH</td>
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<td>415.6513</td>
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<td>0.3000</td>
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<td>STEAM3</td>
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<tr>
<td>XYLITOL</td>
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<td>PREC-PLA</td>
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<td>PREC-XYL</td>
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<td>XYLITOL</td>
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<td>589.7120</td>
</tr>
</tbody>
</table>

SUBSTREAM: MIXED

<table>
<thead>
<tr>
<th>COMPONENTS</th>
<th>MOL/HR</th>
</tr>
</thead>
<tbody>
<tr>
<td>WATER</td>
<td>4.2973x10^4</td>
</tr>
<tr>
<td>GLUCOSE</td>
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<tr>
<td>XYLOSE</td>
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<tr>
<td>AMMONIA</td>
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<tr>
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<td>CASO4</td>
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<td>DIETHER</td>
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</tr>
<tr>
<td>N2</td>
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</tr>
<tr>
<td>METHANOL</td>
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<tr>
<td>ETHYL-01</td>
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</tr>
<tr>
<td>PLA</td>
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</table>

TOTAL FLOW: 6.5652x10^4 MOL/HR
5.1683x10^4 KG/DAY
5.5182x10^6 L/DAY

STATE VARIABLES:

| TEMP C | 25.0000 |
| PRES ATM | 1.0000  |
| VPRAC  | 0.0     |
| DPRAC  | 1.0000  |
| SFRAC  | 0.0     |

| ENTROPY: | | |
| KJ/MOL  | -293.1794 |
| J/KG    | -1.5665x10^7 |
| KW     | -6.6781x10^4 |

| ENTHALPY: | | |
| CAL/MOL-K | -41.8127 |
| CAL/GM-K   | -2.3942  |

| DENSITY: | | |
| MOL/CC  | 4.1228x10^-2 |
| GM/CC   | 0.7716     |
| AVG MW  | 18.7151   |
COMPONENTS: MOL/HR
PHASE:                  MIXED
SUBSTREAM: MIXED

TO   :                  B20
FROM :                  SA
STREAM ID               PROD

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<tr>
<th>ID</th>
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<tr>
<td>XYLITOL</td>
<td>1.4330 $/KG</td>
<td>589.7120</td>
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<tr>
<td>STEAM4</td>
<td>0.0      $/KG</td>
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STATE VARIABLES:

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<th>ID</th>
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<td>XYLITOL</td>
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<tr>
<td>STEAM4</td>
<td>0.0      $/KG</td>
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STREAM COSTS

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<th>ID</th>
<th>PRICE</th>
<th>COST $/HR</th>
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<tbody>
<tr>
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<td>1.4330 $/KG</td>
<td>589.7120</td>
</tr>
<tr>
<td>STEAM4</td>
<td>0.0      $/KG</td>
<td>0.0</td>
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SUBSTREAM: MIXED

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<tr>
<td>GLUCOSE</td>
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<tr>
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STATE VARIABLES:

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<tr>
<td>STEAM4</td>
<td>0.0      $/KG</td>
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STREAM COSTS

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<tbody>
<tr>
<td>XYLITOL</td>
<td>1.4330 $/KG</td>
<td>589.7120</td>
</tr>
<tr>
<td>STEAM4</td>
<td>0.0      $/KG</td>
<td>0.0</td>
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SUBSTREAM: MIXED  
**PHASE:** LIQUID  
**COMPONENTS:** MOL/HR  
WATER  1.0760+04  
GLUCOSE  0.0  
XYLOSE  244.3500  
AMMONIA  0.0  
OTLIGUI  0.0  
H2SO4  0.0  
CAOH  0.0  
CAOS4  0.0  
OTHSOLID  0.0  
CELLULOS  0.0  
ENZ/KYL  239.6406  
NACIT  0.0  
LACTICAC  0.0  
DIETHER  0.0  
N2  0.0  
METHANOL  0.0  
CH2CL2  0.0  
ETHYL-01  0.0  
PLA  0.0  
**TOTAL FLOW:**  
MOL/HR  1.1243+04  
KG/DAY  6404.0166  
L/DAY  7988.6620  
**STATE VARIABLES:**  
TEMP C  95.0000  
PRES ATM  1.0000  
VFAC  0.0  
SFAC  1.0000  
ENTHALPY:  
K/J/MOL  -3.3216+07  
J/KG  -1.3216+07  
KW  -979.5516  
*STATE VARIABLES:*  
TEMP C  313.6615  
PRES ATM  1.0000  
VFAC  0.0  
SFAC  0.0  
ENTROPY:  
CAL/MOL-K  -43.2539  
CAL/GM-K  -1.8224  
DENSITY:  
MOL/CC  3.3776+02  
GM/CC  0.8016  
AVG MW  23.7341  
**STREAM COSTS**  
ID  PRICE  COST $/HR  
--------------  --------------  
AASSAT  7.2647-04  $/L  2.0027  
BGG  0.0  $/KG  0.0  
CAOH  0.1760  $/KG  54.1832  
ENZYMES  0.5070  $/KG  331.0499  
LIQUOR  0.0  $/KG  0.0  
NACIT  1.9180  $/KG  415.6513  
NH3  0.3000  $/KG  374.8750  
PRE-PLA  0.0  $/KG  0.0  
PRE-XYL  0.0  $/KG  0.0  
PRE-C-01  0.0  $/KG  0.0  
SA-IN  0.2756  $/KG  26.9951  
STEAM3  0.0  $/KG  0.0  
XYLITOL  1.4330  $/KG  589.7120  
S1  --  --  
**STREAM COSTS**  
ID  PRICE  COST $/HR  
--------------  --------------  
AASSAT  7.2647-04  $/L  2.0027  
BGG  0.0  $/KG  0.0  
CAOH  0.1760  $/KG  54.1832  
ENZYMES  0.5070  $/KG  331.0499  
LIQUOR  0.0  $/KG  0.0  
NACIT  1.9180  $/KG  415.6513  
NH3  0.3000  $/KG  374.8750  
PRE-PLA  0.0  $/KG  0.0  
PRE-XYL  0.0  $/KG  0.0  
PRE-C-01  0.0  $/KG  0.0  
SA-IN  0.2756  $/KG  26.9951  
STEAM3  0.0  $/KG  0.0
### STREAM ID: S2

**From:** B5  
**To:** WASH

**Substream:** MIXED  
**Phase:** LIQUID

**Components:**  
- **WATER:** 8.2291E5 MOL/HR  
- **GLUCOSE:** 5.8149E-03 KG/MOL  
- **XYLOSE:** 2.3098E-02 KG/MOL  
- **AMMONIA:** 0.0 KG/MOL  
- **OTHLIQUI:** 0.0 KG/MOL  
- **H2SO4:** 0.0 KG/MOL  
- **CAOH2:** 0.0 KG/MOL  
- **CASO4:** 0.0 KG/MOL  
- **OTHSOLID:** 0.0 KG/MOL  
- **CELLULOS:** 5.5705E-04 KG/MOL  
- **ENZ/XYL:** 0.1081 KG/MOL  
- **NACIT:** 0.0 KG/MOL  
- **LACTICAC:** 0.0 KG/MOL  
- **DIETHER:** 4.5375E-05 KG/MOL  
- **N2:** 0.0 KG/MOL  
- **METHANOL:** 0.0 KG/MOL  
- **CH2CL2:** 0.0 KG/MOL  
- **ETHYL-01:** 0.0 KG/MOL  
- **PLA:** 0.0 KG/MOL  

**Total Flow:**  
- **MOL/HR:** 8.2292E5  
- **KG/DAY:** 3.5580E+05  
- **L/DAY:** 4.9848E+05

**State Variables:**  
- **TEMP:** 95.0000 C  
- **PRES:** 1.0000 ATM  
- **VFRAC:** 0.0  
- **LFRAC:** 1.0000  
- **SFRAC:** 0.0

**Enthalpy:**  
- **KJ/MOL:** -282.7809  
- **J/KG:** -1.6875E+04  
- **KW:** -1.5697E+07

**Entropy:**  
- **CAL/MOL-K:** -35.4492  
- **CAL/GM-K:** -2.0232  
- **J/G:** -1.9180E+04  
- **K:** -1.5697E+07  
- **CAL/GM-K:** -1.5697E+07  
- **CAL/GM-K:** -1.5697E+07

**Density:**  
- **MOL/CC:** 3.9621E-02  
- **GM/CC:** 0.7138  
- **AVG MW:** 18.0153

### Stream Costs

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<tr>
<th>ID</th>
<th>PRICE</th>
<th>COST $/HR</th>
</tr>
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<tbody>
<tr>
<td>AASWAT</td>
<td>7.2647E-04 $/L</td>
<td>2.0027</td>
</tr>
<tr>
<td>BSG</td>
<td>0.0 $/KG</td>
<td>0.0</td>
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<tr>
<td>CAOH</td>
<td>0.1760 $/KG</td>
<td>54.1832</td>
</tr>
<tr>
<td>ENZYMES</td>
<td>0.5070 $/KG</td>
<td>331.0499</td>
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<tr>
<td>LIQUOR</td>
<td>1.9180 $/KG</td>
<td>415.6513</td>
</tr>
<tr>
<td>NH3</td>
<td>0.3000 $/KG</td>
<td>374.8750</td>
</tr>
</tbody>
</table>

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### STREAM ID: S3

**From:** POLYHEAT  
**To:** POLYREAC

**Substream:** MIXED  
**Phase:** LIQUID

**Components:**  
- **WATER:** 887.7925 MOL/HR  
- **GLUCOSE:** 32.1773 MOL/HR  
- **XYLOSE:** 0.0 MOL/HR  
- **AMMONIA:** 0.0 MOL/HR  
- **OTHLIQUI:** 0.0 MOL/HR  
- **H2SO4:** 0.0 MOL/HR  
- **CAOH2:** 0.0 MOL/HR  
- **CASO4:** 0.0 MOL/HR  
- **OTHSOLID:** 0.0 MOL/HR  
- **CELLULOS:** 0.0 MOL/HR  
- **ENZ/XYL:** 0.0 MOL/HR  
- **NACIT:** 0.0 MOL/HR  
- **LACTICAC:** 6163.4740 MOL/HR  
- **DIETHER:** 9791.7798 MOL/HR  
- **N2:** 0.0 MOL/HR  
- **METHANOL:** 0.0 MOL/HR  
- **CH2CL2:** 0.0 MOL/HR  
- **ETHYL-01:** 0.0 MOL/HR  
- **PLA:** 0.0 MOL/HR  

**Total Flow:**  
- **MOL/HR:** 1.6875E+04  
- **KG/DAY:** 5.3848E+04  
- **L/DAY:** 6.6764E+04

**State Variables:**  
- **TEMP:** 170.0000 C  
- **PRES:** 1.0000 ATM  
- **VFRAC:** 0.0  
- **LFRAC:** 1.0000  
- **SFRAC:** 0.0

**Enthalpy:**  
- **KJ/MOL:** -241.7789  
- **J/KG:** -1.8185E+06  
- **KW:** -1.1333E+04

**Entropy:**  
- **CAL/MOL-K:** -241.7789  
- **CAL/GM-K:** -241.7789  
- **J/G:** -1.8185E+06  
- **K:** -1.1333E+04  
- **CAL/GM-K:** -1.8185E+06  
- **CAL/GM-K:** -1.8185E+06

**Density:**  
- **MOL/CC:** 6.0662E-03  
- **GM/CC:** 1.0000  
- **AVG MW:** 132.9556

### Stream Costs

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<tr>
<th>ID</th>
<th>PRICE</th>
<th>COST $/HR</th>
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<tbody>
<tr>
<td>AASWAT</td>
<td>7.2647E-04 $/L</td>
<td>2.0027</td>
</tr>
<tr>
<td>BSG</td>
<td>0.0 $/KG</td>
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<tr>
<td>CAOH</td>
<td>0.1760 $/KG</td>
<td>54.1832</td>
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<td>ENZYMES</td>
<td>0.5070 $/KG</td>
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<tr>
<td>LIQUOR</td>
<td>1.9180 $/KG</td>
<td>415.6513</td>
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<tr>
<td>NH3</td>
<td>0.3000 $/KG</td>
<td>374.8750</td>
</tr>
</tbody>
</table>
TOTAL FLOW: 8.6268+04

COMPONENTS: MOL/HR

PHASE: LIQUID

SUBSTREAM: MIXED

TO: B18

SUBSTREAM: MIXED

PHASE: MIXED

COMPONENTS: MOL/HR

WATER 4.4330+02
GLUCOSE 1.8696+02
XYLOSE 0.0
AMMONIA 0.0
OXYCHLORID 0.0
H2SO4 0.0
CAOH2 0.0
CAO4 0.0
PTOSOLID 0.0
CELLULOSE 0.0
XN/XYL 0.0
NACIT 0.0
LACTICAC 0.0
DIETHYL 2.6769
N2 0.0
METHANOL 4.7018+04
CHECL 3.9247+04
BETYL-01 0.0
PLA 0.0

TOTAL FLOW: 8.6268+04
COMPONENTS: MOL/HR
PHASE: MIXED
SUBSTREAM: MIXED
TO : B8
FROM : B5
STREAM ID S10

ID PRICE COST $/HR
--- -----------------------------------------
AASWAT 7.2647-04 /L 2.0027
BSG 0.0 $/KG 0.0
CAOH 0.1760 $/KG 54.1832
ENZYMES 0.5070 $/KG 331.0499
LIQUOR 0.0 $/KG 0.0
NACIT 1.9180 $/KG 415.6513
NH3 0.3000 $/KG 374.8750
PRE-C-PLA 0.0 $/KG 0.0
PRE-C-XYL 0.0 $/KG 0.0
PURE 0.0 $/KG 0.0
SA-IN 0.2756 $/KG 26.3991
STEAM3 0.0 $/KG 0.0
STEAM4 0.0 $/KG 0.0
XYLITOL 1.4330 $/KG 589.7120

STATE VARIABLES:
TEMP C 110.0000
PRES ATM 1.0000
VPFRAC 0.2038
LFPRAC 0.7962
SFRAC 0.0

ENTROPY: K/J/MOL -77.4762
J/KG -5.1257+05

ENERGY:
KJ/MOL 1.9180 $/KG 415.6513

STREAM COSTS
AVG MW 151.1537

-----------------------------

STREAM ID S11
FROM : B8
TO : B8

SUBSTREAM: MIXED
PHASE: MIXED
COMPONENTS: MOL/HR
WATER 3.5305+05
GLUCOSE 0.0
XYLOSE 2.3098-02
AMMONIA 0.0
OTHLIQUI 0.0
NH304 0.0
CAOH2 0.0
CA04 0.0
OTHSOLID 85.5712
CELLULOS 5.5705-04
ENZ/XYL 0.1081

STATE VARIABLES:
TEMP C 102.4610
PRES ATM 1.0000
VPFRAC 0.0
LFPRAC 0.0
SFRAC 0.0

ENTROPY: K/J/MOL -245.1113
J/KG -1.3603+07

ENERGY:
KJ/MOL -245.1113

STREAM COSTS
AVG MW 18.0192

-----------------------------

306
<table>
<thead>
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<th>Component</th>
<th>ID</th>
<th>Price ($/kg)</th>
<th>Cost ($/hr)</th>
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**Total Flow:**
- MOL/HR: 2886.7907
- KG/DAY: 2351.0000
- L/DAY: 2974.8273

**State Variables:**
- TEMP C: 92.0000
- PRES ATM: 1.0000
- VFRAC: 1.0000
- SFRAC: 0.0

**Enthalpy:**
- KJ/MOL: -393.7318
- J/KG: -1.1603+07
- KN: -315.7282

**Entropy:**
- CAL/MOL-K: -49.1532
- CAL/GM-K: -1.4485

**Density:**
- MOL/CC: 2.3290-02
- GM/CC: 0.7803

**AVG MW:**
- XYLITOL: 1.4330
- STEAM4: 0.0
- STEAM3: 0.0
- SA: 0.0
- NH3: 0.3000
- LIQUOR: 0.0
- ENZYMES: 0.5070
- LIQUOR: 0.0
- NACIT: 0.0
- PREC-XYL: 0.0
- PURE: 0.0
- SA-IN: 0.2756
- STEAM4: 0.0
- XYLTOL: 1.4330

---

**STREAM COSTS**

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<tr>
<th>ID</th>
<th>Price ($/L)</th>
<th>Cost ($/HR)</th>
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<tr>
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**Substream:**
- **S12**
  - **FROM:** PSPLIT
  - **TO:** B11

**Components:**
- MOL/HR: 4736.9972
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| MOL/HR: 1704.2599 |
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| L/DAY: 1100.1266 |

| STATE VARIABLES: |
| TEMPERATURE: 37.0000 |
| PRESSURE: 1.0000 |
| VAPOR: 0.0000 |
| LIQUID: 1.0000 |
| ENTHALPY: |
| K/MOL: -190.8871 |
| J/KG: -56619+06 |
| KW: -90.3670 |

| ENTHALPY: |
| CAL/MOL-K: -55.7109 |
| CAL/GM-K: -1.6378 |

| DENSITY: |
| MOL/CC: 3.7180-02 |
| GM/CC: 1.2647 |

| AVG MW: 34.0147 |
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PHASE: LIQUID
SUBSTREAM: MIXED
TO: PLA
FROM: B15
STREAM ID: S21

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STREAM COSTS
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<td>0.0</td>
</tr>
<tr>
<td>SA-IN</td>
<td>0.2756 $/KG</td>
<td>26.9951</td>
</tr>
<tr>
<td>STEAM3</td>
<td>0.0 $/KG</td>
<td>0.0</td>
</tr>
<tr>
<td>STEAM4</td>
<td>1.4330 $/KG</td>
<td>589.7120</td>
</tr>
<tr>
<td>XYLITOL</td>
<td>0.0 $/KG</td>
<td>0.0</td>
</tr>
</tbody>
</table>

STREAM ID: S21
FROM: B15
TO: PLA-FERM
SUBSTREAM: MIXED
TO: B10
FROM: B13
STREAM ID: S22

312
METHANOL               0.0
CH2CL2                 0.0
ETHYL-01               0.0
PLA                    0.0
TOTAL FLOW:            
MOL/HR                 3.5313×10^5
KG/DAY                 1.5272×10^5
L/DAY                  2.1546×10^5
STATE VARIABLES:
TEMP   C               102.4441
PRES   ATM             1.0000
VFRAC                  0.0
LFRAC                  1.0000
SFRA                  0.0
ENTHALPY:              
KJ/MOL                 -282.1051
J/KG                   -1.5656×10^7
KW                     -2.7672×10^4
ENTROPY:               
CAL/MOL                -36.0294
CAL/GM                 -1.9995
DENSITY:               
MOL/CC                  3.9336×10^-2
GM/CC                   0.7088
AVG MW                  18.0192
STREAM COSTS
ID                                 PRICE                           COST $/HR
-----------                        -----------------------------
AASWAT                              7.2647×10^-4   $/L                  2.0027
BSG                                    0.0      $/KG                   0.0
CAOH                                   0.1760   $/KG                  54.1832
ENZYMES                                 0.5070   $/KG                 331.0499
LIQUR                                  0.0      $/KG                   0.0
NACIT                                 1.9180   $/KG                 415.6513
NH3                                    0.3000   $/KG                 374.8750
PRE-C-PLA                          0.0      $/KG                   0.0
PRE-C-XYL                         0.0      $/KG                   0.0
PURE                                   0.0      $/KG                   0.0
SA-IN                                 0.2756   $/KG                 26.9951
STEAM3                                 0.0      $/KG                   0.0
STEAM4                                 0.0      $/KG                   0.0
XYLITOL                               1.4330   $/KG                 589.7120
S23                                  ---
STREAM ID               S23
FROM :                  B16
TO :                  XLAFERM
SUBSTREAM: MIXED
PHASE:          LIQUID
COMPONENTS:  MOL/HR
WATER               3.0202×10^5
GLUCOSE             4.2792
XYLOSE              3836.2129
AMMONIA             0.0
OTHLIQUI            6.2002×10^4
H2SO4               0.0
CAOH2               0.0
CAO4                 0.0
OHTHOSOLID          0.0
CELLULOS            0.0

---

STREAM ID               S24
FROM :                  B17
TO :                  PLAFLASH
SUBSTREAM: MIXED
PHASE:          MIXED
COMPONENTS:  MOL/HR
WATER               4.736.6659
GLUCOSE             32.1775
XYLOSE              0.0
AMMONIA             0.0
OTHLIQUI            0.0

---

STREAM COSTS
ID                                 PRICE                           COST $/HR
-----------                        -----------------------------
AASWAT                              7.2647×10^-4   $/L                  2.0027
BSG                                    0.0      $/KG                   0.0
CAOH                                   0.1760   $/KG                  54.1832
ENZYMES                                 0.5070   $/KG                 331.0499
LIQUR                                  0.0      $/KG                   0.0
NACIT                                 1.9180   $/KG                 415.6513
NH3                                    0.3000   $/KG                 374.8750
PRE-C-PLA                          0.0      $/KG                   0.0
PRE-C-XYL                         0.0      $/KG                   0.0
PURE                                   0.0      $/KG                   0.0
SA-IN                                 0.2756   $/KG                 26.9951
STEAM3                                 0.0      $/KG                   0.0
STEAM4                                 0.0      $/KG                   0.0
XYLITOL                               1.4330   $/KG                 589.7120
<table>
<thead>
<tr>
<th>COMPONENTS: MOL/HR</th>
</tr>
</thead>
<tbody>
<tr>
<td>PHASE:</td>
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<tr>
<td>LIQUID</td>
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<tr>
<td>SUBSTREAM: MIXED</td>
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<tr>
<td>TO   :</td>
</tr>
<tr>
<td>B16</td>
</tr>
<tr>
<td>FROM :</td>
</tr>
<tr>
<td>B20</td>
</tr>
</tbody>
</table>

**TOTAL FLOW:**

- **MOL/HR:** 1.4556
- **KG/DAY:** 5.2684
- **L/DAY:** 1.5779

**STATE VARIABLES:**

- **TEMP C:** 268.0000
- **PRES ATM:** 1.0000
- **VFRA:** 0.9994
- **LFRAC:** 0.0
- **VFRAC:** 0.9994
- **PRES ATM:** 1.0000
- **TEMP C:** 288.0000
- **L/DAY:** 2.2035

**STREAM COSTS**

- **AVG MW:** 151.1560
- **DENSITY:**
- **ENTROPY:**
- **ENTHALPY:**
- **STATE VARIABLES:**
  - **TOTAL FLOW:**
    - **MOL/HR:** 3.6810
    - **KG/DAY:** 1.7510

**STATE VARIABLES:**

- **TOTAL FLOW:**
  - **MOL/HR:** 1.4556
  - **KG/DAY:** 5.2684
  - **L/DAY:** 1.5779

**STREAM COSTS**

- **AVG MW:** 151.1560
- **DENSITY:**
- **ENTROPY:**
- **ENTHALPY:**
- **STATE VARIABLES:**
  - **TOTAL FLOW:**
    - **MOL/HR:** 3.6810
    - **KG/DAY:** 1.7510
**TO:** B1  
**SUBSTREAM:** MIXED  
**PHASE:** MIXED  
**COMPONENTS:** MOL/HR

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<tr>
<th>Component</th>
<th>MOL/HR</th>
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<tr>
<td>WATER</td>
<td>1.0509E+06</td>
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<tr>
<td>GLUCOSE</td>
<td>4.1938</td>
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<tr>
<td>XYLOSE</td>
<td>2.3109E-02</td>
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<td>AMMONIA</td>
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<tr>
<td>OTHLIQUI</td>
<td>0.0</td>
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<tr>
<td>H2SO4</td>
<td>0.0</td>
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<tr>
<td>CASO4</td>
<td>0.0</td>
</tr>
<tr>
<td>OTHSOLID</td>
<td>0.0</td>
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<tr>
<td>CELLULOS</td>
<td>1.4330E+04</td>
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<tr>
<td>ENZ/XYL</td>
<td>0.1082</td>
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<tr>
<td>NACIT</td>
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<tr>
<td>LACTICAC</td>
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<tr>
<td>DIETHER</td>
<td>3.1610E-05</td>
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<tr>
<td>N2</td>
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<tr>
<td>METHANOL</td>
<td>0.0</td>
</tr>
<tr>
<td>CH2CL2</td>
<td>0.0</td>
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<tr>
<td>ETHYL-01</td>
<td>0.0</td>
</tr>
<tr>
<td>PLA</td>
<td>0.0</td>
</tr>
</tbody>
</table>

**TOTAL FLOW:**
- **MOL/HR:** 1.0652E+06
- **KG/DAY:** 5.1633E+05
- **L/DAY:** 8.4619E+08

**STATE VARIABLES:**
- **TEMP:** 140.0000 C
- **PRES:** 1.0000 ATM
- **VFRAC:** 0.9826
- **LFRAC:** 1.7439E-02
- **ENTHALPY:**
  - **KJ/MOL:** 251.2037
  - **J/KG:** 1.2438E+07
  - **KW:** 7.4328E+04
- **ENTROPY:**
  - **CAL/MOL:** 11.3258 K
  - **CAL/GM:** 0.5608 K
- **DENSITY:**
  - **MOL/CC:** 3.0211E-05
  - **GM/CC:** 6.1018E-04
- **AVG MW:** 20.1972

**STREAM COSTS**

<table>
<thead>
<tr>
<th>ID</th>
<th>PRICE</th>
<th>COST $/HR</th>
</tr>
</thead>
<tbody>
<tr>
<td>AASWAT</td>
<td>7.2647E-04 $/L</td>
<td>2.0027</td>
</tr>
<tr>
<td>BSG</td>
<td>0.0 $/KG</td>
<td>0.0</td>
</tr>
<tr>
<td>CAOH</td>
<td>0.1760 $/KG</td>
<td>84.1832</td>
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<tr>
<td>ENZYMES</td>
<td>0.5070 $/KG</td>
<td>331.0499</td>
</tr>
<tr>
<td>LIQUOR</td>
<td>0.0 $/KG</td>
<td>0.0</td>
</tr>
<tr>
<td>NACIT</td>
<td>1.9180 $/KG</td>
<td>415.6513</td>
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<tr>
<td>NR3</td>
<td>0.3000 $/KG</td>
<td>374.8750</td>
</tr>
<tr>
<td>PREC-PLA</td>
<td>0.0 $/KG</td>
<td>0.0</td>
</tr>
<tr>
<td>PREC-XYL</td>
<td>0.0 $/KG</td>
<td>0.0</td>
</tr>
<tr>
<td>PURE</td>
<td>0.0 $/KG</td>
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</tr>
<tr>
<td>SA-IN</td>
<td>0.2756 $/KG</td>
<td>26.9951</td>
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<tr>
<td>STEAM3</td>
<td>0.0 $/KG</td>
<td>0.0</td>
</tr>
<tr>
<td>STEAM4</td>
<td>0.0 $/KG</td>
<td>0.0</td>
</tr>
<tr>
<td>XYLITOL</td>
<td>1.4330 $/KG</td>
<td>589.7120</td>
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**STREAM ID:** S27  
**FROM:** B12  
**TO:** ----  
**SUBSTREAM:** MIXED  
**PHASE:** LIQUID  
**COMPONENTS:** MOL/HR

<table>
<thead>
<tr>
<th>Component</th>
<th>MOL/HR</th>
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<td>WATER</td>
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<tr>
<td>GLUCOSE</td>
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<tr>
<td>XYLOSE</td>
<td>0.0</td>
</tr>
<tr>
<td>AMMONIA</td>
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</tr>
<tr>
<td>OTHLIQUI</td>
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<tr>
<td>H2SO4</td>
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<tr>
<td>CELLULOS</td>
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<td>ENZ/XYL</td>
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<tr>
<td>NACIT</td>
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<tr>
<td>LACTICAC</td>
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<tr>
<td>DIETHER</td>
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</tr>
<tr>
<td>N2</td>
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<tr>
<td>METHANOL</td>
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<tr>
<td>CH2CL2</td>
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<tr>
<td>ETHYL-01</td>
<td>0.0</td>
</tr>
<tr>
<td>PLA</td>
<td>0.0</td>
</tr>
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</table>

**TOTAL FLOW:**
- **MOL/HR:** 1.0652E+06
- **KG/DAY:** 1338.1500
- **L/DAY:** 1055.1884

**STATE VARIABLES:**
- **TEMP:** 32.0000 C
- **PRES:** 1.0000 ATM
- **VFRAC:** 0.0
- **LFRAC:** 1.0000
- **R1:** -251.2037 KJ/MOL
- **J/KG:** -5.6263E+06
- **KW:** -87.1394
- **ENTROPY:**
  - **CAL/MOL:** 56.0912 K
  - **CAL/GM:** 1.6490 K
- **DENSITY:**
  - **MOL/CC:** 3.7283E-02
  - **GM/CC:** 1.2682
- **AVG MW:** 34.0147

**STREAM COSTS**

<table>
<thead>
<tr>
<th>ID</th>
<th>PRICE</th>
<th>COST $/HR</th>
</tr>
</thead>
<tbody>
<tr>
<td>AASWAT</td>
<td>7.2647E-04 $/L</td>
<td>2.0027</td>
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<tr>
<td>BSG</td>
<td>0.0 $/KG</td>
<td>0.0</td>
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<tr>
<td>CAOH</td>
<td>0.1760 $/KG</td>
<td>54.1832</td>
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<tr>
<td>ENZYMES</td>
<td>0.5070 $/KG</td>
<td>331.0499</td>
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<tr>
<td>LIQUOR</td>
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<td>0.0</td>
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<tr>
<td>NACIT</td>
<td>1.9180 $/KG</td>
<td>415.6513</td>
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<tr>
<td>NR3</td>
<td>0.3000 $/KG</td>
<td>374.8750</td>
</tr>
<tr>
<td>PREC-PLA</td>
<td>0.0 $/KG</td>
<td>0.0</td>
</tr>
<tr>
<td>PREC-XYL</td>
<td>0.0 $/KG</td>
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<tr>
<td>PURE</td>
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**STREAM ID:** S27  
**FROM:** B12  
**TO:** ----  
**SUBSTREAM:** MIXED  
**PHASE:** LIQUID  
**COMPONENTS:** MOL/HR

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<th>MOL/HR</th>
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<tbody>
<tr>
<td>WATER</td>
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<tr>
<td>GLUCOSE</td>
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<tr>
<td>XYLOSE</td>
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<tr>
<td>AMMONIA</td>
<td>0.0</td>
</tr>
<tr>
<td>OTHLIQUI</td>
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<tr>
<td>H2SO4</td>
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<tr>
<td>CASO4</td>
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<td>ENZ/XYL</td>
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<tr>
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<tr>
<td>DIETHER</td>
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<tr>
<td>N2</td>
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</tr>
<tr>
<td>METHANOL</td>
<td>0.0</td>
</tr>
<tr>
<td>CH2CL2</td>
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<tr>
<td>ETHYL-01</td>
<td>0.0</td>
</tr>
<tr>
<td>PLA</td>
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</table>

**TOTAL FLOW:**
- **MOL/HR:** 1639.1820
- **KG/DAY:** 1338.1500
- **L/DAY:** 1055.1884

**STATE VARIABLES:**
- **TEMP:** 32.0000 C
- **PRES:** 1.0000 ATM
- **VFRAC:** 0.0
- **LFRAC:** 1.0000
- **R1:** -191.3770 KJ/MOL
- **J/KG:** -5.6263E+06
- **KW:** -87.1394
- **ENTROPY:**
  - **CAL/MOL:** 56.0912 K
  - **CAL/GM:** 1.6490 K
- **DENSITY:**
  - **MOL/CC:** 3.2833E-02
  - **GM/CC:** 1.2682
- **AVG MW:** 34.0147
SA-IN $0.2756 /KG $26.9951
STEAM3 0.0 $/KG 0.0
STEAM4 0.0 $/KG 0.0
XYLITOL 1.4330 $/KG $589.7120

**STREAM ID** S28
FROM : B12
TO : CHROMA

**SUBSTREAM: MIXED**
**PHASE:** LIQUID
**COMPONENTS:** MOL/HR
WATER $3.0202+05
GLUCOSE 0.0
XYLOSE $488.7400
AMMONIA 0.0
OTHLIQUI $6.2002+04
H2SO4 0.0
CAOH2 0.0
CASO4 0.0
OTHSOLID 0.0
CELLULOS $5.5705-04
ENZ/XYL $3182.3591
NACIT 0.0
LACTICAC 0.0
DIETHER $4.5375-05
N2 0.0
METHANOL 0.0
CH2CL2 0.0
ETHYL-01 0.0
PLA 0.0

**TOTAL FLOW:**
MOL/HR $3.6769+05
KG/DAY $1.7377+05
L/DAY $2.2108+05

**STATE VARIABLES:**
TEMP C $32.0000
PRES ATM 1.0000
VFRAC 0.0
LFRAC 1.0000
SFRAC 0.0

**ENTHALPY:**
KJ/MOL $-296.9659
J/KG $-1.5081+07
KW $-3.0331+04

**ENTROPY:**
CAL/MOL-K $-41.2836
CAL/GM-K $-2.0966

**DENSITY:**
MOL/CC $3.9915-02
GM/CC 0.7860
AVG MW $19.6911

**STREAM COSTS**

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<thead>
<tr>
<th>ID</th>
<th>PRICE</th>
<th>COST $/HR</th>
</tr>
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<tbody>
<tr>
<td>AASWAT</td>
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<tr>
<td>BSG</td>
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<td>CAOH</td>
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<td>ENSYMES</td>
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<tr>
<td>LIQUOR</td>
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**STREAM ID** S29
FROM : B21
TO : B5

**SUBSTREAM: MIXED**
**PHASE:** LIQUID
**COMPONENTS:** MOL/HR
WATER $8.2292+05
GLUCOSE $5.8149-03
XYLOSE $2.3098-02
AMMONIA 0.0
OTHLIQUI 0.0
H2SO4 0.0
CAOH2 0.0
CASO4 0.0
OTHSOLID 0.0
CELLULOS $5.5705-04
ENZ/XYL $0.1081
NACIT 0.0
LACTICAC 0.0
DIETHER $4.5375-05
N2 0.0
METHANOL 0.0
CH2CL2 0.0
ETHYL-01 0.0
PLA 0.0

**TOTAL FLOW:**
MOL/HR $8.2292+05
KG/DAY $3.5580+05
L/DAY $4.8293+05

**STATE VARIABLES:**
TEMP C $58.8310
PRES ATM 1.0000
VFRAC 0.0
LFRAC 1.0000
SFRAC 0.0

**ENTHALPY:**
KJ/MOL $-285.9288
J/KG $-1.5871+07
KW $-6.5360+04

**ENTROPY:**
CAL/MOL-K $-38.5986
CAL/GM-K $-2.1425

**DENSITY:**
MOL/CC $4.0896-02
GM/CC 0.7367
AVG MW $18.0153
AASWAT 7.2647-04 $/L 2.0027
BSG 0.0 $/KG 0.0
CAOH 0.1760 $/KG 54.1832
ENZYMES 0.5070 $/KG 331.0499
LIQUOR 0.0 $/KG 0.0
S30 ---

STREAM COSTS
---------

ID PRICE COST $/HR
--------- --------------------------------- 
AASWAT 7.2647-04 $/L 2.0027
BSG 0.0 $/KG 0.0
CAOH 0.1760 $/KG 54.1832
ENZYMES 0.5070 $/KG 331.0499
LIQUOR 0.0 $/KG 0.0
S30 ---

STREAM ID S30
FROM : B21
TO : ----

SUBSTREAM: MIXED
PHASE: LIQUID
COMPONENTS: MOL/HR
WATER 8.1559+05
GLUCOSE 32.1768
XYLOSE 0.0
AMMONIA 0.0
OTHLIQUI 0.0
H2S04 0.0
CAOH2 0.0
CAS04 0.0
OTHSOLID 0.0
CELLULOS 0.0
ENZ/XYL 0.0
NACIT 0.0
LACTICAC 4152.5822
DIETHER 5.3221-08
N2 0.0
METHANOL 0.0
ETHYL-01 0.0
PLA 0.0

TOTAL FLOW:
MOL/HR 8.15711
KG/DAY 69.8562
L/DAY 55.9439

STATE VARIABLES:
TEMP C 58.8310
PRES ATM 1.0000
VFPRAC 0.0
LFPRAC 1.0000
SFPRAC 0.0

ENTHALPY:
KJ/MOL -188.7454
J/KG -5.5489+06

ENTROPY:
CAL/MOL-K -54.1170
CAL/GM-K -1.5910

MOl/CC 3.6710-02
GM/CC 1.2487
AVG MW 34.0347

STATE VARIABLES:
TEMP C 22.7000
PRES ATM 1.0000
VFPRAC 0.0
LFPRAC 1.0000
SFPRAC 0.0

ENTHALPY:
KJ/MOL -291.0845
J/KG -6.6285+04

ENTROPY:
CAL/MOL-K -43.4061
CAL/GM-K -2.3607
DENSITY:  
MOL/CC  4.1336-02  
GM/CC  0.7600  
AVG MW  18.3867

STREAM COSTS

<table>
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<tr>
<th>ID</th>
<th>PRICE</th>
<th>COST $/HR</th>
</tr>
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<tbody>
<tr>
<td>AASWAT</td>
<td>7.2647-04 $/L</td>
<td>2.0027</td>
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<tr>
<td>BSG</td>
<td>0.0 $/KG</td>
<td>0.0</td>
</tr>
<tr>
<td>CAOH</td>
<td>0.1760 $/KG</td>
<td>54.1832</td>
</tr>
<tr>
<td>ENZYMES</td>
<td>0.5070 $/KG</td>
<td>331.0499</td>
</tr>
<tr>
<td>LIQUOR</td>
<td>0.0 $/KG</td>
<td>0.0</td>
</tr>
<tr>
<td>NACIT</td>
<td>1.9180 $/KG</td>
<td>415.6513</td>
</tr>
<tr>
<td>PREC-PLA</td>
<td>0.0 $/KG</td>
<td>0.0</td>
</tr>
<tr>
<td>PREC-XYL</td>
<td>0.0 $/KG</td>
<td>0.0</td>
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<tr>
<td>PURE</td>
<td>0.0 $/KG</td>
<td>0.0</td>
</tr>
<tr>
<td>SA-IN</td>
<td>0.2756 $/KG</td>
<td>26.9951</td>
</tr>
<tr>
<td>STEAM3</td>
<td>0.0 $/KG</td>
<td>0.0</td>
</tr>
<tr>
<td>STEAM4</td>
<td>0.0 $/KG</td>
<td>0.0</td>
</tr>
<tr>
<td>XYLITOL</td>
<td>1.4330 $/KG</td>
<td>589.7120</td>
</tr>
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</table>

STREAM ID: S32  
FROM : LLEREC  
TO : B25  
SUBSTREAM: MIXED  
PHASE: LIQUID  
COMPONENTS: MOL/HR  
WATER  0.0  
GLUCOSE  32.1768  
XYLOSE  0.0  
AMMONIA  0.0  
OTHLIQUI  0.0  
H2SO4  0.0  
CAOH2  0.0  
CAO4  0.0  
OTHOSOLID  0.0  
CELLULOS  0.0  
ENZ/XYL  0.0  
NACIT  0.0  
LACTICAC  3944.9531  
DIETHER  5.3221-08  
N2  0.0  
METHANOL  0.0  
CH2CL2  0.0  
ETRYL-01  0.0  
PLA  0.0  
TOTAL FLOW:  
MOL/HR  3977.1299  
KG/DAY  8667.6887  
L/DAY  9147.5599  
STATE VARIABLES:  
TEMP C  22.7000  
PRES ATM  1.0000  
VF PAC  0.0  
LFPAC  1.0000  
SFPAC  0.0  
ENTHALPY:  
kJ/MOL  -709.1282
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<tr>
<th>ID</th>
<th>PRICE</th>
<th>COST $/HR</th>
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<tbody>
<tr>
<td>AASWAT</td>
<td>7.2647-04 $/L</td>
<td>2.0027</td>
</tr>
<tr>
<td>BSG</td>
<td>0.0 $/KG</td>
<td>0.0</td>
</tr>
<tr>
<td>CAOH</td>
<td>0.1760 $/KG</td>
<td>54.1832</td>
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<td>ENZYMES</td>
<td>0.5070 $/KG</td>
<td>331.0499</td>
</tr>
<tr>
<td>LIQUOR</td>
<td>0.0 $/KG</td>
<td>0.0</td>
</tr>
<tr>
<td>NACIT</td>
<td>1.9180 $/KG</td>
<td>415.6513</td>
</tr>
<tr>
<td>NH3</td>
<td>0.3000 $/KG</td>
<td>374.8750</td>
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<tr>
<td>PREC-PLA</td>
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<tr>
<td>PREC-XYL</td>
<td>0.0 $/KG</td>
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</tr>
<tr>
<td>PURE</td>
<td>0.0 $/KG</td>
<td>0.0</td>
</tr>
<tr>
<td>SA-IN</td>
<td>0.2756 $/KG</td>
<td>26.9951</td>
</tr>
<tr>
<td>STEAM3</td>
<td>0.0 $/KG</td>
<td>0.0</td>
</tr>
<tr>
<td>STEAM4</td>
<td>0.0 $/KG</td>
<td>0.0</td>
</tr>
<tr>
<td>XYLTOL</td>
<td>1.4330 $/KG</td>
<td>589.7120</td>
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<table>
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<th>COST $/HR</th>
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<tr>
<td>XYL</td>
<td>0.0 $/KG</td>
<td>0.0</td>
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<tr>
<td>PLA</td>
<td>0.0 $/KG</td>
<td>0.0</td>
</tr>
</tbody>
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---

STREAM ID: S34
FROM: B23
TO: COOL2
SUBSTREAM: MIXED

PHASE: LIQUID

COMPONENTS: MOL/HR
WATER 2.6898+04
GLUCOSE 0.0
XYLOSE 486.6902
AMMONIA 0.0
OTHRILQUI 0.0
H2SO4 0.0
CAOH2 0.0
CAO4 0.0
OTHERSOLID 0.0
CELLULOS 0.0
ENZ/XYL 3182.0769
NACIT 0.0
LACTICAC 0.0
DIETHER 0.0
METHANOL 0.0
N2 0.0
ETHYL-01 0.0
PLA 0.0
TOTAL FLOW: 3.0569+04

---

STREAM ID: S36
FROM: B23
TO: SPLIT
SUBSTREAM: MIXED

PHASE: LIQUID

COMPONENTS: MOL/HR
WATER 2.1519+04
GLUCOSE 0.0
XYLOSE 486.7000
AMMONIA 0.0
OTHRILQUI 0.0
H2SO4 0.0
CAOH2 0.0
CAO4 0.0
OTHERSOLID 0.0
CELLULOS 0.0
ENZ/XYL 477.3211
NACIT 0.0
LACTICAC 0.0
DIETHER 0.0
N2 0.0
METHANOL 0.0

---

STREAM COSTS
AVG MW 145.9520
DENSITY: 
ENTROPY: 
ENTHALPY: 
STATE VARIABLES:
MOL/HR 3.0569+04
PLA 0.0
ETHYL 0.0
CH2CL2 0.0
METHANOL 0.0
N2 0.0
METHANOL 0.0

---

TOTAL FLOW:
MOL/HR 3.0569+04
L/DAY 2.5010+04
L/DAY 2.6881+04
STATE VARIABLES:
TEMP C 45.9187
PRET ATM 1.0000
VFRAC 0.0
LFRAC 1.0000
SFRA 0.0

---

TOTAL FLOW:
MOL/HR 3.0569+04
L/DAY 2.5010+04
L/DAY 2.6881+04
STATE VARIABLES:
TEMP C 45.9187
PRET ATM 1.0000
VFRAC 0.0
LFRAC 1.0000
SFRA 0.0

---

TOTAL FLOW:
MOL/HR 3.0569+04
L/DAY 2.5010+04
L/DAY 2.6881+04
STATE VARIABLES:
TEMP C 45.9187
PRET ATM 1.0000
VFRAC 0.0
LFRAC 1.0000
SFRA 0.0

---

TOTAL FLOW:
MOL/HR 3.0569+04
L/DAY 2.5010+04
L/DAY 2.6881+04
STATE VARIABLES:
TEMP C 45.9187
PRET ATM 1.0000
VFRAC 0.0
LFRAC 1.0000
SFRA 0.0
CH2CL2 0.0
ETHYL-01 0.0
PLA 0.0

TOTAL FLOW:
MOL/HR 2.2485+04
KG/DAY 1.2808+04
L/DAY 1.5977+04

STATE VARIABLES:
TEMP C 95.0000
PRES ATM 1.0000
VFRAC 0.0
LFRAC 1.0000
SFRAC 0.0

ENTHALPY:
KJ/MOL -313.6615
J/KG -1.3216+07
KW -1959.1032

ENTROPY:
CAL/MOL -43.2539
CAL/GM -1.8224

DENSITY:
MOL/CC 3.3776-02
GM/CC 0.8016
AVG MW 23.7341

STREAM COSTS

ID
PRICE
COST $/HR

AASWAT 7.2647-04 $/L 2.0027
BSG 0.0 $/KG 0.0
CAOH 0.1760 $/KG 84.1832
ENZYMES 0.5070 $/KG 331.0499
LIQUOR 0.0 $/KG 0.0
NACIT 1.9180 $/KG 415.6513
NH3 0.3000 $/KG 374.8750
PREC-PLA 0.0 $/KG 0.0
PREC-XYL 0.0 $/KG 0.0
PURE 0.0 $/KG 0.0
SA-IN 0.2756 $/KG 26.9951
STEAM3 0.0 $/KG 0.0
STEAM4 0.0 $/KG 0.0
XYLITOL 1.4330 $/KG 589.7120

SA-IN

STREAM ID SA-IN
FROM : ----
TO : B8

SUBSTREAM: MIXED
PHASE: LIQUID

COMPONENTS: MOL/HR
WATER 2312.8515
GLUCOSE 0.0
XYLOSE 0.0
AMMONIA 0.0
OTHLIQU 0.0
H2SO4 573.9393
CAOH2 0.0
CSO4 0.0
OTHSOLID 0.0
CELLULOS 0.0
ENZ/XYL 0.0
NACIT 0.0
LACTICAC 0.0
DIETHER 0.0
METHANOL 0.0
CH2CL2 0.0
ETHYL-01 0.0
PLA 0.0

TOTAL FLOW:
MOL/HR 2886.7907
KG/DAY 2351.0000
L/DAY 2857.2687

STATE VARIABLES:
TEMP C 25.0000
PRES ATM 1.0000
VFRAC 0.0
LFRAC 1.0000
SFRAC 0.0

ENTHALPY:
KJ/MOL -601.1851
J/KG -1.1823+07
KW -321.7049

ENTROPY:
CAL/MOL -54.5391
CAL/GM -1.6072

DENSITY:
MOL/CC 3.3776-02
GM/CC 0.8016
AVG MW 33.9333

stream costs

ID
PRICE
COST $/HR

AASWAT 7.2647-04 $/L 1.0027
BSG 0.0 $/KG 0.0
CAOH 0.1760 $/KG 54.1832
ENZYMES 0.5070 $/KG 331.0499
LIQUOR 0.0 $/KG 0.0
NACIT 1.9180 $/KG 415.6513
NH3 0.3000 $/KG 374.8750
PREC-PLA 0.0 $/KG 0.0
PREC-XYL 0.0 $/KG 0.0
PURE 0.0 $/KG 0.0
SA-IN 0.2756 $/KG 26.9951
STEAM3 0.0 $/KG 0.0
STEAM4 0.0 $/KG 0.0
XYLITOL 1.4330 $/KG 589.7120

SA-IN

STREAM ID SACHIN
FROM : WASH2
TO : SACCH

SUBSTREAM: MIXED
PHASE: MIXED

COMPONENTS: MOL/HR
WATER 8.5945+05
GLUCOSE 0.0
XYLOSE 0.0
AMMONIA 9983.5910
PHASE: VAPOR
SUBSTREAM: MIXED
TO: B3
FROM: ETHFLASH

STEAM1
XYLITOL                                1.4330   $/KG                 589.7120
STEAM4                                 0.0      $/KG                   0.0
STEAM3                                 0.0      $/KG                   0.0
SA PURE                                   0.0      $/KG                   0.0
PREC NH3                                    0.3000   $/KG                 374.8750
NACIT                                  1.9180   $/KG                 415.6513
LIQUOR                                 0.0      $/KG                   0.0
ENZYMES                                0.5070   $/KG                 331.0499
CAOH                                   0.1760   $/KG                  54.1832
AASWAT                              7.2647

STATE VARIABLES:
TOTAL FLOW:
MOL/HR                                  9.0597+05
KG/DAY                                   3.9913+05
L/DAY                                    8.5139+06
AVG MW                  18.3566

DENSITY:

ENTROPY:

ENTHALPY:

STATE VARIABLES:

STREAM COSTS
AVG MW                  18.3566

COMPONENTS: MOL/HR
WATER               4126.5819
GluCose            5.8074-03
XYLose              0.0
AMMONIA                0.0
OTHILOIQM              0.0
H2SO4                    0.0
CAH2                    0.0
CASO4                   0.0
OTHILOID                0.0
CELLULOS                0.0
ENZ/XYL                 0.0
NACIT                    0.0
LACTICAC                0.0
DIETHER                  0.0

TOTAL FLOW:
MOL/HR                                  4360.5126
KG/DAY                                   2735.8187
L/DAY                                    3.6715+06
AVG MW                  26.1802

DENSITY:

ENTROPY:

ENTHALPY:

STATE VARIABLES:

STREAM COSTS
AVG MW                  26.1802

COMPONENTS: MOL/HR
WATER               4126.5819
GluCose            5.8074-03
XYLose              0.0
AMMONIA                0.0
OTHILOIQM              0.0
H2SO4                    0.0
CAH2                    0.0
CASO4                   0.0
OTHILOID                0.0
CELLULOS                0.0
ENZ/XYL                 0.0
NACIT                    0.0
LACTICAC                0.0
DIETHER                  0.0

TOTAL FLOW:
MOL/HR                                  4360.5126
KG/DAY                                   2735.8187
L/DAY                                    3.6715+06
AVG MW                  26.1802

STREAM COSTS
AVG MW                  26.1802

COMPONENTS: MOL/HR
WATER               4126.5819
GluCose            5.8074-03
XYLose              0.0
AMMONIA                0.0
OTHILOIQM              0.0
H2SO4                    0.0
CAH2                    0.0
CASO4                   0.0
OTHILOID                0.0
CELLULOS                0.0
ENZ/XYL                 0.0
NACIT                    0.0
LACTICAC                0.0
DIETHER                  0.0

TOTAL FLOW:
MOL/HR                                  4360.5126
KG/DAY                                   2735.8187
L/DAY                                    3.6715+06
AVG MW                  26.1802

STREAM COSTS
AVG MW                  26.1802

STREAM ID: STEAMI
FROM: ETHFLASH
TO: B3

SUBSTREAM: MIXED
PHASE: VAPOR

STREAM ID: STEAM2

321
FROM: DRYPLA  TO: B3

SUBSTREAM: MIXED  PHASE: VAPOR
COMPONENTS: MOL/HR
WATER         2313.9709
GLUCOSE       1.045400
XYLOSE        0.000000
AMMONIA       0.000000
H2SO4         0.000000
CAOH          0.000000
CASO4         0.000000
OTHSLIQU      0.000000
CELLULOS      0.000000
ENZ/XYL       0.000000
NACIT         0.000000
LACTICAC      0.000000
DIETHER       8.651100
N2             0.000000
METHANOL      0.000000
CH2CL2        0.000000
ETHYL-01      0.000000
PLA           9.527724

TOTAL FLOW: MOL/HR  2322.6220
              KG/DAY  1035.8243
              L/DAY   1.691506

STATE VARIABLES:
TEMP   C 99.8609
PRES   ATM 1.0000
VFRAC  1.0000
LFRAC  0.0000
SFRAC  0.0000

ENTHALPY:
KJ/MOL -238.2231
J/KG  1.284907
KW  153.6951

STREAM COSTS
------------

ID PRICE COST $/HR
------- --------- --------
AASWAT 7.2647-04 $/L 2.0027
BSG  0.00 $/KG 0.00
CAOH  0.1760 $/KG 54.1832
ENZYMES 0.5070 $/KG 331.0499
LIQUOR  0.00 $/KG 0.00
NACIT  1.9180 $/KG 415.6513
NH3  0.3000 $/KG 374.8750

STATE VARIABLES:

TEMP   C 110.0000
PRES   ATM 1.2993
VFRAC  1.0000
LFRAC  0.0000
SFRAC  0.0000

ENTROPY:
CAL/MOL-K -9.0810
CAL/GM-K -0.4887

DENSITY:
MOL/CC  3.2956-05
GM/CC  6.1239-04
AVG MN  18.5822

STREAM COSTS
------------

ID PRICE COST $/HR
------- --------- --------
AASWAT 7.2647-04 $/L 2.0027
BSG  0.00 $/KG 0.00
CAOH  0.1760 $/KG 54.1832
ENZYMES 0.5070 $/KG 331.0499
LIQUOR  0.00 $/KG 0.00
NACIT  1.9180 $/KG 415.6513
NH3  0.3000 $/KG 374.8750

STATE VARIABLES:

TEMP   C 110.0000
PRES   ATM 1.2993
VFRAC  1.0000
LFRAC  0.0000
SFRAC  0.0000

ENTROPY:
CAL/MOL-K -9.1396
CAL/GM-K -0.5068

DENSITY:
MOL/CC  4.1753-05
GM/CC  7.5293-04
AVG MN  18.0328
### STEAM 3 to B19

#### COMPONENTS: MOL/HR

<table>
<thead>
<tr>
<th>Component</th>
<th>MOL/HR</th>
</tr>
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<tbody>
<tr>
<td>WATER</td>
<td>2.7512E+05</td>
</tr>
<tr>
<td>GLUCOSE</td>
<td>0.0</td>
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<tr>
<td>XYLOSE</td>
<td>2.3098E+02</td>
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<tr>
<td>AMMONIA</td>
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</tr>
<tr>
<td>OTHLQI</td>
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<tr>
<td>H2SO4</td>
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<td>CAOH2</td>
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<td>CASO4</td>
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</tr>
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<td>ENZ/XYL</td>
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<td>NACIT</td>
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<td>NH</td>
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<tr>
<td>METHANOL</td>
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<tr>
<td>CH2CL2</td>
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</tr>
<tr>
<td>ETHYL-01</td>
<td>0.0</td>
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<tr>
<td>PLA</td>
<td>0.0</td>
</tr>
</tbody>
</table>

#### TOTAL FLOW:

- **MOL/HR**: 2.7512E+05
- **KG/DAY**: 1.1895E+05
- **L/DAY**: 2.0228E+08

#### STATE VARIABLES:

- **TEMP C**: 103.3036
- **PRES ATM**: 1.0000
- **VPFAC**: 1.0000
- **LPFAC**: 0.0
- **SPFAC**: 0.0

#### ENTHALPY:

- **KJ/MOL**: -239.2434
- **J/KG**: -1.3280E+07
- **KW**: -1.8284E+04

#### ENTROPY:

- **CAL/MOL-K**: -8.7585
- **CAL/JMOL**: -0.4862

#### DENSITY:

- **MOL/CC**: 3.2642E-05
- **QM/CC**: 5.8806E-04

#### AVG MW: 18.0153

### STREAM COSTS

<table>
<thead>
<tr>
<th>ID</th>
<th>PRICE</th>
<th>COST $/HR</th>
</tr>
</thead>
<tbody>
<tr>
<td>AASWAT</td>
<td>7.2647E-04</td>
<td>2.0027</td>
</tr>
<tr>
<td>BSG</td>
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<tr>
<td>CAS</td>
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<td>54.1832</td>
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<tr>
<td>ENZYMES</td>
<td>0.3070</td>
<td>331.0499</td>
</tr>
<tr>
<td>LIQUOR</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>NACIT</td>
<td>0.5070</td>
<td>331.0499</td>
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<tr>
<td>XYLITOL</td>
<td>1.4330</td>
<td>589.7120</td>
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</table>

### STEAM 4 to B19

#### COMPONENTS: MOL/HR

<table>
<thead>
<tr>
<th>Component</th>
<th>MOL/HR</th>
</tr>
</thead>
<tbody>
<tr>
<td>WATER</td>
<td>2.7512E+05</td>
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<tr>
<td>GLUCOSE</td>
<td>0.0</td>
</tr>
<tr>
<td>XYLOSE</td>
<td>2.3098E+02</td>
</tr>
<tr>
<td>AMMONIA</td>
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<tr>
<td>OTHLQI</td>
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<tr>
<td>H2SO4</td>
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<td>CAOH2</td>
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</tr>
<tr>
<td>CASO4</td>
<td>0.0</td>
</tr>
<tr>
<td>ENZ/XYL</td>
<td>0.1081</td>
</tr>
<tr>
<td>NACIT</td>
<td>0.0</td>
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<td>DIETR</td>
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<tr>
<td>METHANOL</td>
<td>0.0</td>
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<tr>
<td>CH2CL2</td>
<td>0.0</td>
</tr>
<tr>
<td>ETHYL-01</td>
<td>0.0</td>
</tr>
<tr>
<td>PLA</td>
<td>0.0</td>
</tr>
</tbody>
</table>

#### TOTAL FLOW:

- **MOL/HR**: 2.7512E+05
- **KG/DAY**: 1.1895E+05
- **L/DAY**: 2.0228E+08

#### STATE VARIABLES:

- **TEMP C**: 155.2010
- **PRES ATM**: 1.0000
- **VPFAC**: 1.0000
- **LPFAC**: 0.0
- **SPFAC**: 0.0

#### ENTHALPY:

- **KJ/MOL**: -237.4522
- **J/KG**: 1.3181E+07
- **KW**: 1.8147E+04

#### ENTROPY:

- **CAL/MOL-K**: -7.6939
- **CAL/JMOL**: -0.4271

#### DENSITY:

- **MOL/CC**: 2.8615E-05
- **QM/CC**: 5.1550E-04

#### AVG MW: 18.0153
ENTROPY:

ENTHALPY:

STATE VARIABLES:

TOTAL FLOW:

COMPONENTS: MOL/HR

PHASE:                  MIXED

SUBSTREAM: MIXED

STREAM ID               STOUT
FROM :                  BZ
TO   :                  WATPUR
-----

STREAM COSTS

---

ID                                 PRICE                           COST $/HR
------------

STREAM COSTS

---

AVG MW                  23.5396
DENSITY:

KJ/MOL

SFRAC                  0.0
LFRAC                  0.9885
VFRAC               1.1531
PRES   ATM             1.0000
TEMP   C              25.0000
L/DAY               6.0247+06
KG/DAY              4.2001+05
MOL/HR              8.8567+05
PLA                   0.0
ETHYL

CH2Cl2               0.0
METHANOL            0.0
N2                   0.0
METANOL             0.0
ETHYL-01            0.0
PLA                  9.5277-24
TOTAL FLOW:          6683.1346
KG/DAY              3775.6430
L/DAY               4.4087+05
STATE VARIABLES:

PLA

TOTAL FLOW:          8.5677+05
KG/DAY              4.2001+05
L/DAY               6.0247+06
STATE VARIABLES:

PLA

ENTROPIE:

CAL/MOL-K            -36.9156
CAL/GM-K             -1.5682

---

STREAM COSTS

---

ID                                 PRICE                           COST $/HR
------------

STREAM COSTS

---

ID                                 PRICE                           COST $/HR
------------

STREAM COSTS

---

ID                                 PRICE                           COST $/HR
------------

STREAM COSTS

---

ID                                 PRICE                           COST $/HR
------------

STREAM COSTS

---

ID                                 PRICE                           COST $/HR
------------

STREAM COSTS

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ID                                 PRICE                           COST $/HR
------------

STREAM COSTS

---

ID                                 PRICE                           COST $/HR
------------

STREAM COSTS

---

ID                                 PRICE                           COST $/HR
------------

STREAM COSTS

---

ID                                 PRICE                           COST $/HR
------------
### STATE VARIABLES:

**TOTAL FLOW:**
- COMPONENTS: MOL/HR
- PHASE: LIQUID
- SUBSTREAM: MIXED
- FROM: CAOH
- STREAM ID: SUGARSX

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<tr>
<th>ID</th>
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<th>COST $/HR</th>
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### FROM:
- CAOH

### TO:
- FUGEXYL

### SUBSTREAM: MIXED

**PHASE:** LIQUID

**COMPONENTS:** MOL/HR

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<tr>
<th>ID</th>
<th>PRICE</th>
<th>COST $/HR</th>
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</thead>
<tbody>
<tr>
<td>SUGARSX</td>
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</tbody>
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### TO:
- FUGEXYL

### FROM:
- CAOH

### TOTAL FLOW:
- MOL/HR: 3.6341e+05
- KG/DAY: 1.7317e+05
- L/DAY: 2.2045e+05

### TEMPERATURE:
- C: 25.0000

### PRESSURE:
- ATM: 1.0000

### STREAM COSTS

**AVG MW**

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<tr>
<th>ID</th>
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### STREAM COSTS

**AVG MW**

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<tbody>
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### PETROLEUM

- BSG: 0.0
- ETHYL: 0.0
- CH2CL2: 0.0

### CHEMICALS

- CASO4: 541.0364
- CAOH2: 28.4756
- H2SO4: 32.9029
- NH3: 0.3000
- NACIT: 1.9180
- LIQUOR: 0.0
- ENZYMES: 0.5070
- CAOH: 0.1760
- BSG: 0.0
- AASWAT: 7.2647

### OTHERS

- WATER: 2.9720e+05
- AMMONIA: 0.0
- CELLULOS: 0.0
- N2: 0.0
- METHANOL: 0.0
- ETHYL-01: 0.0
- PLA: 0.0

### TOTAL FLOW:
- MOL/HR: 8.1580e+05

### TEMPERATURE:
- C: 25.0000

### PRESSURE:
- ATM: 1.0000

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### STREAM COSTS

**AVG MW**

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### TOTAL FLOW:
- MOL/HR: 8.1580e+05
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<td>374.8750</td>
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<tr>
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<tr>
<td>STEAM4</td>
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<tr>
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<td>1.4330</td>
<td>589.7120</td>
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STREAM COSTS

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<tr>
<td>STEAM4</td>
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<tr>
<td>XYLITOL</td>
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STREAM ID: WATER1
FROM: WATPUR
TO: B10

SUBSTREAM: MIXED
PHASE: LIQUID
COMPONENTS: MOL/HR
WATER 6395.546
GLUCOSE 5.8149-03
XYLOSE 0.0
AMMONIA 0.0
OTHIQUI 0.0
H2O4 0.0
CAOH2 0.0
CAS04 0.0
OTHSOLID 0.0
CELULOS 0.0
ENS/XYL 0.0
NACIT 0.0
LACTICAC 0.0
DIETER 1.0864-05
N2 0.0
METHANOL 0.0

STATE VARIABLES:
TEMP C 22.7000
PRES ATM 1.0000
VFRAC 0.0
LFRAC 1.0000
SFRAC 0.0

ENTHALPY:
KJ/MOL -289.1608
J/KG -1.6035-07
RW 6.527-04

DENSITY:
MOL/CC 4.1982-02
GM/CC 0.7571
AVG MW 18.0336

STREAM COSTS

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<tr>
<th>ID</th>
<th>PRICE</th>
<th>COST $/HR</th>
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<td>AASWAT</td>
<td>7.2647-04</td>
<td>2.0027</td>
</tr>
<tr>
<td>BSG</td>
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<td>0.0</td>
</tr>
<tr>
<td>CAOH</td>
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<tr>
<td>ENZYMES</td>
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<tr>
<td>LIQUOR</td>
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<tr>
<td>NACIT</td>
<td>1.9180</td>
<td>415.6513</td>
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<tr>
<td>NH3</td>
<td>0.3000</td>
<td>374.8750</td>
</tr>
<tr>
<td>PREC-PLA</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
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<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>PORE</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>SA-IN</td>
<td>0.2756</td>
<td>26.9951</td>
</tr>
<tr>
<td>STEAM3</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>STEAM4</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>XYLITOL</td>
<td>1.4330</td>
<td>589.7120</td>
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</tbody>
</table>

STATE VARIABLES:
TEMP C 90.0000
PRES ATM 1.0000
VFRAC 0.0
LFRAC 1.0000
SFRAC 0.0

ENTHALPY:
KJ/MOL -283.2188
J/KG -1.5721-07
RW 503.1501

DENSITY:
MOL/CC -36.7348
CAL/GM 2.0391

TOTAL FLOW:
MOL/CC 3.9807-02
GM/CC 0.7171
AVG MW 3.9807-02

STREAM ID: WETBSGC
FROM: WASH
TO: B20

SUBSTREAM: MIXED
PHASE: LIQUID
COMPONENTS: MOL/HR
WATER 6395.5524
GLUCOSE 2765.2467
XYLOSE 369.5524
N2 0.0
METHANOL 0.0

STATE VARIABLES:
TEMP C 90.0000
PRES ATM 1.0000
VFRAC 0.0
LFRAC 1.0000
SFRAC 0.0

ENTHALPY:
KJ/MOL -283.2188
J/KG -1.5721-07
RW 503.1501

DENSITY:
MOL/CC -36.7348
CAL/GM 2.0391

TOTAL FLOW:
MOL/CC 3.9807-02
GM/CC 0.7171
AVG MW 3.9807-02

STREAM ID: WETBSGC
FROM: WASH
TO: B20

SUBSTREAM: MIXED
PHASE: LIQUID
COMPONENTS: MOL/HR
WATER 1.0509-06
GLUCOSE 4.1938
XYLOSE 2.3109-02
N2 0.0
METHANOL 0.0

STATE VARIABLES:
TEMP C 90.0000
PRES ATM 1.0000
VFRAC 0.0
LFRAC 1.0000
SFRAC 0.0

ENTHALPY:
KJ/MOL -283.2188
J/KG -1.5721-07
RW 503.1501

DENSITY:
MOL/CC -36.7348
CAL/GM 2.0391

TOTAL FLOW:
MOL/CC 3.9807-02
GM/CC 0.7171
AVG MW 3.9807-02

STREAM ID: WETBSGC
FROM: WASH
TO: B20

SUBSTREAM: MIXED
PHASE: LIQUID
COMPONENTS: MOL/HR
WATER 1.0509-06
GLUCOSE 4.1938
XYLOSE 2.3109-02
N2 0.0
METHANOL 0.0

STATE VARIABLES:
TEMP C 90.0000
PRES ATM 1.0000
VFRAC 0.0
LFRAC 1.0000
SFRAC 0.0

ENTHALPY:
KJ/MOL -283.2188
J/KG -1.5721-07
RW 503.1501

DENSITY:
MOL/CC -36.7348
CAL/GM 2.0391

TOTAL FLOW:
MOL/CC 3.9807-02
GM/CC 0.7171
AVG MW 3.9807-02

STREAM ID: WETBSGC
FROM: WASH
TO: B20

SUBSTREAM: MIXED
PHASE: LIQUID
COMPONENTS: MOL/HR
WATER 1.0509-06
GLUCOSE 4.1938
XYLOSE 2.3109-02
N2 0.0
METHANOL 0.0

STATE VARIABLES:
TEMP C 90.0000
PRES ATM 1.0000
VFRAC 0.0
LFRAC 1.0000
SFRAC 0.0

ENTHALPY:
KJ/MOL -283.2188
J/KG -1.5721-07
RW 503.1501

DENSITY:
MOL/CC -36.7348
CAL/GM 2.0391

TOTAL FLOW:
MOL/CC 3.9807-02
GM/CC 0.7171
AVG MW 3.9807-02

STREAM ID: WETBSGC
FROM: WASH
TO: B20

SUBSTREAM: MIXED
PHASE: LIQUID
COMPONENTS: MOL/HR
WATER 1.0509-06
GLUCOSE 4.1938
XYLOSE 2.3109-02
N2 0.0
METHANOL 0.0

STATE VARIABLES:
TEMP C 90.0000
PRES ATM 1.0000
VFRAC 0.0
LFRAC 1.0000
SFRAC 0.0

ENTHALPY:
KJ/MOL -283.2188
J/KG -1.5721-07
RW 503.1501

DENSITY:
MOL/CC -36.7348
CAL/GM 2.0391

TOTAL FLOW:
MOL/CC 3.9807-02
GM/CC 0.7171
AVG MW 3.9807-02

STREAM ID: WETBSGC
FROM: WASH
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<tr>
<td>AASWAT</td>
<td>7.2647-04 $/L</td>
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<tr>
<td>BSG</td>
<td>0.0 $/KG</td>
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<tr>
<td>CAOH</td>
<td>0.0 $/KG</td>
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<td>ENZYMS</td>
<td>0.5070 $/KG</td>
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<td>LIQUOR</td>
<td>0.0 $/KG</td>
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<td>NACIT</td>
<td>1.9180 $/KG</td>
<td>415.6513</td>
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<td>NR3</td>
<td>0.3000 $/KG</td>
<td>374.8750</td>
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<td>PREC-PLA</td>
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<td>XYLITOL</td>
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**STREAM COSTS**

--------

**ID** | **PRICE** | **COST $/HR**
-------|-----------|-----------

**IN**  | **PRICE** | **COST $/HR**
-------|-----------|-----------

**OUT** | **PRICE** | **COST $/HR**
-------|-----------|-----------

**SUBSTREAM: MIXED**

**PHASE:** MIXED

**COMPONENTS: MOL/HR**

**WATER** 1.0509+06

**GLUCOSE** 4.1938

**XYLOSE** 2.3109+02

**AMMONIA** 0.0

**OTHLIQU** 0.0

**H2SO4** 0.0

**CAOH2** 0.0

**CASO4** 0.0

**OTHSLID** 0.0

**CELLULOS** 1.4330+04

**ENZ/NXYL** 0.1082

**NACIT** 0.0

**LACTICAC** 0.0

**DIETHIER** 3.1610+05

**N2** 0.0

**METHANOL** 0.0

**CH2CL2** 0.0

**ETRYL-01** 0.0

**PLA** 0.0

**TOTAL FLOW:**

**MOL/HR** 1.0562+06

**KG/DAY** 5.1633+05

**L/DAY** 6.7532+05

**STATE VARIABLES:**

**TEMP C** 75.9008

**PRES ATM** 1.0000

**VFRAK** 1.0000

**LFRAK** 1.0000

**SPRAK** 0.0

**ENTHARY:**

**KJ/MOL** -296.9584

**J/KG** -1.4703+07

**KG** -8.7866+04

**ENTROPY:**

**CAL/MOL-K** -40.3760

**CAL/KG-K** -1.9991

**DENSITY:**

**MOL/CC** 3.7655+02

**GM/CC** 0.7646

**AVG MW** 20.1972

**STREAM COSTS**

--------

**ID** | **PRICE** | **COST $/HR**
-------|-----------|-----------

**IN**  | **PRICE** | **COST $/HR**
-------|-----------|-----------

**OUT** | **PRICE** | **COST $/HR**
-------|-----------|-----------

**SUBSTREAM: MIXED**

**PHASE:** LIQUID

**COMPONENTS: MOL/HR**

**WATER** 4.2647-04

**GLUCOSE** 4.1938

**XYLOSE** 2.3109+02

**AMMONIA** 0.0

**OTHLIQU** 0.0

**H2SO4** 0.0
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<td>Xylitol</td>
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**STREAM COSTS**

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PLA: 0.0

COST: $/HR
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TOTAL FLOW:
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KG/DAY
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L/DAY
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PRES
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J/KG
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KW
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J/KG
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ENTROPY:
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J/KG
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DENSITY:
MOL/CC
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GM/CC
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AVG MW
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STREAM COSTS
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PRICE
COST $/HR
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PREC-XYL
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J/KG
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J/KG
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**Block Report**

**Block:** AAS  
**Model:** RYIELD

**Inlet Streams:**  
NH3

**Outlet Stream:**  
AASPROD

**Property Option Set:**  
RK-ASPN REDLICH-KWONG-ASPN EQUATION OF STATE

**Block Report**

**Block:** AAS  
**Model:** RYIELD

**Inlet Streams:**  
NH3

**Outlet Stream:**  
AASPROD

**Property Option Set:**  
RK-ASPN REDLICH-KWONG-ASPN EQUATION OF STATE

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**Mass and Energy Balance**

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**Input Data**

**Two Phase TP Flash**

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**Results**

<table>
<thead>
<tr>
<th>Component</th>
<th>OUTLET TEMPERATURE C</th>
<th>OUTLET PRESSURE ATM</th>
</tr>
</thead>
<tbody>
<tr>
<td>WATER</td>
<td>70.0000</td>
<td>1.00000</td>
</tr>
<tr>
<td>REAT DUTY</td>
<td>-1986.8</td>
<td>-1986.8</td>
</tr>
<tr>
<td>VAPOR FRACTION</td>
<td>0.17000E+01</td>
<td></td>
</tr>
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</table>

**V-L Phase Equilibrium**

<table>
<thead>
<tr>
<th>Component</th>
<th>F(I)</th>
<th>X(I)</th>
<th>Y(I)</th>
<th>K(I)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WATER</td>
<td>0.94114</td>
<td>0.95315</td>
<td>0.25063</td>
<td>0.26295</td>
</tr>
<tr>
<td>AMMONIA</td>
<td>0.12632E-01</td>
<td>0.70189E-20</td>
<td>0.73907</td>
<td>0.10530E+21</td>
</tr>
</tbody>
</table>
OTHLIQ  0.40287E-01  0.40811E-01  0.10117E-01  0.24789
OTHSOLID  0.59417E-02  0.60481E-02  0.18568E-03  0.30732E-01

*** ASSOCIATED UTILITIES ***

UTILITY ID FOR WATER COOLING
RATE OF CONSUMPTION 8.2310+06 KG/DAY
COST 1.5178 $/HR

BLOCK: B1 MODEL: HEATER

----- INPUT DATA -----

INLET STREAM: S26
OUTLET STREAM: WETBSGH
PROPERTY OPTION SET: RK
OUTLET STREAM: 2
PROPERTY OPTION SET: RK

--- RESULTS ---

OUTLET TEMPERATURE C 150.00
OUTLET PRESSURE ATM 1.0000
HEAT DUTY KM 131.12
OUTLET VAPOR FRACTION 0.98367

--- V= PHASE EQUILIBRIUM ---

COMP F(I) X(I) Y(I) K(I)
WATER 0.98654 0.17619 0.99999 5.6758
GLUCOSE 0.39372E-05 0.24105E-03 0.15752E-08 0.65348E-05
XYLOSE 0.21695E-07 0.13196E-05 0.15214E-09 0.811529E-03
CELLULOS 0.13453E-01 0.82357 0.64962E-05 0.78879E-05
ENZ/XYL 0.10515E-06 0.62001E-05 0.32607E-09 0.15290E-04
DIETHIER 0.29675E-10 0.85869E-11 0.30255E-10 3.4966

--- ASSOCIATED UTILITIES ---

UTILITY ID FOR STEAM MPSTEAM
RATE OF CONSUMPTION 5567.5632 KG/DAY
COST 1.0035 $/HR
CO2 EQUIVALENT EMISSIONS 744.8885 KG/DAY

--- OVERALL RESULTS ---

STREAMS:
HEATX COLD

COLDOUT |                           LIQ                             | COLDIN
------
HOT IN  |                           COND
140.8  |                                                           |   90.0

PROPERTY OPTION SET: RK
PRESSURE DROP:         0.0         ATM
PRESSURE PROFILE:      CONSTANT2

ZONE HEAT TRANSFER AND AREA:

PROPERTY OPTION SET: RK

<table>
<thead>
<tr>
<th>DUTY</th>
<th>PRES</th>
<th>TEMP</th>
<th>VFRAC</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.3935 ! 1.0000</td>
<td>90.0084 ! 0.0 !</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11.0093 ! 1.0000</td>
<td>86.7982 ! 0.0 !</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14.6790 ! 1.0000</td>
<td>83.5698 ! 0.0 !</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

------------------------------------------------------------------------
| 18.3488 ! 1.0000 | 80.3229 ! 0.0 ! |
| 22.0185 ! 1.0000 | 77.0572 ! 0.0 ! |
| 25.6883 ! 1.0000 | 73.7724 ! 0.0 ! |
| 29.3581 ! 1.0000 | 70.4682 ! 0.0 ! |
| 33.0278 ! 1.0000 | 67.1443 ! 0.0 ! |

------------------------------------------------------------------------
| 36.6976 ! 1.0000 | 63.8004 ! 0.0 ! |
| 40.3673 ! 1.0000 | 60.4361 ! 0.0 ! |
| 44.0371 ! 1.0000 | 57.0512 ! 0.0 ! |
| 47.7069 ! 1.0000 | 53.6454 ! 0.0 ! |
| 51.3766 ! 1.0000 | 50.2183 ! 0.0 ! |

------------------------------------------------------------------------
| 55.0464 ! 1.0000 | 46.7697 ! 0.0 ! |
| 58.7161 ! 1.0000 | 43.2992 ! 0.0 ! |
| 62.3869 ! 1.0000 | 39.8067 ! 0.0 ! |
| 66.0566 ! 1.0000 | 36.2918 ! 0.0 ! |
| 69.7254 ! 1.0000 | 32.7542 ! 0.0 ! |

------------------------------------------------------------------------
| 73.3952 ! 1.0000 | 29.1937 ! 0.0 ! |
| 77.0649 ! 1.0000 | 25.6101 ! 0.0 ! |

------------------------------------------------------------------------

HEATX HOT-TQCU B2 TQCUV INLET

PROPERTY OPTION SET: RK
PRESSURE DROP:         0.0         ATM
PRESSURE PROFILE:      CONSTANT2

<table>
<thead>
<tr>
<th>DUTY</th>
<th>PRES</th>
<th>TEMP</th>
<th>VFRAC</th>
</tr>
</thead>
<tbody>
<tr>
<td>332.0000</td>
<td>9.4760</td>
<td>0.0000</td>
<td>0.0</td>
</tr>
</tbody>
</table>

------------------------------------------------------------------------
| 0.0 ! 1.0000 | 99.8458 ! 0.0 ! |
| 3.6698 ! 1.0000 | 93.2006 ! 0.0 ! |
| 7.3935 ! 1.0000 | 90.0084 ! 0.0 ! |

------------------------------------------------------------------------
| 11.0093 ! 1.0000 | 86.7982 ! 0.0 ! |
| 14.6790 ! 1.0000 | 83.5698 ! 0.0 ! |

------------------------------------------------------------------------
| 18.3488 ! 1.0000 | 80.3229 ! 0.0 ! |
| 22.0185 ! 1.0000 | 77.0572 ! 0.0 ! |
| 25.6883 ! 1.0000 | 73.7724 ! 0.0 ! |
| 29.3581 ! 1.0000 | 70.4682 ! 0.0 ! |
| 33.0278 ! 1.0000 | 67.1443 ! 0.0 ! |

------------------------------------------------------------------------
| 36.6976 ! 1.0000 | 63.8004 ! 0.0 ! |
| 40.3673 ! 1.0000 | 60.4361 ! 0.0 ! |
| 44.0371 ! 1.0000 | 57.0512 ! 0.0 ! |
| 47.7069 ! 1.0000 | 53.6454 ! 0.0 ! |
| 51.3766 ! 1.0000 | 50.2183 ! 0.0 ! |

------------------------------------------------------------------------
| 55.0464 ! 1.0000 | 46.7697 ! 0.0 ! |
| 58.7161 ! 1.0000 | 43.2992 ! 0.0 ! |
| 62.3869 ! 1.0000 | 39.8067 ! 0.0 ! |
| 66.0566 ! 1.0000 | 36.2918 ! 0.0 ! |
| 69.7254 ! 1.0000 | 32.7542 ! 0.0 ! |

------------------------------------------------------------------------
| 73.3952 ! 1.0000 | 29.1937 ! 0.0 ! |
| 77.0649 ! 1.0000 | 25.6101 ! 0.0 ! |

------------------------------------------------------------------------

HEATX COLD-TQCU B2 TQCUV INLET

PROPERTY OPTION SET: RK
PRESSURE DROP:         0.0         ATM
PRESSURE PROFILE:      CONSTANT2

<table>
<thead>
<tr>
<th>DUTY</th>
<th>PRES</th>
<th>TEMP</th>
<th>VFRAC</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0 ! 1.0000</td>
<td>100.0000 ! 0.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.6698 ! 1.0000</td>
<td>93.2006 ! 0.0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

---

**BLOCK: B3  MODEL: MIXER**

---

**INLET STREAMS:**

STEAM2  STEAM1

**OUTLET STREAM:** S1

**PROPERTY OPTION SET:** RK-ASPEN REDLICH-KWONG-ASPEN EQUATION OF STATE

---

**MASS AND ENERGY BALANCE***

<table>
<thead>
<tr>
<th>TOTAL BALANCE</th>
<th>IN</th>
<th>OUT</th>
<th>RELATIVE DIFF.</th>
</tr>
</thead>
<tbody>
<tr>
<td>MOLE (MOL/HR)</td>
<td>6683.33</td>
<td>6683.33</td>
<td>0.00000</td>
</tr>
<tr>
<td>MASS (KG/DAY)</td>
<td>3775.64</td>
<td>3775.64</td>
<td>0.00000</td>
</tr>
<tr>
<td>ENTHALPY (KW)</td>
<td>-420.616</td>
<td>-420.616</td>
<td>-0.270287E-15</td>
</tr>
</tbody>
</table>

---

**CO2 EQUIVALENT SUMMARY***

**FEED STREAMS CO2E:** 0.00000 KG/DAY

**PRODUCT STREAMS CO2E:** 0.00000 KG/DAY

**NET STREAMS CO2E PRODUCTION:** 0.00000 KG/DAY

---

**INPUT DATA***

**TWO PHASE FLASH**

MAXIMUM NO. ITERATIONS: 30

OUTLET PRESSURE: MINIMUM OF INLET STREAM PRESSURES 0.000100000

---

**BLOCK: B4  MODEL: SEP**

---

**INLET STREAMS:** MEOHIN  S7

**OUTLET STREAMS:** PLAOUT  S8

**PROPERTY OPTION SET:** IDEAL / IDEAL LIQUID / IDEAL GAS

---

**MASS AND ENERGY BALANCE***

<table>
<thead>
<tr>
<th>TOTAL BALANCE</th>
<th>IN</th>
<th>OUT</th>
<th>RELATIVE DIFF.</th>
</tr>
</thead>
<tbody>
<tr>
<td>MOLE (MOL/HR)</td>
<td>86273.5</td>
<td>86273.5</td>
<td>0.168672E-15</td>
</tr>
<tr>
<td>MASS (KG/DAY)</td>
<td>126829.</td>
<td>126829.</td>
<td>0.137684E-14</td>
</tr>
<tr>
<td>ENTHALPY (KW)</td>
<td>-4469.96</td>
<td>-4469.96</td>
<td>-0.134255E-03</td>
</tr>
</tbody>
</table>

---

**CO2 EQUIVALENT SUMMARY***

**FEED STREAMS CO2E:** 0.00000 KG/DAY

**PRODUCT STREAMS CO2E:** 0.00000 KG/DAY

**NET STREAMS CO2E PRODUCTION:** 0.00000 KG/DAY

**UTILITIES CO2E PRODUCTION:** 7.0093E+31 KG/DAY

---

**INPUT DATA***

**FRACTION OF FEED SUBSTREAM= MIXED STREAM= PLAOUT CPT= PLA FRACTION= 1.00000**

---

**RESULTS***

---

**BLOCK: B5  MODEL: HEATX**

---

**NOT SIDE:**

---

**COLD SIDE:**

---

**HEAT DUTY KW:** 0.12338E+32

---

**COMPONENT = WATER**

STREAK SUBSTREAM SPLIT FRACTION S8 MIXED 1.00000

**COMPONENT = GLUCOSE**

STREAK SUBSTREAM SPLIT FRACTION S8 MIXED 1.00000

**COMPONENT = DIETER**

STREAK SUBSTREAM SPLIT FRACTION S8 MIXED 1.00000

**COMPONENT = METHANOL**

STREAK SUBSTREAM SPLIT FRACTION S8 MIXED 1.00000

**COMPONENT = CH2CL2**

STREAK SUBSTREAM SPLIT FRACTION S8 MIXED 1.00000

---

**ASSOCIATED UTILITIES***

**UTILITY ID FOR STEAM LPSTEAM**

RATE OF CONSUMPTION: 4.8634E+32 KG/DAY

COST: 8.4392E+28 $/HR

CO2 EQUIVALENT EMISSIONS: 7.0093E+31 KG/DAY

---

333
**TEMPERATURE LEAVING EACH ZONE:**

**PRESSURE DROP:**

**LOG**

**HEAT TRANSFER COEFFICIENT:**

**DUTY AND AREA:**

**V= 0.0000D+00 |                                    |       V= 0.0000D+00**

**T= 9.5000**

**S2        <**

**V= 1.0000D+00  |                                    |       V= 8.6317D+00**

**P= 1.0000D+00  |                                    |       T= 1.0246D+02**

**T= 1.4512D+02  |                                    |       T= 1.0246D+02**

**STREAMS:**

**PROPERTY OPTION SET:** RK

**PRESSURE PROFILE:** CONSTANT2

**ZONE Heat Transfer and Area:**

**PROPERTY EQUATION OF STATE**

**ASPEN REDLICH-KWONG**

**HEATX HOT-TQCUR B5 TQCURV INLET**

**HEATX COLD-TQCUR B5 TQCURV INLET**

---

<table>
<thead>
<tr>
<th>HOT</th>
<th>VAP</th>
<th>COND</th>
<th>HOT OUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>145.1</td>
<td>103.1</td>
<td>102.5</td>
<td></td>
</tr>
</tbody>
</table>

**ZONE HEAT DUTY | AREA | LMTD | AVERAGE U | UA**

<table>
<thead>
<tr>
<th>1</th>
<th>KW</th>
<th>SQM</th>
<th>C</th>
<th>CAL/SEC-SQCM-K</th>
<th>CAL/SEC-K</th>
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</thead>
<tbody>
<tr>
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<td>5.7160</td>
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<tr>
<td>2</td>
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<td>0.0203</td>
<td>5115.9747</td>
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</table>

---

**ZONE HEAT TRANSFER AND AREA:**

**PROPERTY OPTION SET:** RK-ASPEN REDLICH-KWONG-ASPEN EQUATION OF STATE

---

**ZONE**

**DUTY**

**PRESS**

**TEMP**

**VFRAC**

<table>
<thead>
<tr>
<th>HOT</th>
<th>VAP</th>
<th>COND</th>
<th>HOT OUT</th>
</tr>
</thead>
<tbody>
<tr>
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<td>1.0000</td>
<td>95.0000</td>
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<td>34.2643</td>
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<tr>
<td>68.5286</td>
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<td>91.5714</td>
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</tr>
<tr>
<td>102.7929</td>
<td>1.0000</td>
<td>89.8554</td>
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<tr>
<td>137.0573</td>
<td>1.0000</td>
<td>88.1384</td>
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<tr>
<td>142.1845</td>
<td>1.0000</td>
<td>87.8814</td>
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<td>239.8551</td>
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<td>274.1144</td>
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<td>81.2610</td>
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<td>77.8171</td>
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<tr>
<td>719.5803</td>
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<td>58.8310</td>
<td>0.0</td>
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</tbody>
</table>

---

**HEATX HOT-TQCUR B5 TQCURV INLET**

---

**ZONE**

**DUTY**

**PRESS**

**TEMP**

**VFRAC**

<table>
<thead>
<tr>
<th>HOT</th>
<th>VAP</th>
<th>COND</th>
<th>HOT OUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>145.1</td>
<td>103.1</td>
<td>102.5</td>
<td></td>
</tr>
</tbody>
</table>

---

**HEATX COLD-TQCUR B5 TQCURV INLET**

---

**ZONE**

**DUTY**

**PRESS**

**TEMP**

**VFRAC**

<table>
<thead>
<tr>
<th>HOT</th>
<th>VAP</th>
<th>COND</th>
<th>HOT OUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>145.1</td>
<td>103.1</td>
<td>102.5</td>
<td></td>
</tr>
</tbody>
</table>
### Block: B6 Model: MIXER

**Pressure Option Set:** RK-ASBEN REDLICH-KWONG-ASBEN EQUATION OF STATE

<table>
<thead>
<tr>
<th><strong>Duty</strong></th>
<th><strong>Pres</strong></th>
<th><strong>Temp</strong></th>
<th><strong>VPRAC</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>KW</strong></td>
<td><strong>ATM</strong></td>
<td><strong>C</strong></td>
<td>****</td>
</tr>
<tr>
<td>102.7929</td>
<td>1.0000</td>
<td>24.9705</td>
<td>1.0000</td>
</tr>
<tr>
<td>102.4718</td>
<td>1.0000</td>
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<td>1.0000</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

---

### Block: B7 Model: MIXER

**Pressure Option Set:** RK-ASBEN REDLICH-KWONG-ASBEN EQUATION OF STATE

**Outlet Stream:** ETHOUT1 ETHOUT2

**Outlet Pressure:** Minimum of Inlet Stream Pressures

**Convergence Tolerance:** 0.000100000

**Maximum No. Iterations:** 30

---

### Block: B8 Model: HEATX

**Outlet Stream:** ETHOUT1 ETHOUT2

**Outlet Pressure:** Minimum of Inlet Stream Pressures

**Convergence Tolerance:** 0.000100000

**Maximum No. Iterations:** 30

---

### Block: B9 Model: HEATX

**Outlet Stream:** S10

**Outlet Pressure:** Minimum of Inlet Stream Pressures

**Convergence Tolerance:** 0.000100000

---

### Block: B10 Model: HEATX

**Outlet Stream:** SA-IN

**Outlet Pressure:** Minimum of Inlet Stream Pressures

**Convergence Tolerance:** 0.000100000

---

### Block: B11 Model: HEATX

**Outlet Stream:** SA-IN

**Outlet Pressure:** Minimum of Inlet Stream Pressures

**Convergence Tolerance:** 0.000100000

---

### Block: B12 Model: HEATX

**Outlet Stream:** SA-IN

**Outlet Pressure:** Minimum of Inlet Stream Pressures

**Convergence Tolerance:** 0.000100000

---

### Block: B13 Model: HEATX

**Outlet Stream:** SA-IN

**Outlet Pressure:** Minimum of Inlet Stream Pressures

**Convergence Tolerance:** 0.000100000

---
FLOW DIRECTION AND SPECIFICATION:
COUNTERCURRENT HEAT EXCHANGER
SPECIFIED COLD OUTLET TEMP
SPECIFIED VALUE C 92.0000
LMTD CORRECTION FACTOR 1.00000

PRESSURE SPECIFICATION:
HOT SIDE PRESSURE DROP ATM 0.0000
COLD SIDE PRESSURE DROP ATM 0.0000

HEAT TRANSFER COEFFICIENT SPECIFICATION:
HOT LIQUID COLD LIQUID CAL/SEC-SQM-K 0.0203
HOT 2-PHASE COLD LIQUID CAL/SEC-SQM-K 0.0203
HOT LIQUID COLD 2-PHASE CAL/SEC-SQM-K 0.0203
HOT 2-PHASE COLD 2-PHASE CAL/SEC-SQM-K 0.0203
HOT LIQUID COLD VAPOR CAL/SEC-SQM-K 0.0203
HOT 2-PHASE COLD VAPOR CAL/SEC-SQM-K 0.0203
HOT VAPOR COLD VAPOR CAL/SEC-SQM-K 0.0203

*** OVERALL RESULTS ***

DUTY AND AREA:
CALCULATED HEAT DUTY KW 5.9767
CALCULATED (REQUIRED) AREA SQM 0.2101
PER CENT OVER-DESIGN 0.0000

HEAT TRANSFER COEFFICIENT:
AVERAGE COEFFICIENT (DIRTY) CAL/SEC-SQM-K 0.0203
UA DIRTY CAL/SEC-K 42.6577

LOG-MEAN TEMPERATURE DIFFERENCE:
LMTD CORRECTION FACTOR 1.0000
LMTD (CORRECTED) C 33.4645
NUMBER OF SHELLS IN SERIES 1

PRESSURE DROP:
HOTSIDE, TOTAL ATM 0.0000
COLDSIDE, TOTAL ATM 0.0000

*** ZONE RESULTS ***

TEMPERATURE LEAVING EACH ZONE:
HOT

<table>
<thead>
<tr>
<th>HOT IN</th>
<th>COND</th>
<th>HOT OUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>102.5</td>
<td></td>
<td>102.5</td>
</tr>
</tbody>
</table>

COLD

HEATX COLD-TQCU BS TQCURV INLET

PROPERTY OPTION SET: RK
PRESSURE PROFILE: CONSTANT2
PROPERTY OPTION SET: RK
PRESSURE PROFILE: CONSTANT2

<table>
<thead>
<tr>
<th>DUTY</th>
<th>PRES</th>
<th>TEMP</th>
<th>VFRAC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

---

HEATX HOT-TQCU BS TQCURV INLET

PROPERTY OPTION SET: RK
PRESSURE PROFILE: CONSTANT2
PRESSURE DROP: 0.0 ATM
PROPERTY OPTION SET: RK
PRESSURE PROFILE: CONSTANT2
PRESSURE DROP: 0.0 ATM

---

336
**FLASH SPECS FOR STREAM S16**

<table>
<thead>
<tr>
<th>TWO PHASE TP FLASH</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PRESSURE DROP</strong></td>
</tr>
<tr>
<td>ATM</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>MAXIMUM NO. ITERATIONS</strong></td>
</tr>
<tr>
<td><strong>CONVERGENCE TOLERANCE</strong></td>
</tr>
</tbody>
</table>

**FLASH SPECS FOR STREAM S17**

<table>
<thead>
<tr>
<th>TWO PHASE TP FLASH</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PRESSURE DROP</strong></td>
</tr>
<tr>
<td>ATM</td>
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<tr>
<td></td>
</tr>
<tr>
<td><strong>MAXIMUM NO. ITERATIONS</strong></td>
</tr>
<tr>
<td><strong>CONVERGENCE TOLERANCE</strong></td>
</tr>
</tbody>
</table>

**PROPERTY OPTION SET:** RK-ASPN REDLICH-KWONG-ASPEN EQUATION OF STATE

**CO2 EQUIVALENT SUMMARY**

<table>
<thead>
<tr>
<th><strong>COMPONENT</strong></th>
<th><strong>FRACTION OF FEED</strong></th>
<th><strong>SUBSTREAM- MIXED</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>STRAIN- S16</strong></td>
<td><strong>CPT- WATER</strong></td>
<td><strong>FRACTION</strong></td>
</tr>
<tr>
<td><strong>GLUCOSE</strong></td>
<td>1.00000</td>
<td></td>
</tr>
<tr>
<td><strong>XYLOSE</strong></td>
<td>1.00000</td>
<td></td>
</tr>
<tr>
<td><strong>OTHLIQUI</strong></td>
<td>1.00000</td>
<td></td>
</tr>
<tr>
<td><strong>LACTICAC</strong></td>
<td>1.00000</td>
<td></td>
</tr>
<tr>
<td><strong>DIETHER</strong></td>
<td>1.00000</td>
<td></td>
</tr>
</tbody>
</table>

**RESULTS**

<table>
<thead>
<tr>
<th><strong>HEAT DUTY</strong></th>
<th><strong>KW</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>6.1474</strong></td>
<td></td>
</tr>
</tbody>
</table>

| **COMPONENT = WATER** | **RATE OF CONSUMPTION** | **0.3543** KG/DAY |
| **COMPONENT = GLUCOSE** | **STRAIN- S16** | **MIXED** | **1.00000** |
| **COMPONENT = OTHSLIQUI** | **STRAIN- S17** | **MIXED** | **1.00000** |
| **COMPONENT = LACTICAC** | **STRAIN- S17** | **MIXED** | **1.00000** |

**ASSOCIATED UTILITIES**

| **UTILITY ID FOR STEAM** | **LPSTEAM** |

**INLET STREAMS:**

| **WATER** | **KWH** | **65364.2** |

| **XYLOSE** | **DIETHER** | **LACTICAC** | **OTHLIQUI** | **GLUCOSE** |

**OUTLET STREAMS:**

| **S16** | **S17** |

**PROPERTY OPTION SET:** RK-ASPN REDLICH-KWONG-ASPEN EQUATION OF STATE

**MASS AND ENERGY BALANCE**

<table>
<thead>
<tr>
<th><strong>IN</strong></th>
<th><strong>OUT</strong></th>
<th><strong>RELATIVE DIFF.</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>824587</strong></td>
<td><strong>824587</strong></td>
<td><strong>8.00000</strong></td>
</tr>
<tr>
<td><strong>368323</strong></td>
<td><strong>368323</strong></td>
<td><strong>-0.474103E-15</strong></td>
</tr>
</tbody>
</table>

**CO2 EQUIVALENT SUMMARY**

| **FEED STREAMS CO2E** | **0.00000** KG/DAY |
| **PRODUCT STREAMS CO2E** | **0.00000** KG/DAY |
| **NET STREAMS CO2E PRODUCTION** | **0.00000** KG/DAY |
| **UTILITIES CO2E PRODUCTION** | **0.510582E-01** KG/DAY |
| **TOTAL CO2E PRODUCTION** | **0.510582E-01** KG/DAY |

**INPUT DATA**

| **FLASH SPECS FOR STREAM S16** |
| **TWO PHASE TP FLASH** |
| **PRESSURE DROP** |
| **ATM** |
| **0.0** |
| **MAXIMUM NO. ITERATIONS** | **30** |
| **CONVERGENCE TOLERANCE** | **0.000100000** |

| **FLASH SPECS FOR STREAM S17** |
| **TWO PHASE TP FLASH** |
| **PRESSURE DROP** |
| **ATM** |
| **0.0** |
| **MAXIMUM NO. ITERATIONS** | **30** |
| **CONVERGENCE TOLERANCE** | **0.000100000** |
PRESSURE SPECIFICATION:

FLOW DIRECTION AND SPECIFICATION:

CONVERGENCE TOLERANCE 0.000100000

MAXIMUM NO. ITERATIONS 30

TWO PHASE FLASH

FLASH SPECS FOR COLD SIDE:

CONVERGENCE TOLERANCE 0.000100000

MAXIMUM NO. ITERATIONS 30

TWO PHASE FLASH

PROPERTY OPTION SET: RK

OUTLET STREAM: S13

INLET STREAM: S12

----------

PROPERTY OPTION SET: RK

COLD SIDE PRESSURE DROP 0.00000 ATM

LMTD CORRECTION FACTOR 1.00000

SPECIFIED VALUE C 180.0000

TOTAL CO2 PRODUCTION 0.00000 KG/DAY

*** 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 HOT OUTLET TEMP

SPECIFIED VALUE C 180.0000

LMTD CORRECTION FACTOR 1.00000

PRESSURE SPECIFICATION:

HOT SIDE PRESSURE DROP ATM 0.0000

COLD SIDE PRESSURE DROP ATM 0.0000

HEAT TRANSFER COEFFICIENT SPECIFICATION:

HOT LIQUID COLD LIQUID CAL/SEC-SQM-K 0.0203

HOT 2-PHASE COLD LIQUID CAL/SEC-SQM-K 0.0203

HOT VAPOR COLD LIQUID CAL/SEC-SQM-K 0.0203

HOT LIQUID COLD 2-PHASE CAL/SEC-SQM-K 0.0203

HOT 2-PHASE COLD 2-PHASE CAL/SEC-SQM-K 0.0203

HOT VAPOR COLD 2-PHASE CAL/SEC-SQM-K 0.0203

HOT LIQUID COLD VAPOR CAL/SEC-SQM-K 0.0203

HOT 2-PHASE COLD VAPOR CAL/SEC-SQM-K 0.0203

HOT VAPOR COLD VAPOR CAL/SEC-SQM-K 0.0203

*** OVERALL RESULTS ***

STREAMS:

---------

STMPLA ----> HOT ----> S14

T= 2.8800D+02 | P= 1.0000D+00

T= 1.8800D+02 | P= 1.0000D+00

V= 8.2084D-01 | V= 8.2084D-01

V= 1.0000D+00 | V= 1.0000D+00

S13 ----> COLD ----> S12

T= 2.3748D+02 | T= 1.1000D+02

P= 1.0000D+00 | P= 1.0000D+00

V= 2.0384D-01 |
### HEATX HOT-TQCUR B11 TQCURV INLET

---

**PRESSURE PROFILE:** CONSTANT2

**PRESSURE DROP:** 0.0 ATM

**PROPERTY OPTION SET:** RK-ASPN REDLICH-KWONG-ASPN EQUATION OF STATE

---

**DUTY** | **PRES** | **TEMP** | **VFRAC** |
--- | --- | --- | --- |
| 0.0 | 1.0000 | 237.4817 | 0.8208 |
| 11.1368 | 1.0000 | 235.8254 | 0.7739 |
| 22.2735 | 1.0000 | 233.9689 | 0.7260 |
| 33.4103 | 1.0000 | 231.6728 | 0.6832 |
| 39.7047 | 1.0000 | 230.5620 | 0.6585 |
| 44.5470 | 1.0000 | 229.4687 | 0.6399 |
| 55.6838 | 1.0000 | 226.7364 | 0.5982 |
| 66.8205 | 1.0000 | 223.6388 | 0.5584 |
| 77.9573 | 1.0000 | 220.0653 | 0.5208 |
| 89.0940 | 1.0000 | 215.9624 | 0.4857 |
| 100.2308 | 1.0000 | 211.7270 | 0.4532 |
| 111.3676 | 1.0000 | 205.9321 | 0.4237 |
| 122.5043 | 1.0000 | 199.0007 | 0.3971 |
| 133.6411 | 1.0000 | 193.1491 | 0.3735 |
| 144.7778 | 1.0000 | 185.6739 | 0.3527 |
| 155.9146 | 1.0000 | 177.4986 | 0.3344 |
| 167.0513 | 1.0000 | 168.6774 | 0.3179 |
| 178.1881 | 1.0000 | 159.2970 | 0.3027 |
| 189.3248 | 1.0000 | 149.4814 | 0.2878 |
| 200.4616 | 1.0000 | 139.3983 | 0.2720 |

---

**NET STREAMS CO2E PRODUCTION** 0.00000 KG/DAY

**PRODUCT STREAMS CO2E** 0.00000 KG/DAY

**FEED STREAMS CO2E** 0.00000 KG/DAY

---

### TOTAL BALANCE

**MOLE(MOL/HR )** 369331.00000 369331.00000

**ENTHALPY(KW )** -30418.20000 -30418.20000 0.235412E-06

---

**INLET STREAM:** S28

**PROPERTY OPTION SET:** RK-ASPN REDLICH-KWONG-ASPN EQUATION OF STATE

---

**COMPONENT = OTHSOLID**

**COMPONENT = OT**

**COMPONENT = XYLOSE**

---

**ASPEN EQUATION OF STATE**

---

**ASPEN REDLICH**

---

**KWONG**

---

**HEAT DUTY** 0.0 KW

---

**OUTLET STREAMS:** S27 S28

---

**PROPERTY OPTION SET:** RK-ASPN REDLICH-KWONG-ASPN EQUATION OF STATE

---

**CONVERGENCE TOLERANCE** 0.000100000

---

**PRESSURE DROP:** 0.0 ATM

---

**MAXIMUM NO. ITERATIONS** 30

---

**PRESSURE DROP:** 0.0 ATM

---

**MAXIMUM NO. ITERATIONS** 30

---

**CONVERGENCE TOLERANCE** 0.000100000

---

**FRACTION OF FEED**

---

**SUBSTREAM= MIXED**

---

**STREAM= S27**

---

**CPF= OTHSOLID FRACTION=** 1.00000

---

**CELLULOS** 1.00000

---

**RESULTS***

---

**HEAT DUTY** -0.71608H-02

---

**COMPONENT = WATER**

---

**STREAM** S28 MIXED 1.00000

---

**COMPONENT = XYLOSE**

---

**STREAM** S28 MIXED 1.00000

---

**COMPONENT = OTHSOLID**

---

**STREAM** S28 MIXED 1.00000
### BLOCK: B14  MODEL: MIXER
-----------------------------
**INLET STREAM:** ETHIN
**OUTLET STREAM:** ETHIN2
**PROPERTY OPTION SET:** RK

**PROPERTY OPTION SET: RK-ASPN REDLICH-KWONG-ASPN EQUATION OF STATE**

#### *** CO2 EQUIVALENT SUMMARY ***

**FEED STREAMS CO2E**

<table>
<thead>
<tr>
<th>Component</th>
<th>Mass (kg/day)</th>
<th>Mole (mol/hr)</th>
<th>Enthalpy (J/mol)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WATER</td>
<td>3.5691e+7</td>
<td>3.5691e+7</td>
<td>7.3894e+6</td>
</tr>
<tr>
<td>XYLOSE</td>
<td>3.6138e-07</td>
<td>3.6138e-07</td>
<td>2.2355e+06</td>
</tr>
<tr>
<td>ODSOLID</td>
<td>3.6138e-07</td>
<td>3.6138e-07</td>
<td>2.2355e+06</td>
</tr>
<tr>
<td>CELLULOSE</td>
<td>3.5691e+7</td>
<td>3.5691e+7</td>
<td>7.3894e+6</td>
</tr>
<tr>
<td>ENZ/XYL</td>
<td>3.0062e-07</td>
<td>3.0062e-07</td>
<td>6.2871e+06</td>
</tr>
</tbody>
</table>

#### *** INPUT DATA ***

**V-L PHASE EQUILIBRIUM:**

<table>
<thead>
<tr>
<th>COMP</th>
<th>P(X)</th>
<th>X(I)</th>
<th>Y(I)</th>
<th>K(I)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WATER</td>
<td>0.59976</td>
<td>0.99976</td>
<td>0.99991</td>
<td>1.0002</td>
</tr>
<tr>
<td>XYLOSE</td>
<td>0.5407e-07</td>
<td>0.5407e-07</td>
<td>0.1544e-11</td>
<td>8.2360e-04</td>
</tr>
<tr>
<td>ODSOLID</td>
<td>0.2432e-03</td>
<td>0.2432e-03</td>
<td>0.3688e-04</td>
<td>0.1522</td>
</tr>
<tr>
<td>CELLULOSE</td>
<td>0.1577e-03</td>
<td>0.1577e-03</td>
<td>0.3666e-04</td>
<td>0.1565e-05</td>
</tr>
<tr>
<td>ENZ/XYL</td>
<td>0.3062e-06</td>
<td>0.3062e-06</td>
<td>0.8791e-11</td>
<td>0.2871e-04</td>
</tr>
<tr>
<td>DIETHYL</td>
<td>0.9728e-10</td>
<td>0.9728e-10</td>
<td>0.5443e-04</td>
<td>0.5569e-06</td>
</tr>
</tbody>
</table>

#### *** ASSOCIATED UTILITIES ***

**UTILITY ID FOR WATER:** COOLINGW
**RATE OF CONSUMPTION:** 1.4991e+07 KG/DAY
**COST:** 2.7643 $/HR

---

### BLOCK: B15  MODEL: HEATER
-----------------------------
**COST**

<table>
<thead>
<tr>
<th>Component</th>
<th>Rate of Consumption</th>
<th>utility_id</th>
<th>Cost (kg/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WATER</td>
<td>9.79178</td>
<td>LPSTEAM</td>
<td>0.000000</td>
</tr>
<tr>
<td>XYLENE</td>
<td>9.79178</td>
<td>LPSTEAM</td>
<td>0.000000</td>
</tr>
</tbody>
</table>

**OUTLET STREAM:** ETHIN2

**PROPERTY OPTION SET: RK-ASPN REDLICH-KWONG-ASPN EQUATION OF STATE**

#### *** INPUT DATA ***

**V-L PHASE EQUILIBRIUM:**

<table>
<thead>
<tr>
<th>COMP</th>
<th>P(X)</th>
<th>X(I)</th>
<th>Y(I)</th>
<th>K(I)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WATER</td>
<td>0.99568</td>
<td>0.99568</td>
<td>1.0000</td>
<td>0.4804e-01</td>
</tr>
<tr>
<td>GLUCOSE</td>
<td>0.43164e-02</td>
<td>0.43164e-02</td>
<td>0.13508e-13</td>
<td>0.15207e-12</td>
</tr>
</tbody>
</table>

---

**TOTAL BALANCE**

<table>
<thead>
<tr>
<th>Component</th>
<th>Mass (kg/day)</th>
<th>mole (mol/hr)</th>
<th>enthalpy (J/mol)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WATER</td>
<td>1.4991e+07</td>
<td>1.4991e+07</td>
<td>7.3894e+6</td>
</tr>
<tr>
<td>XYLENE</td>
<td>9.79178</td>
<td>9.79178</td>
<td>2.2355e+06</td>
</tr>
</tbody>
</table>

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**TOTAL BALANCE**

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<tr>
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<td>2.2355e+06</td>
</tr>
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<th>enthalpy (J/mol)</th>
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</tr>
<tr>
<td>XYLENE</td>
<td>9.79178</td>
<td>9.79178</td>
<td>2.2355e+06</td>
</tr>
</tbody>
</table>
CO2 EQUIVALENT EMISSIONS 1379.3933 KG/DAY

*** MASS AND ENERGY BALANCE ***

IN     OUT     RELATIVE DIFF.

TOTAL BALANCE  
MOL (MOL/HR) | 368101.  368101.  0.0000
MASS (KG/DAY) | 175104.  175104.  0.0000
ENTHALPY (KW) | -30468.0  -30468.4  -0.134007E-02

*** CO2 EQUIVALENT SUMMARY ***

FEED STREAMS CO2E 0.00000 KG/DAY
PRODUCT STREAMS CO2E 0.00000 KG/DAY
NET STREAMS CO2E PRODUCTION 0.00000 KG/DAY
UTILITIES CO2E PRODUCTION 673.492 KG/DAY
TOTAL CO2E PRODUCTION 673.492 KG/DAY

** PLANT COLD WATER (RK)**

OUTLET STREAM: S25
CO2 EQUIVALENT EMISSIONS 1379.3933 KG/DAY
PROPERTY OPTION SET: RK-ASPEN

OUTLET VAPOR FRACTION 0.0000
OUTLET PRESSURE ATM 1.0000
OUTLET TEMPERATURE °C 32.000
CONVERGENCE TOLERANCE 0.00100000
MAXIMUM NO. ITERATIONS 100

*** RESULTS ***

OUTLET TEMPERATURE °C 288.00
OUTLET PRESSURE ATM 1.0000
HEAT DUTY KW 80.893
OUTLET VAPOR FRACTION 0.99943

V-L PHASE EQUILIBRIUM:

COMP  F(I)  X(I)  Y(I)  K(I)
WATER        0.82048  0.82048  0.84207  0.364148E-01
GLUCOSE      0.11625E-04  0.11625E-04  0.11737E-16  0.358212E-13
XYLOSE       0.10427E-01  0.10427E-01  0.89227E-08  0.383936E-07
OXYGEOX      0.16044  0.16044  0.117593  0.33266E-01
ENZ/XYL      0.64838E-03  0.64838E-03  0.16842E-08  0.921666E-07

*** ASSOCIATED UTILITIES ***

UTILITY ID FOR ELECTRICITY ELEC
RATE OF CONSUMPTION 80.8934 KW
COST 6.2692 $/HR
CO2 EQUIVALENT EMISSIONS 673.4923 KG/DAY

*** Mass and Energy Balance ***

IN     OUT     RELATIVE DIFF.

TOTAL BALANCE  
MOL (MOL/HR) | 14557.0  14557.0  0.0000
MASS (KG/DAY) | 52808.1  52808.1  0.0000
ENTHALPY (KW) | -79.4113  1.45976E-14  -1.01838E-02

** BLOCK: B16 MODEL: HEATER **

PROPERTY OPTION SET: RK-ASPEN
REDLICH-KWONG-ASPEN EQUATION OF STATE

** BLOCK: B17 MODEL: HEATER **

PROPERTY OPTION SET: RK-ASPEN
REDLICH-KWONG-ASPEN EQUATION OF STATE

** BLOCK: B18 MODEL: DSTWU **

PROPERTY OPTION SET: RK-ASPEN
REDLICH-KWONG-ASPEN EQUATION OF STATE

OUTLET VAPOR FRACTION 0.99943
RECIPROCY FOR LIGHT KEY 0.58550
TOP STAGE PRESSURE (ATM ) 1.00000
BOTTOM STAGE PRESSURE (ATM ) 1.00000
NO. OF EQUILIBRIUM STAGES 10.00000
DISTILLATE VAPOR FRACTION 0.0

*** RESULTS ***
DISTILLATE TEMP. (C ) 40.1463
BOTTOM TEMP. (C ) 55.1613
MINIMUM REFLUX RATIO 1.21895
ACTUAL REFLUX RATIO 5.88645
MINIMUM STAGES 8.46443
ACTUAL EQUILIBRIUM STAGES 10.00000
NUMBER OF ACTUAL STAGES ABOVE FEED 9.23358
DIST. VS FEED 0.26705
CONDENSER COOLING REQUIRED (KW ) 1,239.61
NET CONDENSER DUTY (KW ) 1,265.35
REBOILER HEATING REQUIRED (KW ) 1,265.35
NET REBOILER DUTY (KW ) 1,265.35

BLOCK: B19 MODEL: HEATX
-----------
HOT SIDE:
-----------
INLET STREAM: PL4
OUTLET STREAM: S4
PROPERTY OPTION SET: RK

COLD SIDE:
-----------
INLET STREAM: STEAM4
OUTLET STREAM: STEAM5
PROPERTY OPTION SET: RK

*** MASS AND ENERGY BALANCE ***

TOTAL BALANCE

MOL (MOL/HR ) 304235. 304235. 8.00000

MASS (KG/DAY ) 224573. 0.253919E-15

ENTHALPY (KW ) -18773.2 -18773.2 -0.193786E-15

*** CO2 EQUIVALENT SUMMARY ***

FEED STREAMS CO2: 0.00000 KG/DAY
PRODUCT STREAMS CO2: 0.00000 KG/DAY
NET STREAMS CO2 PRODUCTION: 0.00000 KG/DAY
UTILITIES CO2 PRODUCTION: 0.00000 KG/DAY
TOTAL CO2 PRODUCTION: 0.00000 KG/DAY

*** 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 HOT OUTLET TEMP 103.3

SPECIFIED VALUE C 110.0000
LMTD CORRECTION FACTOR 1.00000

PRESSURE SPECIFICATION:

HOT SIDE PRESSURE DROP ATM 0.0000
COLD SIDE PRESSURE DROP ATM 0.0000

HEAT TRANSFER COEFFICIENT SPECIFICATION:
HOT LIQUID COLD LIQUID CAL/SEC-SQM-K 0.0203
HOT LIQUID COLD 2-PHASE CAL/SEC-SQM-K 0.0203
HOT LIQUID COLD VAPOR CAL/SEC-SQM-K 0.0203
HOT VAPOR COLD LIQUID CAL/SEC-SQM-K 0.0203
HOT VAPOR COLD 2-PHASE CAL/SEC-SQM-K 0.0203
HOT VAPOR COLD VAPOR CAL/SEC-SQM-K 0.0203
HOT 2-PHASE COLD LIQUID CAL/SEC-SQM-K 0.0203
HOT 2-PHASE COLD VAPOR CAL/SEC-SQM-K 0.0203
HOT VAPOR COLD 2-PHASE CAL/SEC-SQM-K 0.0203

*** OVERALL RESULTS ***

STREAMS:

---

PL4 -------> ZONA: HOT

STEAM4 ------< ZONA: COLD

DUTY AND AREA:
CALCULATED HEAT DUTY KW 136.8932
CALCULATED (REQUIRED) AREA SQM 15.7617
ACTUAL EXCHANGER AREA SQM 15.7617
PER CENT OVER-DESIGN 0.0000

HEAT TRANSFER COEFFICIENT:
AVG COEFFICIENT DIRTY CAL/SEC-SQM-K 0.0203
UA DIRTY CAL/SEC-K 3199.9323

LOG-MEAN TEMPERATURE DIFFERENCE:
LMTD CORRECTION FACTOR 1.0000
LMTD (CORRECTED) C 10.2178
NUMBER OF SHELLS IN SERIES 1

PRESSURE DROP:
HOT SIDE, TOTAL ATM 0.0000
COLD SIDE, TOTAL ATM 0.0000

*** ZONE RESULTS ***

TEMPERATURE LEAVING EACH ZONE:

HOT

COLD

342
ZOE heat transfer and area:

ZONE | HEAT DUTY | AREA | LMTD | AVERAGE U | UA
---|---|---|---|---|---
1 | 136.893 | 15.7617 | 10.2178 | 0.8203 | 319.9323

HEATX COLD-QCUI B19 QCURV INLET

---

<table>
<thead>
<tr>
<th>Duty</th>
<th>Pres</th>
<th>Temp</th>
<th>VFRAC</th>
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<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
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</tbody>
</table>

---

PROPERTY OPTION SET: RK-ASPEN REDLICH-KWONG-ASPEN EQUATION OF STATE

---

PROPERTY DROP: 0.0 ATM

---

PRESSURE PROFILE: CONSTANT2

---

FLOW DIRECTION AND SPECIFICATION:

CONVERGENCE TOLERANCE                                     0.000100000
MAXIMUM NO. ITERATIONS                                   30
TWO PHASE      FLASH

---

TOTAL BALANCE

| ENTALPY (KW/HR ) | 0.103501E+07 | 0.103501E+07 | 0.00000 |
| MASS (KG/DAY)   | 0.103501E+07 | 0.103501E+07 | 0.00000 |

---

*** MASS AND ENERGY BALANCE ***

IN | OUT | RELATIVE DIFF.
---|---|---
TOTAL BALANCE | 0.103501E+07 | 0.103501E+07 | 0.00000 |

---

*** CO2 EQUIVALENT SUMMARY ***

FEED STREAMS CO2E | 0.00000 | KG/DAY |
PRODUCT STREAMS CO2E | 0.00000 | KG/DAY |
NET STREAMS CO2E PRODUCTION | 0.00000 | KG/DAY |
UTILITIES CO2E PRODUCTION | 0.00000 | KG/DAY |
TOTAL CO2E PRODUCTION | 0.00000 | KG/DAY |

---

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
### Temperature Leaving Each Zone:

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<thead>
<tr>
<th>HOT</th>
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### Heat Transfer Coefficient Specification:

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<th>HOT LIQUID</th>
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<tbody>
<tr>
<td>HOT VAPOR</td>
<td>COLD LIQUID</td>
<td>CAL/SEC-SQM-K</td>
<td>0.0203</td>
</tr>
<tr>
<td>HOT LIQUID</td>
<td>COLD VAPOR</td>
<td>CAL/SEC-SQM-K</td>
<td>0.0203</td>
</tr>
<tr>
<td>HOT VAPOR</td>
<td>COLD VAPOR</td>
<td>CAL/SEC-SQM-K</td>
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<tr>
<td>HOT LIQUID</td>
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### Duty and Area:

<table>
<thead>
<tr>
<th>HOT LIQUID</th>
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<tr>
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<tr>
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<td>COLD VAPOR</td>
<td>CAL/SEC-SQM-K</td>
<td>0.0203</td>
</tr>
</tbody>
</table>

### Pressure Drop:

| HOT SIDE PRESSURE DROP | ATM | 0.0000 |
| COLD SIDE PRESSURE DROP | ATM | 0.0000 |

### Property Option Set:

- RK
- ASPEN REDLICH-KWONG-ASPIN EQUATION OF STATE
- ASPEN EQUATION OF STATE
! ! ! !

| KW | AM | C | ! | ! | ! | ! | ! | ! |

| 8.0 | 1.0000 | 150.0000 | 0.9917 |
| 644.6749 | 1.0000 | 108.2917 | 0.9788 |
| 1289.3498 | 1.0000 | 104.1842 | 0.9332 |
| 1394.0247 | 1.0000 | 103.7788 | 0.8852 |
| 2578.6996 | 1.0000 | 103.5626 | 0.8372 |
| 3223.3745 | 1.0000 | 103.4115 | 0.7893 |
| 3668.0494 | 1.0000 | 103.2992 | 0.7413 |
| 4512.7443 | 1.0000 | 103.1897 | 0.6934 |
| 5157.3992 | 1.0000 | 103.1388 | 0.6454 |
| 5802.0741 | 1.0000 | 103.0806 | 0.5975 |
| 6446.7490 | 1.0000 | 103.0231 | 0.5495 |
| 7091.4239 | 1.0000 | 102.9610 | 0.5016 |
| 7736.0988 | 1.0000 | 102.9058 | 0.4536 |
| 8380.7738 | 1.0000 | 102.8525 | 0.4056 |
| 9025.4487 | 1.0000 | 102.8085 | 0.3576 |
| 9670.1236 | 1.0000 | 102.7649 | 0.3097 |
| 1.0315+04 | 1.0000 | 102.6253 | 0.2617 |
| 1.0959+04 | 1.0000 | 102.5831 | 0.2137 |
| 1.1604+04 | 1.0000 | 102.5328 | 0.1657 |
| 1.2249+04 | 1.0000 | 102.4828 | 0.1178 |

** CO2 EQUIVALENT SUMMARY **

TOTAL BALANCE

| MOLEC/MOL/HR | 823001. | 823001. | 0.0000 |
| MASS/KG/DAY | 355871. | 355871. | 0.163564E-15 |
| ENTHALPY/IN | -65564.2 | -65564.2 | -0.107334E-08 |

** INPUT DATA **

FLASH SPECS FOR STREAM S29

| TWO PHASE TP FLASH | PRESSURE DROP | ATM | 0.0 |

MAXIMUM NO. ITERATIONS 30

CONVERGENCE TOLERANCE 0.000100000

PROPERTY OPTION SET: RK-ASPEN REDLICH-KONG-ASPEN EQUATION OF STATE

*** MASS AND ENERGY BALANCE ***

IN | OUT | RELATIVE DIFF.

HEAT DUTY

KW | 0.701568-04

COMPONENT WATER

STREAM SUBSTREAM S30 S30

SPLIT FRACTION 1.00000

COMPONENT GLUCOSE

STREAM SUBSTREAM S29 S29

SPLIT FRACTION 1.00000

COMPONENT XYLose

STREAM SUBSTREAM S29 S29

SPLIT FRACTION 1.00000

COMPONENT OTHERSOLID

STREAM SUBSTREAM S29 S29

SPLIT FRACTION 1.00000

COMPONENT CELLULOSE

STREAM SUBSTREAM S29 S29

SPLIT FRACTION 1.00000

COMPONENT ETHYL-01

STREAM SUBSTREAM S30 S30

SPLIT FRACTION 1.00000

COMPONENT AMMONIA

STREAM SUBSTREAM S30 S30

SPLIT FRACTION 1.00000

COMPONENT XYLOSE

STREAM SUBSTREAM S30 S30

SPLIT FRACTION 1.00000

COMPONENT GLUTARICACID

STREAM SUBSTREAM S30 S30

SPLIT FRACTION 1.00000

COMPONENT DIETHER

STREAM SUBSTREAM S30 S30

SPLIT FRACTION 1.00000

COMPONENT Methylene

STREAM SUBSTREAM S30 S30

SPLIT FRACTION 1.00000

COMPONENT CASO4

STREAM SUBSTREAM S30 S30

SPLIT FRACTION 1.00000

COMPONENT CAOH2

STREAM SUBSTREAM S30 S30

SPLIT FRACTION 1.00000

COMPONENT H2SO4

STREAM SUBSTREAM S30 S30

SPLIT FRACTION 1.00000

COMPONENT N2

STREAM SUBSTREAM S30 S30

SPLIT FRACTION 1.00000

COMPONENT LACTICACID

STREAM SUBSTREAM S30 S30

SPLIT FRACTION 1.00000

COMPONENT NACIT

STREAM SUBSTREAM S30 S30

SPLIT FRACTION 1.00000

COMPONENT LACTICACID

STREAM SUBSTREAM S30 S30

SPLIT FRACTION 1.00000

COMPONENT DIETHER

STREAM SUBSTREAM S30 S30

SPLIT FRACTION 1.00000

COMPONENT ETHYL-01

STREAM SUBSTREAM S30 S30

SPLIT FRACTION 1.00000

COMPONENT AMMONIA

STREAM SUBSTREAM S30 S30

SPLIT FRACTION 1.00000

COMPONENT XYLOSE

STREAM SUBSTREAM S30 S30

SPLIT FRACTION 1.00000

COMPONENT OTHERSOLID

STREAM SUBSTREAM S30 S30

SPLIT FRACTION 1.00000

COMPONENT CELLULOSE

STREAM SUBSTREAM S30 S30

SPLIT FRACTION 1.00000

COMPONENT ETHYL-01
TOTAL BALANCE

MOLE (MOL/HR) | 368101. 368101. 0.0000
MAM (KG/DAY) | 175104. 175104. 0.0000
ENTROPY (KM) | -30468.0 -30468.0 0.0000

*** CO2 EQUIVALENT SUMMARY ***

FEED STREAMS CO2E 0.00000 KG/DAY
PRODUCT STREAMS CO2E 0.00000 KG/DAY
NET STREAMS CO2E PRODUCTION 0.00000 KG/DAY
UTILITIES CO2E PRODUCTION 0.00000 KG/DAY
TOTAL CO2E PRODUCTION 0.00000 KG/DAY

*** INPUT DATA ***

FLOW DIRECTION AND SPECIFICATION:

MAXIMUM NO. ITERATIONS 30
TWO PHASE FLASH
FLASH SPECS FOR COLD SIDE:
CONVERGENCE TOLERANCE 0.000100000
MAXIMUM NO. ITERATIONS 30
INLET STREAM: 8

PROPERTY OPTION SET: RK

OUTLET STREAM: S34

INLET STREAM: 5

PROPERTY OPTION SET: RK-ASSEN REDILICH-KWONG-ASSEN EQUATION OF STATE

COLD SIDE:

---

INLET STREAM: 8

OUTLET STREAM: S36

PROPERTY OPTION SET: RK-ASSEN REDILICH-KWONG-ASSEN EQUATION OF STATE

---

TOTAL BALANCE

MOLE (MOL/HR) | 53054.4 53054.4 0.0000
MAM (KG/DAY) | 37818.3 37818.3 -0.19239E-15
ENTROPY (KM) | -5157.08 -5157.08 0.0000

*** CO2 EQUIVALENT SUMMARY ***

FEED STREAMS CO2E 0.00000 KG/DAY
PRODUCT STREAMS CO2E 0.00000 KG/DAY
NET STREAMS CO2E PRODUCTION 0.00000 KG/DAY
UTILITIES CO2E PRODUCTION 0.00000 KG/DAY
TOTAL CO2E PRODUCTION 0.00000 KG/DAY

*** INPUT DATA ***

FLASH SPECS FOR HOT SIDE:

MAXIMUM NO. ITERATIONS 30
CONVERGENCE TOLERANCE 0.000100000

FLASH SPECS FOR COLD SIDE:

MAXIMUM NO. ITERATIONS 30
CONVERGENCE TOLERANCE 0.000100000

FLOW DIRECTION AND SPECIFICATION:

SPECIFIED COLD OUTLET TEMP C 95.0000
LMTD CORRECTION FACTOR 1.0000

PRESSURE SPECIFICATION:

HOT SIDE PRESSURE DROP ATM 0.0000
COLD SIDE PRESSURE DROP ATM 0.0000

*** OVERALL RESULTS ***

STREAMS:

-------------------------------------

DUTY AND AREA:
CALCULATED HEAT DUTY KW 53.0440
CALCULATED (REQUIRED) AREA SQM 3.0516
ACTUAL EXCHANGER AREA SQM 3.0516
PER CENT OVER-DESIGN 0.0000

HEAT TRANSFER COEFFICIENT:
AVERAGE COEFFICIENT (DIRTY) CAL/SEC 0.0000
UA (DIRTY) CAL/SEC-K 619.5430

LOG-MEAN TEMPERATURE DIFFERENCE:
LMTD CORRECTION FACTOR 1.0000
LMTD (CORRECTED) C 20.4495
NUMBER OF SHELLS IN SERIES 1

PRESSURE DROP:
HOTSIDE, TOTAL ATM 0.0000
COLDSIDE, TOTAL ATM 0.0000

*** ZONE RESULTS ***

TEMPERATURE LEAVING EACH ZONE:

HOT

-------------------------------------

COLD
<table>
<thead>
<tr>
<th>KW</th>
<th>DUTY</th>
<th>PRES</th>
<th>TEMP</th>
<th>VFRAC</th>
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---

**PROPERTY OPTION SET: RK-ASPEN REDLICH-KWONG-ASPEN EQUATION OF STATE**

---

**PRESSURE PROFILE:** CONSTANT2
**PRESSURE DROP:** 0.0

---

**DUTY | PRES | TEMP | VFRAC**
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<th></th>
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---

**PROPERTY OPTION SET:** RK-ASPEN REDLICH-KWONG-ASPEN EQUATION OF STATE

---

**INLET STREAMS:** S32 S33

---

**OUTLET STREAM:** SUGARS

---

**PROPERTY OPTION SET:** RK-ASPEN REDLICH-KWONG-ASPEN EQUATION OF STATE

---

**OUTLET STREAM:** PURE

---

**INLET STREAMS:** S32 S33

---

**OUTLET STREAM:** SUGARS

---

**PROPERTY OPTION SET:** RK-ASPEN REDLICH-KWONG-ASPEN EQUATION OF STATE

---

**OUTLET STREAM:** SUGARS

---

**PROPERTY OPTION SET:** RK-ASPEN REDLICH-KWONG-ASPEN EQUATION OF STATE

---

**OUTLET STREAM:** SUGARS

---

**PROPERTY OPTION SET:** RK-ASPEN REDLICH-KWONG-ASPEN EQUATION OF STATE

---

**TOTAL BALANCE**

---

**TOTAL BALANCE OUTLET STREAM: SUGARS X**

---

**INPUT DATA**

---

**STEP DATA**

---

**CO2 EQUIVALENT SUMMARY**

---

**INPUT DATA**

---

**CONVERGENCE TOLERANCE**

---

**OUTLET PRESSURE:** MINIMUM OF INLET STREAM PRESSURES

---

**BLOCK: CAOH-NEU MODEL: RSTOIC**

---

**INLET STREAMS:** XYSUGARS CAOH

---

**OUTLET STREAM:** SUGARS

---

**PROPERTY OPTION SET:** RK-ASPEN REDLICH-KWONG-ASPEN EQUATION OF STATE

---

**OUTLET STREAM:** SUGARS

---

**PROPERTY OPTION SET:** RK-ASPEN REDLICH-KWONG-ASPEN EQUATION OF STATE

---

**TOTAL BALANCE**

---

**TOTAL BALANCE OUTLET STREAM: SUGARS X**

---

**INPUT DATA**

---

**CONVERGENCE TOLERANCE**

---

**OUTLET PRESSURE:** MINIMUM OF INLET STREAM PRESSURES

---

**BLOCK: B25 MODEL: MIXER**

---

**INLET STREAMS:** S32 S33

---

**OUTLET STREAM:** FORX

---

**PROPERTY OPTION SET:** RK-ASPEN REDLICH-KWONG-ASPEN EQUATION OF STATE

---

**OUTLET STREAM:** PURE

---

**INLET STREAMS:** S32 S33

---

**OUTLET STREAM:** SUGARS

---

**PROPERTY OPTION SET:** RK-ASPEN REDLICH-KWONG-ASPEN EQUATION OF STATE

---

**TOTAL BALANCE**

---

**TOTAL BALANCE OUTLET STREAM: SUGARS X**

---

**INPUT DATA**

---

**CONVERGENCE TOLERANCE**

---

**OUTLET PRESSURE:** MINIMUM OF INLET STREAM PRESSURES

---

**BLOCK: CAOH-NEU MODEL: RSTOIC**

---

**INLET STREAMS:** XYSUGARS CAOH

---

**OUTLET STREAM:** SUGARS

---

**PROPERTY OPTION SET:** RK-ASPEN REDLICH-KWONG-ASPEN EQUATION OF STATE

---

**OUTLET STREAM:** SUGARS

---

**PROPERTY OPTION SET:** RK-ASPEN REDLICH-KWONG-ASPEN EQUATION OF STATE

---

**TOTAL BALANCE**

---

**TOTAL BALANCE OUTLET STREAM: SUGARS X**

---

**INPUT DATA**

---

**CONVERGENCE TOLERANCE**

---

**OUTLET PRESSURE:** MINIMUM OF INLET STREAM PRESSURES

---

**BLOCK: B25 MODEL: MIXER**

---

**INLET STREAMS:** S32 S33

---

**OUTLET STREAM:** FORX

---

**PROPERTY OPTION SET:** RK-ASPEN REDLICH-KWONG-ASPEN EQUATION OF STATE

---

**OUTLET STREAM:** PURE

---

**INLET STREAMS:** S32 S33

---

**OUTLET STREAM:** SUGARS

---

**PROPERTY OPTION SET:** RK-ASPEN REDLICH-KWONG-ASPEN EQUATION OF STATE

---

**TOTAL BALANCE**

---

**TOTAL BALANCE OUTLET STREAM: SUGARS X**

---

**INPUT DATA**

---

**CONVERGENCE TOLERANCE**

---

**OUTLET PRESSURE:** MINIMUM OF INLET STREAM PRESSURES

---

**BLOCK: CAOH-NEU MODEL: RSTOIC**

---

**INLET STREAMS:** XYSUGARS CAOH

---

**OUTLET STREAM:** SUGARS

---

**PROPERTY OPTION SET:** RK-ASPEN REDLICH-KWONG-ASPEN EQUATION OF STATE

---

**OUTLET STREAM:** SUGARS

---

**PROPERTY OPTION SET:** RK-ASPEN REDLICH-KWONG-ASPEN EQUATION OF STATE

---

**TOTAL BALANCE**

---

**TOTAL BALANCE OUTLET STREAM: SUGARS X**

---

**INPUT DATA**

---

**CONVERGENCE TOLERANCE**

---

**OUTLET PRESSURE:** MINIMUM OF INLET STREAM PRESSURES
### Utilities CO2 Emission

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<tr>
<th>Total CO2 Emission</th>
<th>6206.90</th>
<th>KG/DAY</th>
</tr>
</thead>
</table>

### Model: MIXER

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<thead>
<tr>
<th>CO2 Equivalent Emissions</th>
<th>6206.9036</th>
<th>KG/DAY</th>
</tr>
</thead>
</table>

| Cost | 57.7773 | $/HR |

### Rate of Consumption

| Rate of Consumption | 745.5137 | KW |

### Utility ID for Electricity

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<tr>
<th>Cellulose: SLEC</th>
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### Block: CHLMIX Model: MIXER

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<tr>
<th>Inlet Streams:</th>
<th>PLA CHCL2IN</th>
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### Outlet Stream: S7

| Property Option Set: RK-ASPEN REDLICH-KWONG-ASPEN EQUATION OF STATE |

### V-L Phase Equilibrium

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<th>Component</th>
<th>F(I)</th>
<th>X(I)</th>
<th>Y(I)</th>
<th>K(I)</th>
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### Input Data

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<th>Reaction Extents:</th>
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<table>
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<tr>
<th>Reaction Number</th>
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</table>

### Co2 Equivalent Summary

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<th>Mole(Mol/HR)</th>
<th>0.00000</th>
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<tbody>
<tr>
<td>Net Streams</td>
<td>Mole(Mol/HR)</td>
<td>Mole(Mol/HR)</td>
<td>0.00000</td>
</tr>
<tr>
<td>Product Streams</td>
<td>Mole(Mol/HR)</td>
<td>Mole(Mol/HR)</td>
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<td>Utilities CO2E Production</td>
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### Input Data

<table>
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<tr>
<th>Block: CHROMA Model: SEP</th>
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</table>

<table>
<thead>
<tr>
<th>Reaction Conversion Specs: Number = 1</th>
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</thead>
<tbody>
<tr>
<td>Substream = MIXED Key Comp = CAOH2 Conv Frac = 0.9500</td>
</tr>
</tbody>
</table>

**Results**

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<tr>
<th>IN</th>
<th>OUT</th>
<th>RELATIVE DIFF.</th>
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<tbody>
<tr>
<td>IN</td>
<td>OUT</td>
<td>RELATIVE DIFF.</td>
</tr>
</tbody>
</table>

### Mass and Energy Balance

<table>
<thead>
<tr>
<th>Feed Streams CO2E</th>
<th>0.00000</th>
<th>KG/DAY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Product Streams CO2E</td>
<td>0.00000</td>
<td>KG/DAY</td>
</tr>
<tr>
<td>Utilities CO2E Production</td>
<td>0.00000</td>
<td>KG/DAY</td>
</tr>
<tr>
<td>Total CO2E Production</td>
<td>0.00000</td>
<td>KG/DAY</td>
</tr>
</tbody>
</table>

### Input Data

<table>
<thead>
<tr>
<th>Feed Streams S18:</th>
<th>S18 S20</th>
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<table>
<thead>
<tr>
<th>Property Option Set: RK-ASPEN REDLICH-KWONG-ASPEN EQUATION OF STATE</th>
</tr>
</thead>
</table>

### Results

<table>
<thead>
<tr>
<th>Inlet Stream:</th>
<th>S28</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outlet Streams:</td>
<td>S18 S20</td>
</tr>
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</table>

### Associated Utilities

<table>
<thead>
<tr>
<th>Utility ID for Electricity</th>
<th>SLEC</th>
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### Mass and Energy Balance

<table>
<thead>
<tr>
<th>Total Balance</th>
<th>Mole(Mol/HR)</th>
<th>Mole(Mol/HR)</th>
<th>0.00000</th>
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</thead>
<tbody>
<tr>
<td>Net Streams</td>
<td>Mole(Mol/HR)</td>
<td>Mole(Mol/HR)</td>
<td>0.00000</td>
</tr>
<tr>
<td>Product Streams</td>
<td>Mole(Mol/HR)</td>
<td>Mole(Mol/HR)</td>
<td>0.00000</td>
</tr>
<tr>
<td>Utilities CO2E Production</td>
<td>Mole(Mol/HR)</td>
<td>Mole(Mol/HR)</td>
<td>0.00000</td>
</tr>
<tr>
<td>Total CO2E Production</td>
<td>Mole(Mol/HR)</td>
<td>Mole(Mol/HR)</td>
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</table>

<table>
<thead>
<tr>
<th>Fraction of Feed</th>
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<table>
<thead>
<tr>
<th>Substream Mixed:</th>
<th>S18</th>
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<table>
<thead>
<tr>
<th>Property Option Set: RK-ASPEN REDLICH-KWONG-ASPEN EQUATION OF STATE</th>
</tr>
</thead>
</table>

### Results

<table>
<thead>
<tr>
<th>Heat Duty</th>
<th>KW</th>
<th>-0.37033</th>
</tr>
</thead>
</table>
COMPONENT = WATER
STREAM SUBSTREAM SPLIT FRACTION
S20 MIXED 1.00000

COMPONENT = XYLOSE
STREAM SUBSTREAM SPLIT FRACTION
S20 MIXED 1.00000

COMPONENT = OTHLIQUI
STREAM SUBSTREAM SPLIT FRACTION
S18 MIXED 1.00000

COMPONENT = ENZ/XYL
STREAM SUBSTREAM SPLIT FRACTION
S20 MIXED 1.00000

BLOCK: COOL2 MODEL: HEATER
----------------------------------
INLET STREAM: S34
OUTLET STREAM: 7
PROPERTY OPTION SET: RK-ASPEN REDLICH-KWONG-ASPEN EQUATION OF STATE

*** MASS AND ENERGY BALANCE ***
IN OUT RELATIVE DIFF.
TOTAL BALANCE
MOLE(MOL/HR) 30569.1 30569.1 0.00000
MASS(KG/DAY) 25010.3 25010.3 -0.00000
ENTHALPY(KW) -3197.97 -3235.16 0.114952E-01

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

*** INPUT DATA ***
FLASH SPECS FOR STREAM LIQUOR
TWO PHASE TP FLASH
PRESSURE DROP ATM 0.0
MAXIMUM NO. ITERATIONS 30
CONVERGENCE TOLERANCE 0.000100000

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

FRACTION OF FEED
SUBSTREAM= MIXED
STREAM= XYLITOL CPT= WATER FRACTION= 0.0
GLUCOSE 0.0
XYLOSE 0.0
AMMONIA 0.0
OTHLIQUI 0.0
H2SO4 0.0
CAOH2 0.0
CASO4 0.0
OTHSOLID 0.0
CELLULOS 0.0
NACIT 0.0
LACTICAC 0.0
DIKBER 0.0
N2 0.0
METHANOL 0.0
METHYL 0.0
CH2CL2 0.0
ETHYL-01 0.0

*** RESULTS ***
HEAT DUTY KW -7.1129

V-L PHASE EQUILIBRIUM :

COMP X(I) X(I) X(I) X(I)
WATER 0.87992 0.87992 1.0000 0.747E-02
XYLOSE 0.15986E-01 0.15986E-01 0.12020E-09 0.49075E-10
ENZ/XYL 0.10409 0.10409 0.14751E-08 0.575138E-02

*** ASSOCIATED UTILITIES ***

UTILITY ID FOR REFRIGERANT REFRI
RIDGE

REFRIGERATE RATE OF CONSUMPTION 8.013E+05 KG/DAY
COST 0.3668 S/HR
CO2 EQUIVALENT EMISSIONS 179.5814 KG/DAY

COMPONENT = LIQUOR
STREAM SUBSTREAM SPLIT FRACTION
LIQUOR MIXED 1.00000
V-L PHASE EQUILIBRIUM:

<table>
<thead>
<tr>
<th>COMPONENT</th>
<th>ENZ/XYL</th>
</tr>
</thead>
<tbody>
<tr>
<td>STREAM</td>
<td>SUBSTREAM</td>
</tr>
<tr>
<td></td>
<td>SPLIT FRACTION</td>
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<tr>
<td>XYLITOL</td>
<td>MIXED</td>
</tr>
<tr>
<td>1.00000</td>
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</table>

**BLOCK: DRYPLA MODEL: FLASH2**

---

**INLET STREAM:** S9

**OUTLET VAPOR STREAM:** STEAM2

**OUTLET LIQUID STREAM:** PLANE2

**PROPERTY OPTION SET:** RK-ASPN REDLICH-KWONG-ASPN EQUATION OF STATE

---

**CO2 EQUIVALENT SUMMARY***

**TOTAL BALANCE**

**MOLE (MOL/HR)**

<table>
<thead>
<tr>
<th></th>
<th>14557.0</th>
<th>14557.0</th>
<th>0.00000</th>
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</table>

**MASS (KG/DAY)**

<table>
<thead>
<tr>
<th></th>
<th>52808.1</th>
<th>52808.1</th>
<th>-0.55122E-15</th>
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**ENTHALPY (KW)**

<table>
<thead>
<tr>
<th></th>
<th>-313.283</th>
<th>-326.788</th>
<th>0.41325E-01</th>
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**CO2 EQUIVALENT SUMMARY***

**FEED STREAMS CO2E**

0.00000 KG/DAY

**PRODUCT STREAMS CO2E**

0.00000 KG/DAY

**UTILITIES CO2E PRODUCTION**

0.00000 KG/DAY

**TOTAL CO2E PRODUCTION**

0.00000 KG/DAY

---

**CO2 EQUIVALENT SUMMARY***

**FEED STREAMS CO2E**

0.00000 KG/DAY

**PRODUCT STREAMS CO2E**

0.00000 KG/DAY

**UTILITIES CO2E PRODUCTION**

0.00000 KG/DAY

**TOTAL CO2E PRODUCTION**

0.00000 KG/DAY

---

**CO2 EQUIVALENT SUMMARY***

**FEED STREAMS CO2E**

0.00000 KG/DAY

**PRODUCT STREAMS CO2E**

0.00000 KG/DAY

**UTILITIES CO2E PRODUCTION**

0.00000 KG/DAY

**TOTAL CO2E PRODUCTION**

0.00000 KG/DAY

---

**CO2 EQUIVALENT EMISIONS**

**TOTAL BALANCE**

**MOLE (MOL/HR)**

<table>
<thead>
<tr>
<th></th>
<th>0.45799E</th>
<th>0.26301E</th>
<th>-0.13313E</th>
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</table>

**MATH (KG/DAY)**

<table>
<thead>
<tr>
<th></th>
<th>143964.0</th>
<th>143963.0</th>
<th>0.379056E</th>
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</table>

**ENTHALPY (KW)**

<table>
<thead>
<tr>
<th></th>
<th>143072.1</th>
<th>143071.1</th>
<th>0.90000</th>
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**CO2 EQUIVALENT EMISIONS**

**TOTAL BALANCE**

**MOL (MOL/HR)**

<table>
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<tr>
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**MATH (KG/DAY)**

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<tr>
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**ENTHALPY (KW)**

<table>
<thead>
<tr>
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<th>-252.717</th>
<th>-214.285</th>
<th>-0.150578</th>
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**CO2 EQUIVALENT EMISIONS**

**TOTAL BALANCE**

**MOL (MOL/HR)**

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<tr>
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<th>14548.6</th>
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<th>0.00000</th>
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**MATH (KG/DAY)**

<table>
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<tr>
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<th>-0.15561E</th>
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**RESULTS**

<table>
<thead>
<tr>
<th>OUTLET TEMPERATURE</th>
<th>C</th>
<th>103.30</th>
</tr>
</thead>
<tbody>
<tr>
<td>OUTLET PRESSURE</td>
<td>ATM</td>
<td>1.0000</td>
</tr>
<tr>
<td>HEAT DUTY</td>
<td>MW</td>
<td>799.64</td>
</tr>
<tr>
<td>VAPOR FRACTION</td>
<td></td>
<td>0.9000</td>
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</tbody>
</table>

**V-L PHASE EQUILIBRIUM:**

<table>
<thead>
<tr>
<th>COMP</th>
<th>F(I)</th>
<th>X(I)</th>
<th>Y(I)</th>
<th>X(I)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WATER</td>
<td>0.98799</td>
<td>0.87991</td>
<td>1.0000</td>
<td>1.1365</td>
</tr>
<tr>
<td>XYLUS</td>
<td>0.15988E-02</td>
<td>0.15987E-01</td>
<td>0.83956E-07</td>
<td>0.52515E-05</td>
</tr>
<tr>
<td>ENZ/XYL</td>
<td>0.10410E-01</td>
<td>0.10410</td>
<td>0.39305E-06</td>
<td>0.37756E-05</td>
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**ASSOCIATED UTILITIES**

<table>
<thead>
<tr>
<th>UTILITY ID FOR STEAM</th>
<th>LPSTEAM</th>
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<tbody>
<tr>
<td>RATE OF CONSUMPTION</td>
<td>1.4973E+05</td>
</tr>
<tr>
<td>COST</td>
<td>25.9825</td>
</tr>
<tr>
<td>CO2 EQUIVALENT EMISSIONS</td>
<td>2.1580E+04</td>
</tr>
<tr>
<td>MAXIMUM NO. ITERATIONS</td>
<td>30</td>
</tr>
<tr>
<td>CONVERGENCE TOLERANCE</td>
<td>0.000100000</td>
</tr>
<tr>
<td>PRESSURE DROP</td>
<td>0.0</td>
</tr>
<tr>
<td>TWO PHASE TP FLASH</td>
<td>0.0</td>
</tr>
</tbody>
</table>

**MASS AND ENERGY BALANCE**

<table>
<thead>
<tr>
<th>IN</th>
<th>OUT</th>
<th>RELATIVE DIFF.</th>
</tr>
</thead>
<tbody>
<tr>
<td>780116.</td>
<td>780116.</td>
<td>-0.298457E-15</td>
</tr>
<tr>
<td>352906.</td>
<td>352906.</td>
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<tr>
<td>5.9485.</td>
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<td>0.223443E-01</td>
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**CO2 EQUIVALENT SUMMARY**

<table>
<thead>
<tr>
<th>FRACTION OF FEED</th>
<th>MIXED</th>
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</thead>
<tbody>
<tr>
<td>TOTAL BALANCE</td>
<td></td>
</tr>
<tr>
<td>TWO PHASE TP FLASH</td>
<td></td>
</tr>
<tr>
<td>PRESSURE DROP</td>
<td>0.0</td>
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<tr>
<td>MAXIMUM NO. ITERATIONS</td>
<td>30</td>
</tr>
<tr>
<td>CONVERGENCE TOLERANCE</td>
<td>0.000100000</td>
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</tbody>
</table>

**INPUT DATA**

<table>
<thead>
<tr>
<th>STREAM</th>
<th>XYSUGARS</th>
<th>CPT= WATER</th>
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</thead>
<tbody>
<tr>
<td>FRACTION</td>
<td></td>
<td>0.26717</td>
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</tbody>
</table>

**RESULTS**

<table>
<thead>
<tr>
<th>OUTLET TEMPERATURE</th>
<th>C</th>
<th>110.00</th>
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<tbody>
<tr>
<td>OUTLET PRESSURE</td>
<td>ATM</td>
<td>1.2993</td>
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<td>HEAT DUTY</td>
<td>MW</td>
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</tr>
<tr>
<td>VAPOR FRACTION</td>
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<td>0.1000</td>
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**V-L PHASE EQUILIBRIUM:**

<table>
<thead>
<tr>
<th>COMP</th>
<th>F(I)</th>
<th>X(I)</th>
<th>Y(I)</th>
<th>X(I)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WATER</td>
<td>0.98933</td>
<td>0.98827</td>
<td>0.98930</td>
<td>1.5108</td>
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<tr>
<td>OTHSOLID</td>
<td>0.61292E-02</td>
<td>0.66888E-02</td>
<td>0.10969E-02</td>
<td>0.16400</td>
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<tr>
<td>CELLULOS</td>
<td>0.45370E-02</td>
<td>0.5041E-02</td>
<td>0.71400E-02</td>
<td>0.14656E-05</td>
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<tr>
<td>ENZ/XYL</td>
<td>0.13594E-06</td>
<td>0.15490E-06</td>
<td>0.45692E-11</td>
<td>0.28949E-04</td>
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<tr>
<td>DIETHYL</td>
<td>0.60580E-10</td>
<td>0.38726E-14</td>
<td>0.60577E-09</td>
<td>0.15642E+06</td>
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**RESULTS**

<table>
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<tr>
<th>HEAT DUTY</th>
<th>KW</th>
<th>2126.4</th>
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<tbody>
<tr>
<td>COMPONENT</td>
<td>WATER</td>
<td></td>
</tr>
<tr>
<td>FRACTION</td>
<td>XYSUGARS MIXED</td>
<td>0.26717</td>
</tr>
</tbody>
</table>
FLASh SPECS FOR STREAM PLASUGAR
TWO PHASE TP FLASH
PRESSURE DROP ATM 0.0
MAXIMUM NO. ITERATIONS 30
CONVERGENCE TOLERANCE 0.000100000

FLASh SPECS FOR STREAM PREC-PLA
TWO PHASE TP FLASH
PRESSURE DROP ATM 0.0
MAXIMUM NO. ITERATIONS 30
CONVERGENCE TOLERANCE 0.000100000

FRACTION OF FEED SUBSTREAM= MIXED
STREAM= PLASUGAR CPT= WATER FRACTION= 0.95000
GLUCOSE 1.00000
XYLOSE 1.00000
AMMONIA 0.0
OTHLIQUI 1.00000
H2SO4 0.0
CASO4 0.0
ENZ/XYL 0.0
NACIT 0.0

*** RESULTS ***
HEAT DUTY KW 0.53618E-01

COMPONENT = WATER STREAM SUBSTREAM SPLIT FRACTION
PLASUGAR MIXED 0.95000
PREC-PLA MIXED 0.050000

COMPONENT = GLUCOSE STREAM SUBSTREAM SPLIT FRACTION
PLASUGAR MIXED 1.00000

COMPONENT = AMMONIA STREAM SUBSTREAM SPLIT FRACTION
PREC-PLA MIXED 1.00000

COMPONENT = OTHSLiD STREAM SUBSTREAM SPLIT FRACTION
PREC-PLA MIXED 1.00000

COMPONENT = ENZ/XYL STREAM SUBSTREAM SPLIT FRACTION
PREC-PLA MIXED 1.00000

COMPONENT = NACIT STREAM SUBSTREAM SPLIT FRACTION
PREC-PLA MIXED 1.00000

BLOCK: FUGEXYL MODEL: SEP
INLET STREAM: SUGARX OUTLET STREAMS: XYLsUGAR PREC-XYL
PROPERTY OPTION SET: RK-ASPH REDlich-KWONG-ASPHEN EQUATION OF STATE

*** MASS AND ENERGY BALANCE ***
TOTAL BALANCE IN OUT RELATIVE DIFF.
COMPONENT = CAOH2
STREAM SUBSTREAM SPLIT FRACTION
    PREC-XYL MIXED 1.00000

COMPONENT = CASO4
STREAM SUBSTREAM SPLIT FRACTION
    PREC-XYL MIXED 1.00000

** BLOCK: LLE MODEL: EXTRACT **

** INLETS **
- S16 STAGE 1
- ETHIN2 STAGE 5

** OUTLETS **
- S33 STAGE 1
- S31 STAGE 5

** PROPERTY OPTION SET: RK ASPEN REDLICH-KWONG ASPEN EQUATION OF STATE **

** *** MASS AND ENERGY BALANCE *** **

<table>
<thead>
<tr>
<th>IN</th>
<th>OUT</th>
<th>RELATIVE DIFF.</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOTAL BALANCE</td>
<td></td>
<td>0.139809E-15</td>
</tr>
<tr>
<td>MOLE(MOL/HR)</td>
<td></td>
<td>832675.</td>
</tr>
<tr>
<td>MASS(KG/DAY)</td>
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<tr>
<td>ENTHALPY(KW)</td>
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<td>-66438.5</td>
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</table>

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

<table>
<thead>
<tr>
<th>FEED STREAMS CO2E</th>
<th>KG/DAY</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRODUCT STREMS</td>
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<tr>
<td>NET STREAMS CO2E</td>
<td>KG/DAY</td>
</tr>
<tr>
<td>UTILITIES CO2E PRODUCTION</td>
<td>KG/DAY</td>
</tr>
<tr>
<td>TOTAL CO2E PRODUCTION</td>
<td>KG/DAY</td>
</tr>
</tbody>
</table>

** *** COMPONENT SPLIT FRACTIONS *** **

<table>
<thead>
<tr>
<th>OUTLET STREAMS</th>
<th>S33</th>
<th>S31</th>
</tr>
</thead>
<tbody>
<tr>
<td>COMPENT: WATER</td>
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<td>.99891</td>
</tr>
<tr>
<td>GLUCOSE</td>
<td>.15580E-04</td>
<td>.99998</td>
</tr>
<tr>
<td>LACTICAC</td>
<td>.34822</td>
<td>.65178</td>
</tr>
<tr>
<td>DIETHER</td>
<td>1.00000</td>
<td>.54353E-11</td>
</tr>
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</table>

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

| L1 BUBBLE POINT ERROR | 0.91371E-06 | STAGE= 2 |
| L2 BUBBLE POINT ERROR | 0.10697E-05 | STAGE= 4 |
| COMPONENT MASS BALANCE | 0.47830E-15 | STAGE= 5 |
| ENERGY BALANCE        | 0.15117E-16 | STAGE= 5 |

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

** **** KEY COMPONENT SPECIFICATIONS **** **

| KEY COMPONENTS FOR LIQUID1 | WATER |
| KEY COMPONENTS FOR LIQUID2 | LACTICAC |
| KEY COMPONENTS FOR LIQUID2 | DIETHER |

** **** PROFILES **** **

<table>
<thead>
<tr>
<th>TEMP-SPEC STAGE 1 TEMP C</th>
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### MASS FLOW PROFILES

<table>
<thead>
<tr>
<th>STAGE</th>
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<th>FEED RATE</th>
<th>PRODUCT RATE</th>
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<tbody>
<tr>
<td></td>
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<td></td>
</tr>
<tr>
<td></td>
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**OUTLET STREAMS:**
- WASTE
- S32

**INLET STREAM:**
- S31

### LIQUID1 PROFILE

<table>
<thead>
<tr>
<th>STAGE</th>
<th>WATER</th>
<th>GLUCOSE</th>
<th>LACTICAC</th>
<th>DIETHER</th>
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<tr>
<td>1</td>
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<td>0.8035E-02</td>
<td>0.9245E+12</td>
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<td>0.3282E+12</td>
</tr>
<tr>
<td>4</td>
<td>0.99301</td>
<td>0.3914E+04</td>
<td>0.4991E-02</td>
<td>0.1610E+12</td>
</tr>
<tr>
<td>5</td>
<td>0.99490</td>
<td>0.3925E+04</td>
<td>0.5065E-02</td>
<td>0.6492E+13</td>
</tr>
</tbody>
</table>

### LIQUID2 PROFILE

<table>
<thead>
<tr>
<th>STAGE</th>
<th>WATER</th>
<th>GLUCOSE</th>
<th>LACTICAC</th>
<th>DIETHER</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.6883E+01</td>
<td>0.3665E+07</td>
<td>0.7202E+00</td>
<td>0.7591E+00</td>
</tr>
<tr>
<td>2</td>
<td>0.6659E+01</td>
<td>0.3571E+07</td>
<td>0.1879E+00</td>
<td>0.7458E+00</td>
</tr>
<tr>
<td>3</td>
<td>0.6319E+01</td>
<td>0.3082E+07</td>
<td>0.1934E+00</td>
<td>0.7432E+00</td>
</tr>
<tr>
<td>4</td>
<td>0.5790E+01</td>
<td>0.2297E+07</td>
<td>0.1780E+00</td>
<td>0.7430E+00</td>
</tr>
<tr>
<td>5</td>
<td>0.5003E+01</td>
<td>0.1355E+07</td>
<td>0.1300E+00</td>
<td>0.8189E+00</td>
</tr>
</tbody>
</table>

### K-VALUES

<table>
<thead>
<tr>
<th>STAGE</th>
<th>WATER</th>
<th>GLUCOSE</th>
<th>LACTICAC</th>
<th>DIETHER</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.6935E+01</td>
<td>0.9942E+03</td>
<td>2.3597E-01</td>
<td>0.8212E+12</td>
</tr>
<tr>
<td>2</td>
<td>0.6703E+01</td>
<td>0.9148E+03</td>
<td>2.0501E-01</td>
<td>0.1310E+13</td>
</tr>
<tr>
<td>3</td>
<td>0.6369E+01</td>
<td>0.7881E+03</td>
<td>2.4684E-01</td>
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<tr>
<td>4</td>
<td>0.5535E+01</td>
<td>0.5865E+03</td>
<td>2.9740E-01</td>
<td>0.4759E+13</td>
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<td>5</td>
<td>0.5029E+01</td>
<td>0.3453E+03</td>
<td>2.7830E-01</td>
<td>0.1262E+14</td>
</tr>
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</table>

### MASS-XI-PROFILE

<table>
<thead>
<tr>
<th>STAGE</th>
<th>WATER</th>
<th>GLUCOSE</th>
<th>LACTICAC</th>
<th>DIETHER</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.96069</td>
<td>0.3796E+03</td>
<td>0.3929E+00</td>
<td>0.8402E+11</td>
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<tr>
<td>2</td>
<td>0.96021</td>
<td>0.3794E+03</td>
<td>0.3941E+00</td>
<td>0.5070E+11</td>
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<tr>
<td>3</td>
<td>0.96163</td>
<td>0.3795E+03</td>
<td>0.3799E+00</td>
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<tr>
<td>4</td>
<td>0.96581</td>
<td>0.3807E+03</td>
<td>0.3305E+00</td>
<td>0.1479E+11</td>
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<tr>
<td>5</td>
<td>0.9740</td>
<td>0.3849E+03</td>
<td>0.2481E+00</td>
<td>0.6009E+12</td>
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</tbody>
</table>

### MASS-X2-PROFILE

<table>
<thead>
<tr>
<th>STAGE</th>
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<th>GLUCOSE</th>
<th>LACTICAC</th>
<th>DIETHER</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.8496E-02</td>
<td>0.4797E-05</td>
<td>0.0661E+00</td>
<td>0.9883E+05</td>
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<tr>
<td>2</td>
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<td>0.4440E-07</td>
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<tr>
<td>3</td>
<td>0.7846E-02</td>
<td>0.3827E-07</td>
<td>0.1207E+00</td>
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<tr>
<td>4</td>
<td>0.7093E-02</td>
<td>0.2815E-07</td>
<td>0.1096E+00</td>
<td>0.8832E+05</td>
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<tr>
<td>5</td>
<td>0.5925E-02</td>
<td>0.1603E-07</td>
<td>0.7733E+00</td>
<td>0.9167E+05</td>
</tr>
</tbody>
</table>

### INPUT DATA

- FLASH SPEC. FOR STREAM WASTE
- TWO PHASE TP FLASH
- PRESSURE DROP ATM
- MAXIMUM NO. ITERATIONS: 30
- CONVERGENCE TOLERANCE: 0.0001

### RESULTS

- NEAT DUTY: 25.895 kW
- COMPONENT: WATER
- STREAM: S32 SPLIT FRACTION
- MIXED: 1.00000

### CO2 EQUIVALENT SUMMARY

<table>
<thead>
<tr>
<th>STREAM</th>
<th>FEED</th>
<th>PRODUCT</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.00000</td>
</tr>
</tbody>
</table>
### CO2 EQUIVALENT SUMMARY

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO2 EQUIVALENT EMISSIONS</td>
<td>337.6993 KG/DAY</td>
</tr>
<tr>
<td>COST</td>
<td>3.1435 $/HR</td>
</tr>
<tr>
<td>RATE OF CONSUMPTION</td>
<td>40.5612 KW</td>
</tr>
<tr>
<td>UTILITY ID FOR ELECTRICITY</td>
<td>ELEC</td>
</tr>
<tr>
<td>PROPERTY OPTION SET</td>
<td>RK</td>
</tr>
<tr>
<td>OUTLET LIQUID STREAM</td>
<td>PLA</td>
</tr>
<tr>
<td>INLET STREAM</td>
<td>S24</td>
</tr>
<tr>
<td>VAPOR FRACTION</td>
<td>0.0000</td>
</tr>
<tr>
<td>HEAT DUTY</td>
<td>170.00</td>
</tr>
<tr>
<td>VAPOR FRACTION</td>
<td>0.0000</td>
</tr>
</tbody>
</table>

### RESULTS

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>OUTLET TEMPERATURE</td>
<td>288.00</td>
</tr>
<tr>
<td>OUTLET PRESSURE</td>
<td>1.0000</td>
</tr>
<tr>
<td>HEAT DUTY</td>
<td>0.83530B-08</td>
</tr>
<tr>
<td>VAPOR FRACTION</td>
<td>0.59944</td>
</tr>
</tbody>
</table>

### CO2 EQUIVALENT SUMMARY

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOTAL CO2 PRODUCTION</td>
<td>786.143 KG/DAY</td>
</tr>
<tr>
<td>UTILITIES CO2 PRODUCTION</td>
<td>0.0000</td>
</tr>
<tr>
<td>NET STREAMS CO2 PRODUCTION</td>
<td>0.0000</td>
</tr>
<tr>
<td>FEED STREAMS CO2</td>
<td>0.0000</td>
</tr>
</tbody>
</table>

### INPUT DATA

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPECIFIED PRESSURE</td>
<td>ATM 1.0000</td>
</tr>
<tr>
<td>MAXIMUM NO. ITERATIONS</td>
<td>30</td>
</tr>
<tr>
<td>CONVERGENCE TOLERANCE</td>
<td>0.0001000000</td>
</tr>
</tbody>
</table>

### RESULTS

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>OUTLET TEMPERATURE</td>
<td>170.00</td>
</tr>
<tr>
<td>OUTLET PRESSURE</td>
<td>1.0000</td>
</tr>
<tr>
<td>HEAT DUTY</td>
<td>94.424</td>
</tr>
<tr>
<td>VAPOR FRACTION</td>
<td>0.0000</td>
</tr>
</tbody>
</table>

### CO2 EQUIVALENT SUMMARY

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOTAL CO2 PRODUCTION</td>
<td>0.00000 KG/DAY</td>
</tr>
</tbody>
</table>

### INPUT DATA

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPECIFIED PRESSURE</td>
<td>ATM 1.0000</td>
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<td>MAXIMUM NO. ITERATIONS</td>
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<tr>
<td>CONVERGENCE TOLERANCE</td>
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### RESULTS

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>OUTLET TEMPERATURE</td>
<td>170.00</td>
</tr>
<tr>
<td>OUTLET PRESSURE</td>
<td>1.0000</td>
</tr>
<tr>
<td>HEAT DUTY</td>
<td>94.424</td>
</tr>
<tr>
<td>VAPOR FRACTION</td>
<td>0.0000</td>
</tr>
</tbody>
</table>

### CO2 EQUIVALENT SUMMARY

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOTAL CO2 PRODUCTION</td>
<td>0.00000 KG/DAY</td>
</tr>
</tbody>
</table>

### INPUT DATA

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPECIFIED PRESSURE</td>
<td>ATM 1.0000</td>
</tr>
<tr>
<td>MAXIMUM NO. ITERATIONS</td>
<td>30</td>
</tr>
<tr>
<td>CONVERGENCE TOLERANCE</td>
<td>0.0001000000</td>
</tr>
</tbody>
</table>

### RESULTS

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>OUTLET TEMPERATURE</td>
<td>170.00</td>
</tr>
<tr>
<td>OUTLET PRESSURE</td>
<td>1.0000</td>
</tr>
<tr>
<td>HEAT DUTY</td>
<td>94.424</td>
</tr>
<tr>
<td>VAPOR FRACTION</td>
<td>0.0000</td>
</tr>
</tbody>
</table>

### CO2 EQUIVALENT SUMMARY

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOTAL CO2 PRODUCTION</td>
<td>0.00000 KG/DAY</td>
</tr>
</tbody>
</table>

**V-L PHASE EQUILIBRIUM:**

### RESULTS

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>OUTLET TEMPERATURE</td>
<td>170.00</td>
</tr>
<tr>
<td>OUTLET PRESSURE</td>
<td>1.0000</td>
</tr>
<tr>
<td>HEAT DUTY</td>
<td>94.424</td>
</tr>
<tr>
<td>VAPOR FRACTION</td>
<td>0.0000</td>
</tr>
</tbody>
</table>

### CO2 EQUIVALENT SUMMARY

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOTAL CO2 PRODUCTION</td>
<td>0.00000 KG/DAY</td>
</tr>
</tbody>
</table>

**V-L PHASE EQUILIBRIUM:**

### RESULTS

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>OUTLET TEMPERATURE</td>
<td>170.00</td>
</tr>
<tr>
<td>OUTLET PRESSURE</td>
<td>1.0000</td>
</tr>
<tr>
<td>HEAT DUTY</td>
<td>94.424</td>
</tr>
<tr>
<td>VAPOR FRACTION</td>
<td>0.0000</td>
</tr>
</tbody>
</table>

### CO2 EQUIVALENT SUMMARY

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOTAL CO2 PRODUCTION</td>
<td>0.00000 KG/DAY</td>
</tr>
</tbody>
</table>
### Block: POLYREAC Model: RSTOIC

- **Carbon Equivalent Emissions:** 786.1430 kg/day
- **Cost of Consumption:** 94.4240 kW
- **Utility ID for Electricity:** ELEC

#### Reaction Extents:
- **Vapor Fraction:** 0.32022
- **Heat Duty:** 816.75 kW
- **Outlet Pressure:** 1.0000 ATM
- **Outlet Temperature:** 170.00 °C
- **Vapor Fraction:** 0.32922

### Block: POLYREAC Model: RK

#### Mass and Energy Balance:
- **Enthalpy (KW):**
  - Mol/HR: 105620.0
  - Mass (KG/DAY): 105620.0
  - Mole (MOL/HR): 29109.6, 29115.2, 5.60316

#### Property Option Set:
- **RK**

### Block: PSPLIT Model: FSPLIT

- **Outlet Stream:** PROD
- **Outlet Streams:** S9, S12
- **Inlet Stream:** S4

#### Mass and Energy Balance:
- **Enthalpy (KW):**
  - Mol/HR: 105620.0
  - Mass (KG/DAY): 105620.0
  - Mole (MOL/HR): 0.106808E+07, 0.112766E+07, 59587.4

#### Property Option Set:
- **RK**

### Block: HYDRO Model: RYIELD

- **Outlet Stream:** WETBSG S11
- **Outlet Stream:** PROD-H
- **Property Option Set:** RK-ASPEN REDLICH-KWONG-ASPEN EQUATION OF STATE

### Summary:

- **CO2 Equivalent Emission:**
  - **Generation:** 0.00000 kg/day
  - **Utilities:** 0.00000 kg/day
  - **Net Streams:** 0.00000 kg/day
  - **Product Streams:** 0.00000 kg/day
  - **Feed Streams:** 0.00000 kg/day

---

**Note:** The above text contains a mix of chemical and process engineering terms, which are crucial for understanding the operations of the POLYREAC and PSPLIT models. Each block represents different processes, such as reaction extents, mass and energy balances, and utility costs, which are essential for the overall operation and optimization of the chemical processes.
SACCH: MODEL: RYIELD

**CO2 EQUIVALENT SUMMARY**

<table>
<thead>
<tr>
<th>Mass (kg/day)</th>
<th>0.00000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mole (mol/hr)</td>
<td>0.00000</td>
</tr>
<tr>
<td>Total CO2 Production</td>
<td>0.00000</td>
</tr>
</tbody>
</table>

**INPUT DATA**

Two Phase TP Flash

- Specified Temperature: 25.0000
- Specified Pressure: 1.0000
- Maximum No. Iterations: 30
- Convergence Tolerance: 0.00010000

 MASS-YIELD

- Substream Mixed:
  - OTHLIQUI: 0.481
  - OTHSOLID: 0.63000

INERTS:

- WATER: 0.209
- H2SO4: 0.247

**RESULTS**

- Outlet Temperature: 150.00
- Outlet Pressure: 1.0000
- Heat Duty: 508.70
- Vapor Fraction: 0.11530

**CO2 EQUIVALENT SUMMARY**

- Feed Streams CO2: 0.00000 kg/day
- Product Streams CO2: 0.00000 kg/day
- Net Streams CO2 Production: 0.00000 kg/day
- Utilities CO2 Production: 0.00000 kg/day
- Total CO2 Production: 0.00000 kg/day

**INPUT DATA**

- Two Phase TP Flash
- Specified Temperature: 25.0000
- Specified Pressure: 1.0000
- Maximum No. Iterations: 30
- Convergence Tolerance: 0.00010000

**RESULTS**

- Outlet Temperature: 25.00
- Outlet Pressure: 1.0000
- Heat Duty: 508.70
- Vapor Fraction: 0.11531

**CO2 EQUIVALENT SUMMARY**

- Feed Streams CO2: 0.00000 kg/day
- Product Streams CO2: 0.00000 kg/day
- Net Streams CO2 Production: 0.00000 kg/day
- Utilities CO2 Production: 0.00000 kg/day
- Total CO2 Production: 0.00000 kg/day

**INPUT DATA**

- Two Phase TP Flash
- Specified Temperature: 25.0000
- Specified Pressure: 1.0000
- Maximum No. Iterations: 30
- Convergence Tolerance: 0.00010000

**RESULTS**

- Outlet Temperature: 25.00
- Outlet Pressure: 1.0000
- Heat Duty: 508.70
- Vapor Fraction: 0.11531

**CO2 EQUIVALENT SUMMARY**

- Feed Streams CO2: 0.00000 kg/day
- Product Streams CO2: 0.00000 kg/day
- Net Streams CO2 Production: 0.00000 kg/day
- Utilities CO2 Production: 0.00000 kg/day
- Total CO2 Production: 0.00000 kg/day

**INPUT DATA**

- Two Phase TP Flash
- Specified Temperature: 25.0000
- Specified Pressure: 1.0000
- Maximum No. Iterations: 30
- Convergence Tolerance: 0.00010000

**RESULTS**

- Outlet Temperature: 25.00
- Outlet Pressure: 1.0000
- Heat Duty: 508.70
- Vapor Fraction: 0.11531

**CO2 EQUIVALENT SUMMARY**

- Feed Streams CO2: 0.00000 kg/day
- Product Streams CO2: 0.00000 kg/day
- Net Streams CO2 Production: 0.00000 kg/day
- Utilities CO2 Production: 0.00000 kg/day
- Total CO2 Production: 0.00000 kg/day

**INPUT DATA**

- Two Phase TP Flash
- Specified Temperature: 25.0000
- Specified Pressure: 1.0000
- Maximum No. Iterations: 30
- Convergence Tolerance: 0.00010000

**RESULTS**

- Outlet Temperature: 25.00
- Outlet Pressure: 1.0000
- Heat Duty: 508.70
- Vapor Fraction: 0.11531

**CO2 EQUIVALENT SUMMARY**

- Feed Streams CO2: 0.00000 kg/day
- Product Streams CO2: 0.00000 kg/day
- Net Streams CO2 Production: 0.00000 kg/day
- Utilities CO2 Production: 0.00000 kg/day
- Total CO2 Production: 0.00000 kg/day

**INPUT DATA**

- Two Phase TP Flash
- Specified Temperature: 25.0000
- Specified Pressure: 1.0000
- Maximum No. Iterations: 30
- Convergence Tolerance: 0.00010000

**RESULTS**

- Outlet Temperature: 25.00
- Outlet Pressure: 1.0000
- Heat Duty: 508.70
- Vapor Fraction: 0.11531

**CO2 EQUIVALENT SUMMARY**

- Feed Streams CO2: 0.00000 kg/day
- Product Streams CO2: 0.00000 kg/day
- Net Streams CO2 Production: 0.00000 kg/day
- Utilities CO2 Production: 0.00000 kg/day
- Total CO2 Production: 0.00000 kg/day

**INPUT DATA**

- Two Phase TP Flash
- Specified Temperature: 25.0000
- Specified Pressure: 1.0000
- Maximum No. Iterations: 30
- Convergence Tolerance: 0.00010000

**RESULTS**

- Outlet Temperature: 25.00
- Outlet Pressure: 1.0000
- Heat Duty: 508.70
- Vapor Fraction: 0.11531

**CO2 EQUIVALENT SUMMARY**

- Feed Streams CO2: 0.00000 kg/day
- Product Streams CO2: 0.00000 kg/day
- Net Streams CO2 Production: 0.00000 kg/day
- Utilities CO2 Production: 0.00000 kg/day
- Total CO2 Production: 0.00000 kg/day

**INPUT DATA**

- Two Phase TP Flash
- Specified Temperature: 25.0000
- Specified Pressure: 1.0000
- Maximum No. Iterations: 30
- Convergence Tolerance: 0.00010000

**RESULTS**

- Outlet Temperature: 25.00
- Outlet Pressure: 1.0000
- Heat Duty: 508.70
- Vapor Fraction: 0.11531

**CO2 EQUIVALENT SUMMARY**

- Feed Streams CO2: 0.00000 kg/day
- Product Streams CO2: 0.00000 kg/day
- Net Streams CO2 Production: 0.00000 kg/day
- Utilities CO2 Production: 0.00000 kg/day
- Total CO2 Production: 0.00000 kg/day

**INPUT DATA**

- Two Phase TP Flash
- Specified Temperature: 25.0000
- Specified Pressure: 1.0000
- Maximum No. Iterations: 30
- Convergence Tolerance: 0.00010000

**RESULTS**

- Outlet Temperature: 25.00
- Outlet Pressure: 1.0000
- Heat Duty: 508.70
- Vapor Fraction: 0.11531
**CO2 EQUIVALENT SUMMARY ***

*** INPUT DATA ***

**CO2 EQUIVALENT SUMMARY ***

** INPUT DATA ***

** RESULTS ***

** BLOCK: WASH2 MODEL: MIXER **

** BLOCK: WASH3 MODEL: MIXER **

** BLOCK: WASH MODEL: MIXER **

** INPUT DATA ***
Utility Report

Utility Usage: Air (General)

Input Data:
- Inlet Temperature: 30.0000 C
- Outlet Temperature: 35.0000 C
- Heat Transfer Coefficient: 2.6512E-03 CAL/SEC-SQCM-K
- Cooling Value: 5000.0000 J/KG
- Price: 0.0 $/CAL

Result:
- Cooling Value: 5000.0000 J/KG
- Indexed Price: 0.0 $/CAL

This utility is purchased

Usage:

<table>
<thead>
<tr>
<th>Block ID</th>
<th>Model</th>
<th>Duty</th>
<th>Usage Rate</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>ETHFlash</td>
<td>FLASH2</td>
<td>27.7031</td>
<td>4.7871E+05</td>
<td>0.0</td>
</tr>
</tbody>
</table>

Total: 27.7031 4.7871E+05 0.0

Utility Usage: CoolingW (Water)

Input Data:
- Inlet Temperature: 20.0000 C
- Outlet Temperature: 25.0000 C
- Inlet Pressure: 1.0000 ATM
- Outlet Pressure: 1.0000 ATM
- Heat Transfer Coefficient: 8.9567E-02 CAL/SEC-SQCM-K
- Cooling Value: 8.8760-10 J/KG
- Price: 8.8760-10 $/CAL

Result:
- Cooling Value: 2.0876E+04 J/KG
- Indexed Price: 8.8760-10 $/CAL

This utility is purchased

Usage:

- Inlet Temperature: 30.0000 C
- Outlet Temperature: 35.0000 C
- Heat Transfer Coefficient: 2.6512E-03 CAL/SEC-SQCM-K
- Cooling Value: 5000.0000 J/KG
- Price: 0.0 $/CAL

Utility Usage: Associated Utilities

- Utility ID for Electricity: ELECTRIC
  - Rate of Consumption: 9.5405 KW
  - Cost: 0.6650 $/HR
  - CO2 Equivalent Emissions: 71.4381 KG/DAY

Inlet Stream: S23
Outlet Stream: 3
Property Option Set: RK-ASPN REDLICH-KWONG-ASPN EQUATION OF STATE

Mass and Energy Balance

| IN          | OUT       | Generation | Relative Diff. |
|-------------|-----------|------------|----------------|----------------|
| TOTAL BALANCE | MOLE(MOL/HR ) | 368101.       369331.       1229.13 | -0.315206E-15 |
| MASS(KG/DAY ) | 175104.       175104.                     0.00000     |
| ENTHALPY(KW ) | -30424.4 | -30418.2 | -0.203185E-03 |

CO2 Equivalent Summary

- Feed Streams CO2E: 0.00000 KG/DAY
- Product Streams CO2E: 0.00000 KG/DAY
- Net Streams CO2E Production: 0.00000 KG/DAY
- Utilities CO2E Production: 0.00000 KG/DAY
- Total CO2E Production: 0.00000 KG/DAY

Results

- Outlet Temperature: 32.000 C
- Outlet Pressure: 1.0000 ATM
- Heat Duty: 6.1818 KW
- Vapor Fraction: 0.0000

V-L Phase Equilibrium

- COMP: F(I) X(I) Y(I) X(I)
- WATER: 0.81774 0.81774 0.84177 0.36429E-01
- XYLOX: 0.13233E-02 0.13233E-02 0.10967E-08 0.29393E-07
- OTHLIQUI: 0.16786 0.16786 0.15786 0.33278E-01
- OTHLIQUI: 0.44383E-02 0.44383E-02 0.36749E-03 0.29303E-02
- ENZ/XYL: 0.86166E-02 0.86166E-02 0.21456E-07 0.89122E-07

Utility Report

Utility Usage: Air (General)

Input Data:
- Inlet Temperature: 30.0000 C
- Outlet Temperature: 35.0000 C
- Heat Transfer Coefficient: 2.6512-03 CAL/SEC-SQCM-K
- Cooling Value: 5000.0000 J/KG
- Price: 0.0 $/CAL

Result:
- Cooling Value: 5000.0000 J/KG
- Indexed Price: 0.0 $/CAL

This utility is purchased

Usage:

<table>
<thead>
<tr>
<th>Block ID</th>
<th>Model</th>
<th>Duty</th>
<th>Usage Rate</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>ETHFLASH</td>
<td>FLASH2</td>
<td>27.7031</td>
<td>4.7871E+05</td>
<td>0.0</td>
</tr>
</tbody>
</table>

Total: 27.7031 4.7871E+05 0.0

Utility Usage: CoolingW (Water)

Input Data:
- Inlet Temperature: 20.0000 C
- Outlet Temperature: 25.0000 C
- Inlet Pressure: 1.0000 ATM
- Outlet Pressure: 1.0000 ATM
- Heat Transfer Coefficient: 8.9567E-02 CAL/SEC-SQCM-K
- Cooling Value: 8.8760-10 J/KG
- Price: 8.8760-10 $/CAL

Result:
- Cooling Value: 2.0876E+04 J/KG
- Indexed Price: 8.8760-10 $/CAL

This utility is purchased

Usage:
### High Pressure Steam, Inlet Temp=250 C, Outlet Temp=249 C, Pres=572 psia

**INPUT DATA:**
- Inlet Temperature: 250,000 C
- Outlet Temperature: 249,000 C
- Inlet Vapor Fraction: 1.0
- Outlet Vapor Fraction: 0.0
- Heat Transfer Coefficient: 0.1433 Cal/sec-Sqcm-K
- CO2 Data Source: US-EPA-Rule-E9-5711
- CO2 Fuel Source: Natural Gas
- CO2 Emission Factor: 2.3400
- Total CO2 Emissions: 4640.0210 KG/DAY

**RESULT:**
- Heating Value: 6.0000+05 J/KG
- Indexed Price: 1.7794+08 $/Cal
- CO2 Emission Factor: 2.3400
- Total CO2 Emissions: 459.6242 KG/DAY

---

### High Pressure Steam, Inlet Temp=250 C, Outlet Temp=249 C, Pres=572 psia

**INPUT DATA:**
- Inlet Temperature: 250,000 C
- Outlet Temperature: 249,000 C
- Inlet Vapor Fraction: 1.0
- Outlet Vapor Fraction: 0.0
- Heat Transfer Coefficient: 0.1433 Cal/sec-Sqcm-K
- CO2 Data Source: US-EPA-Rule-E9-5711
- CO2 Fuel Source: Natural Gas
- CO2 Emission Factor: 2.3400
- Total CO2 Emissions: 459.6242 KG/DAY

**RESULT:**
- Heating Value: 6.0000+05 J/KG
- Indexed Price: 1.7794+08 $/Cal
- CO2 Emission Factor: 2.3400
- Total CO2 Emissions: 459.6242 KG/DAY

---

### Fired Heater, Inlet Temp=1000 C, Outlet Temp=400 C

**INPUT DATA:**
- Inlet Temperature: 1000.0000 C
- Outlet Temperature: 400.0000 C
- Heat Transfer Coefficient: 2.6512+03 Cal/sec-Sqcm-K
- CO2 Data Source: US-EPA-Rule-E9-5711
- CO2 Fuel Source: Natural Gas
- CO2 Emission Factor: 2.3400
- Thermal Efficiency: 0.8500

**RESULT:**
- Heating Value: 1.7794+08 $/Cal

---

### Utility Usage: Furnace (General)

**INPUT DATA:**
- Inlet Temperature: 250,000 C
- Outlet Temperature: 249,000 C
- Inlet Vapor Fraction: 1.0
- Outlet Vapor Fraction: 0.0
- Heat Transfer Coefficient: 0.1433 Cal/sec-Sqcm-K
- CO2 Data Source: US-EPA-Rule-E9-5711
- CO2 Fuel Source: Natural Gas
- CO2 Emission Factor: 2.3400
- Total CO2 Emissions: 459.6242 KG/DAY

**RESULT:**
- Heating Value: 1.7794+08 $/Cal

---

### Utility Usage: Electric (Elec)

**INPUT DATA:**
- Emission Sources
  - CO2 Data Source: US-EPA-Rule-E9-5711
  - CO2 Fuel Source: Natural Gas
  - CO2 Emission Factor: 2.3400
  - Total CO2 Emissions: 1.1319+04 KG/DAY

**RESULT:**
- Index Price: 7.7500-02 $/Kwhr
- Total CO2 Emissions: 6369.7795 KG/DAY

---

### Utility Usage: HP Steam (Steam)

**INPUT DATA:**
- Inlet Temperature: 250.000 C
- Outlet Temperature: 249.000 C
- Inlet Vapor Fraction: 1.0
- Outlet Vapor Fraction: 0.0
- Heat Transfer Coefficient: 0.1433 Cal/sec-Sqcm-K
- CO2 Data Source: US-EPA-Rule-E9-5711
- CO2 Fuel Source: Natural Gas
- CO2 Emission Factor: 2.3400
- Total CO2 Emissions: 459.6242 KG/DAY

**RESULT:**
- Heating Value: 1.7193+06 J/KG
- Indexed Price: 1.0467+08 $/Cal
- Total CO2 Emissions: 459.6242 KG/DAY

---

### Utility Usage: Furnace (General)

**INPUT DATA:**
- Inlet Temperature: 1000.0000 C
- Outlet Temperature: 400.0000 C
- Heat Transfer Coefficient: 2.6512+03 Cal/sec-Sqcm-K
- CO2 Data Source: US-EPA-Rule-E9-5711
- CO2 Fuel Source: Natural Gas
- CO2 Emission Factor: 2.3400
- Thermal Efficiency: 0.8500

**RESULT:**
- Heating Value: 6.0000+05 J/KG
- Indexed Price: 1.7794+08 $/Cal

---

### Utility Usage: Furnace (General)

**INPUT DATA:**
- Inlet Temperature: 1000.0000 C
- Outlet Temperature: 400.0000 C
- Heat Transfer Coefficient: 2.6512+03 Cal/sec-Sqcm-K
- CO2 Data Source: US-EPA-Rule-E9-5711
- CO2 Fuel Source: Natural Gas
- CO2 Emission Factor: 2.3400
- Thermal Efficiency: 0.8500

**RESULT:**
- Heating Value: 1.7794+08 $/Cal

OUTLET TEMPERATURE                  174.0000  C
INLET TEMPERATURE                  175.0000  C
TOTAL CO2 EMISSIONS               744.8885  KG/DAY
CO2 EMISSION FACTOR               2.3400
INDEXED PRICE                     9.2110
HEATING VALUE                     2.0348-06  J/KG
INDEX TYPE                             FUEL
RESULT:
CO2 EMISSION FACTOR               2.3400
CO2 FUEL SOURCE                         NATURAL_GAS
CO2 DATA SOURCE                         US
HEAT TRANSFER COEFFICIENT            0.1433  CAL/SEC-SQCM-K
OUTLET VAPOR FRACTION                0.5000
INLET VAPOR FRACTION                 1.0000

-------------------
TOTAL:         131.1182         5567.5632            1.0385

744.8885567.56321.0385
-------------------

OUTLET TEMPERATURE                  174.0000  C
INLET TEMPERATURE                  175.0000  C
TOTAL CO2 EMISSIONS               744.8885  KG/DAY
CO2 EMISSION FACTOR               2.3400
INDEXED PRICE                     9.2110
HEATING VALUE                     2.0348-06  J/KG
INDEX TYPE                             FUEL
RESULT:
CO2 EMISSION FACTOR               2.3400
CO2 FUEL SOURCE                         NATURAL_GAS
CO2 DATA SOURCE                         US
HEAT TRANSFER COEFFICIENT            0.1433  CAL/SEC-SQCM-K
OUTLET VAPOR FRACTION                0.0
INLET VAPOR FRACTION                 1.0000

-------------------
TOTAL:         131.1182         5567.5632            1.0385

744.8885567.56321.0385
-------------------

UTILITY USAGE:  NONCONDS  (STEAM)
THIS UTILITY IS PURCHASED
USAGE:
RESULT:
HEATING VALUE                     2.0348-06  J/KG
INDEXED PRICE                     9.2110-09 $/CAL
CO2 EMISSION FACTOR               2.3400-07 KG/CAL
TOTAL CO2 EMISSIONS               744.8885  KG/DAY
CO2 FUEL SOURCE                         NATURAL_GAS
CO2 DATA SOURCE                         US
HEAT TRANSFER COEFFICIENT            0.1433  CAL/SEC-SQCM-K
OUTLET VAPOR FRACTION                0.0
INLET VAPOR FRACTION                 1.0000

-------------------
TOTAL:         131.1182         5567.5632            1.0385

744.8885567.56321.0385
-------------------

UTILITY USAGE:  NONCONDS  (STEAM)
THIS UTILITY IS PURCHASED
USAGE:
RESULT:
HEATING VALUE                     2.0348-06  J/KG
INDEXED PRICE                     9.2110-09 $/CAL
CO2 EMISSION FACTOR               2.3400-07 KG/CAL
TOTAL CO2 EMISSIONS               744.8885  KG/DAY
CO2 FUEL SOURCE                         NATURAL_GAS
CO2 DATA SOURCE                         US
HEAT TRANSFER COEFFICIENT            0.1433  CAL/SEC-SQCM-K
OUTLET VAPOR FRACTION                0.0
INLET VAPOR FRACTION                 1.0000

-------------------
TOTAL:         131.1182         5567.5632            1.0385

744.8885567.56321.0385
-------------------
<table>
<thead>
<tr>
<th>BLOCK ID</th>
<th>MODEL</th>
<th>DUTY</th>
<th>USAGE RATE</th>
<th>COST</th>
<th>CO2E</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>POLYHEAT HEATER</td>
<td>94.4269</td>
<td>7534.8920</td>
<td>0.7479</td>
<td></td>
</tr>
<tr>
<td></td>
<td>TOTAL:</td>
<td>94.4269</td>
<td>7534.8920</td>
<td>0.7479</td>
<td></td>
</tr>
</tbody>
</table>

UTILITY USAGE: REFRIDGE (REFRIGERANT)

REFRIGERANT 1, INLET TEMP=-25 C, OUTLET TEMP=-24 C

INPUT DATA:

- INLET TEMPERATURE: -25.0000 C
- OUTLET TEMPERATURE: -24.0000 C
- HEAT TRANSFER COEFFICIENT: 3.1050-02 CAL/SEC-SQCM-K
- CO2 FUEL SOURCE: NATURAL_GAS
- CO2 EMISSION FACTOR: 2.3400-07 KG/CAL
- THERMAL EFFICIENCY: 1.0000
- COOLING VALUE: 4000.0000 J/KG
- PRICE: 1.1472-08 $/CAL
- INDEX TYPE: FUEL

RESULT:

- COOLING VALUE: 4000.0000 J/KG
- INDEXED PRICE: 1.1472-08 $/CAL
- CO2 EMISSION FACTOR: 2.3400-07 KG/CAL
- TOTAL CO2 EMISSIONS: 179.5814 KG/DAY

THIS UTILITY IS PURCHASED

USAGE:

<table>
<thead>
<tr>
<th>BLOCK ID</th>
<th>MODEL</th>
<th>DUTY</th>
<th>USAGE RATE</th>
<th>COST</th>
<th>CO2E</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>COOL2 HEATER</td>
<td>37.1890</td>
<td>8.0328E+05</td>
<td>0.3668</td>
<td></td>
</tr>
<tr>
<td></td>
<td>TOTAL:</td>
<td>37.1890</td>
<td>8.0328E+05</td>
<td>0.3668</td>
<td></td>
</tr>
</tbody>
</table>

Prices include a 6.60% utility fee.
Appendix A4 – Aspen Process Flowsheet
Appendix A5 – Xylitol Quality Sheet

### Specifications and Quality Standards of Xylitol

<table>
<thead>
<tr>
<th>Identification \ Grade</th>
<th>FCC</th>
<th>USP</th>
<th>JP</th>
<th>BP/EP</th>
<th>E967</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assay</td>
<td><strong>%</strong></td>
<td>98.5-101.0</td>
<td>98.5-101.0</td>
<td>≥98.0</td>
<td>98.0-102.0</td>
</tr>
<tr>
<td>Other Polyols</td>
<td><strong>%</strong></td>
<td>≤1.0</td>
<td>≤2.0</td>
<td>-</td>
<td>≤2.0 (Related Substances)</td>
</tr>
<tr>
<td>Loss, on Drying</td>
<td><strong>%</strong></td>
<td>≤0.5 (Water)</td>
<td>≤0.5 (Water)</td>
<td>≤1.0</td>
<td>≤1.0 (Water)</td>
</tr>
<tr>
<td>Residue on Ignition</td>
<td><strong>%</strong></td>
<td>≤0.1</td>
<td>≤0.5</td>
<td>≤0.1</td>
<td>-</td>
</tr>
<tr>
<td>Reducing Sugar</td>
<td><strong>%</strong></td>
<td>≤0.3</td>
<td>≤0.2</td>
<td>To pass test (Sugar)</td>
<td>≤0.2</td>
</tr>
<tr>
<td>Heavy Metals (as Pb)</td>
<td><strong>%</strong></td>
<td>-</td>
<td>≤0.001</td>
<td>≤0.0005</td>
<td>-</td>
</tr>
<tr>
<td>Nickel</td>
<td><strong>%</strong></td>
<td>≤0.0001</td>
<td>-</td>
<td>To pass test</td>
<td>≤0.0001</td>
</tr>
<tr>
<td>Lead</td>
<td><strong>%</strong></td>
<td>≤0.0001</td>
<td>-</td>
<td>-</td>
<td>≤0.00005</td>
</tr>
<tr>
<td>Acidity or Alkalinity</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>pH</td>
<td>-</td>
<td>-</td>
<td>5.0-7.0</td>
<td>-</td>
<td>5.0-7.0</td>
</tr>
<tr>
<td>Sulfate (as SO4)</td>
<td><strong>%</strong></td>
<td>-</td>
<td>-</td>
<td>≤0.008</td>
<td>-</td>
</tr>
<tr>
<td>Chloride</td>
<td><strong>%</strong></td>
<td>-</td>
<td>-</td>
<td>≤0.005</td>
<td>-</td>
</tr>
<tr>
<td>Arsenic (as As2O3)</td>
<td><strong>%</strong></td>
<td>-</td>
<td>-</td>
<td>≤0.00013</td>
<td>-</td>
</tr>
<tr>
<td>Melting Range °C</td>
<td>-</td>
<td>-</td>
<td>93.0-95.0</td>
<td>92-96</td>
<td>92-96</td>
</tr>
<tr>
<td>Conductivity (μS/cm)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>&gt;20</td>
<td>-</td>
</tr>
<tr>
<td>Identification Test</td>
<td>To pass test</td>
<td>To pass test</td>
<td>To pass test</td>
<td>Pass A, B and C</td>
<td>-</td>
</tr>
<tr>
<td>Bacterial Endotoxins</td>
<td>IU/g</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>≤2,5IU(s≤100g/l)</td>
</tr>
<tr>
<td>Bacterial and Fungi</td>
<td>CFU/g</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Escherichia Coli</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Salmonella</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Organic Volatile Impurities</td>
<td>-</td>
<td>Meets the requirement</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Residual solvents</td>
<td>-</td>
<td>Meets the requirement</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Consult Standard</td>
<td>FCC V</td>
<td>USP29</td>
<td>JP X IV</td>
<td>BP2005 / EP5</td>
<td>E967</td>
</tr>
</tbody>
</table>

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Email: trace@huachem.com
P.C.: 310013
Fax: 86-571-85812010
http: // www.huachem.com
Appendix A6 – Sample Equations

I. Physical and Chemical Equations

1. pH Calculation

\[
pH = \log \left( \frac{\text{mol } H^+ \text{ released}}{\text{mol acid added}} \times \frac{\text{mol acid}}{L} \right)
\]

\[
pH = \log \left( \frac{2 \text{ mol } H^+}{\text{mol sulfuric acid}} \times .211M \text{ sulfuric acid} \right)
\]

\[= 0.37 \]

2. Fermentation Kinetic Equations

A. Solute Concentration (when desired input solute concentration known)

\[S = S_i \times \frac{X}{Y_{X/S}}\]

\[S = 80 \frac{g \text{ xylose}}{L} \times \frac{14 g \text{ cells}}{L} \times \frac{0.34 g \text{ cells}}{g \text{ xylose consumed}}
\]

\[= 38.82 \frac{g \text{ xylose}}{L} \]

B. Input Solute Concentration (when desired solute concentration known)

\[S_i = S + \frac{X}{Y_{X/S}}\]

\[S_i = 5 \frac{g \text{ glucose}}{L} + \frac{2 g \text{ cells}}{L} \times \frac{0.05 g \text{ cells}}{g \text{ glucose consumed}}
\]

\[= 8.39 \frac{g \text{ glucose}}{L} \]

C. \(D_{opt}\)

\[D_{opt} = \mu_{max} (1 - \frac{K_S}{K_S + S})\]

\[D_{opt} = 0.18 \text{ hr}^{-1} \left(1 - \frac{13.11}{13.11 + 5.0} \right) = 0.10 \text{ hr}^{-1} \]

D. Heat of Fermentation

\[Q_{GR} = \mu \times \frac{X}{Y_{H}} \times V\]

\[Q_{GR} = (0.18 \text{ hr}^{-1}) \times \left(2 \frac{g \text{ cells}}{L} \right) \times (23 \, 050 \text{ kJ/g cell}) \times (76.3 \, 300 \text{ L})
\]

\[= 6.43 \times 10^6 \text{ kJ/h} \]

E. Product Concentration

\[P = \frac{q_p \times X}{D} \]
II. Financial Equations

1. Return on Investment

\[ ROI = \frac{Net\ Earnings}{Total\ Capital\ Investment} \times 100 \]

\[ ROI = \frac{\$10,790,200}{\$42,378,200} \times 100 = 25.5\% \]

2. Internal Rate of Return

\[ IRR = \sum_{n=0}^{N} \frac{C_n}{(1+r)^n} \times 100 = 3.09\% \]

Where \( C_n \) is the cash flow at year \( N \), and \( r \) is the calculated IRR.