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Cocoa Liquor, Butter, & Powder Production

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Abstract
This project recommends a design for a cocoa processing plant to produce cocoa liquor, powder, and butter from fermented cocoa beans, in accordance with US Patent 6,066,350. The recommended design minimizes the use of external utilities by optimizing various heat integration strategies. The plant has a capacity of 120,000 tonnes/year and will be located in Tema, Ghana. The proposed design yields 25,000 tonnes/year of alkalized cocoa liquor with 54% fat, 52,000 tonnes/year of cocoa butter, 36,000 tonnes/year of 3% fat alkalized cocoa powder, and 9,000 tonnes/year of below 0.5% fat alkalized cocoa powder. The cocoa butter and powders made in this process are of Food Grade quality and are compliant with FDA regulations, and have less than 1 PPM residual solvent concentrations. A total permanent investment of $19M is required. Despite this, the process has an estimated IRR of 33.5% and an NPV of $29M. It is recommended that the company bring this plant into operation and commence additional research, with emphasis in the cocoa powder market, and the effectiveness of solvent extraction and removal.

Disciplines
Biochemical and Biomolecular Engineering | Chemical Engineering | Engineering

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Department of Chemical and Biomolecular Engineering
220 South 33rd Street
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April 12, 2016

Dear Dr. Holleran, Professor Fabiano, and Mr. Tieri,

Enclosed you will find a proposed design for the cocoa processing facility, specified in the problem statement provided by Mr. Stephen M. Tieri of DuPont. The proposed plant is for the industrial production of 120,000 tonnes/year of food-grade cocoa liquor, butter, and powder from fermented cocoa beans in Tema, Ghana. The overall process produces 25,000 tonnes/year of cocoa liquor, 52,000 tonnes/year of cocoa butter, 36,000 tonnes/year of low-fat cocoa powder, and 9,000 tonnes/year fat-free cocoa powder. The process implements solvent extraction technology as specified by U.S. Patent 6,610,343 issued to Cargill, Inc in 2003. Fermented cocoa beans are cleaned in a series of mechanical cleaners and a de-stoner. The beans are then processed via roasting, sterilizing, and de-shelling. The prepared nibs are ground into cocoa liquor, which is further treated with solvent to de-fat the cocoa powder. The cocoa powder and butter products are taken through flash and steam stripping towers to remove residual solvent.

This report contains a detailed process design and profitability analysis of the proposed plant. The calculations and sensitivity analyses that led to critical design decisions for the processes in this plant are included. Production was assumed to be 24 hours a day for 292 days a year.

Rigorous profitability analysis was performed to determine plant feasibility. The proposed plant is found to be economically feasible. The total permanent investment of the plant is $19M, and the expected NPV is $29M by 2033. It has an estimated IRR of 33.5% and the ROI is 33.7%. It is recommended to pursue plant production using the outlined process design, but continue to research the solvent extraction performance.

Sincerely,

Mack Asselstine	Joseph Mollo
___________________	___________________
Jesus Morales	Vasiliki Papanikolopoulos
___________________	___________________

Cocoa Liquor, Butter, & Powder Production

Mack Asselstine | Joe Mollo | Jesus Morales | Vasiliki Papanikolopoulos

Project submitted to: Dr. Sean Holleran
Prof. Leonard Fabiano

Project proposed by: Mr. Stephen Tieri

Department of Chemical and Biomolecular Engineering
School of Engineering and Applied Science
University of Pennsylvania
April 12, 2016

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Section 1: Abstract

This project recommends a design for a cocoa processing plant to produce cocoa liquor, powder, and butter from fermented cocoa beans, in accordance with US Patent 6,066,350. The recommended design minimizes the use of external utilities by optimizing various heat integration strategies. The plant has a capacity of 120,000 tonnes/year and will be located in Tema, Ghana. The proposed design yields 25,000 tonnes/year of alkalized cocoa liquor with 54% fat, 52,000 tonnes/year of cocoa butter, 36,000 tonnes/year of 3% fat alkalized cocoa powder, and 9,000 tonnes/year of below 0.5% fat alkalized cocoa powder. The cocoa butter and powders made in this process are of Food Grade quality and are compliant with FDA regulations, and have less than 1 PPM residual solvent concentrations. A total permanent investment of $19M is required. Despite this, the process has an estimated IRR of 33.5% and an NPV of $29M. It is recommended that the company bring this plant into operation and commence additional research, with emphasis in the cocoa powder market, and the effectiveness of solvent extraction and removal.

Section 2: Introduction and Background Information

2.1 Introduction

Cocoa powder and butter are traditionally produced by mechanically pressing cocoa liquor. This method of producing cocoa powder has numerous disadvantages, including long processing times and increased operating costs to reduce powder fat contents to 20% or lower. Low fat and fat-free cocoa powders, defined as having 3-5% and 0.5% fat by weight, are not feasible with batch pressing because the lower limit of extraction is 10-11%. In 2003, Cargill patented a process to extract cocoa butter from liquor using solvent extraction. The process uses a low molecular weight straight-chained alkane as the solvent. Cargill's solvent extraction process may be run continuously, eliminating long press times, and is able to produce low fat and fat-free cocoa powders (Purtle et al, 2003).

This project proposes a cocoa processing plant to produce solvent-extracted low fat and fat-free cocoa powder varieties using butane. Despite its flammability, the major advantage to using butane is that it is highly miscible in cocoa butter due its hydrocarbon properties. The price for butane is also expected to remain steady, and this makes it a suitable solvent for the proposed process.

The process begins with a traditional cocoa processing section, consisting of industrial scale cleaning and destoning units, roasters, winnowers, and alkalizing units. Cocoa beans from the Forastero trees in West Africa were used as they are the most common for large-scale processing ("Growing Cocoa", 2013). The process is run continuously over the course of the year and beans are assumed to be available year-round, sourced from a licensed buying company. A detailed justification for this assumption is found in Section 10.1.

To achieve the desired product requirements, a separation section is needed following traditional processing. Separation operations include centrifugation, evaporation, steam stripping, filtration, and cocoa powder drying. The final cocoa powder product is 3% or 0.5% cocoa butter by weight, and is sold at a competitive price.

The proposed plant will be located in Tema, Ghana and will produce approximately 120,000 tonnes/year of cocoa liquor, butter, and powder. This location was chosen due to both its abundance in cocoa beans and the commercial success of past and current cocoa processing endeavors.

2.2 Objective Time Chart

Project Name Cocoa Liquor, Butter, and Powder Production

Project Advisors Stephen M. Tieri, Dr. Sean Holleran, Professor Leonard Fabiano

Project Leaders Mack Asselstine, Joseph Mollo, Jesus Morales, Vasiliki Papanikolopoulos

Specific Goals Quantify the value of solvent extraction technology to separate cocoa butter and cocoa powder from cocoa liquor, and design a commercial plant to produce 120 MT/yr of cocoa liquor, butter and powder based on this technology.

Project Scope In-scope:

1. Manufacturing process for cocoa butter and powder beginning from prepared cocoa liquor
2. Design main process to include new solvent extraction technology as the final separation steps.
3. Final product must be of Food Grade quality, fit for human consumption, and meet all FDA and other regulatory standards
4. Maintain process integrity and by adhering to current good manufacturing practices and be as environmentally friendly as possible
5. Determine if process with new solvent technology is best when compared to cost and production value of older processing methods

Out-of-scope:

1. Processing final cocoa powder into a variety of different products
2. Flavored milk product, baking mixes and traditional chocolate
3. Emerging technology in cocoa processing.

Deliverables Business opportunity assessment:

1. What is the market for low-fat and fat-free grades of cocoa powder, and that for purified cocoa butter in general?
2. How does the solvent extraction process compare to traditional processes?

Technical Feasibility assessment:

1. Is it technically feasible?

Manufacturing capability assessment:

1. Can the plant be built and the process utilized without significant capital investment?

Product life-cycle assessment:

1. Will the final product be of Food Grade Quality and meet FDA standards for a safe and consumable product?

Timeline Complete design and economic analysis by April 12, 2016.

2.3 Innovation Map

The innovation map for this process is outlined below. Low fat and fat-free cocoa powders can be quickly produced in large quantities. Because this process is a more effective separation of cocoa butter from cocoa powders, butter yields are greater when solvent is used to process the cocoa. This improvement is a financial boon, as cocoa butter is the most lucrative product of this process. Mr. Todd Gusek, author of the Cargill 2003 patent, noted that the butter produced in this manner possesses a higher than normal cocoa butter cooling curve. This is advantageous to confectionaries as it allows the cocoa butter to solidify more readily at higher temperatures, making it less susceptible to melting.

The powder produced by this process also has advantages over the powder separated by traditional means. Most directly, lower fat content in the cocoa powder yields a healthier powder, both from the lack of fat and from the relative rise in antioxidant and flavanol content associated with it. Also, conventionally-produced powders tend to suffer from clumping as a result of their higher fat contents; manufacturers then add lecithin, an emulsifier, to avoid this issue. For this process, lecithin is no longer necessary, as the powder is already quite dispersible in liquids; the lack of this additive creates a more genuine tasting powder and a cheaper product.

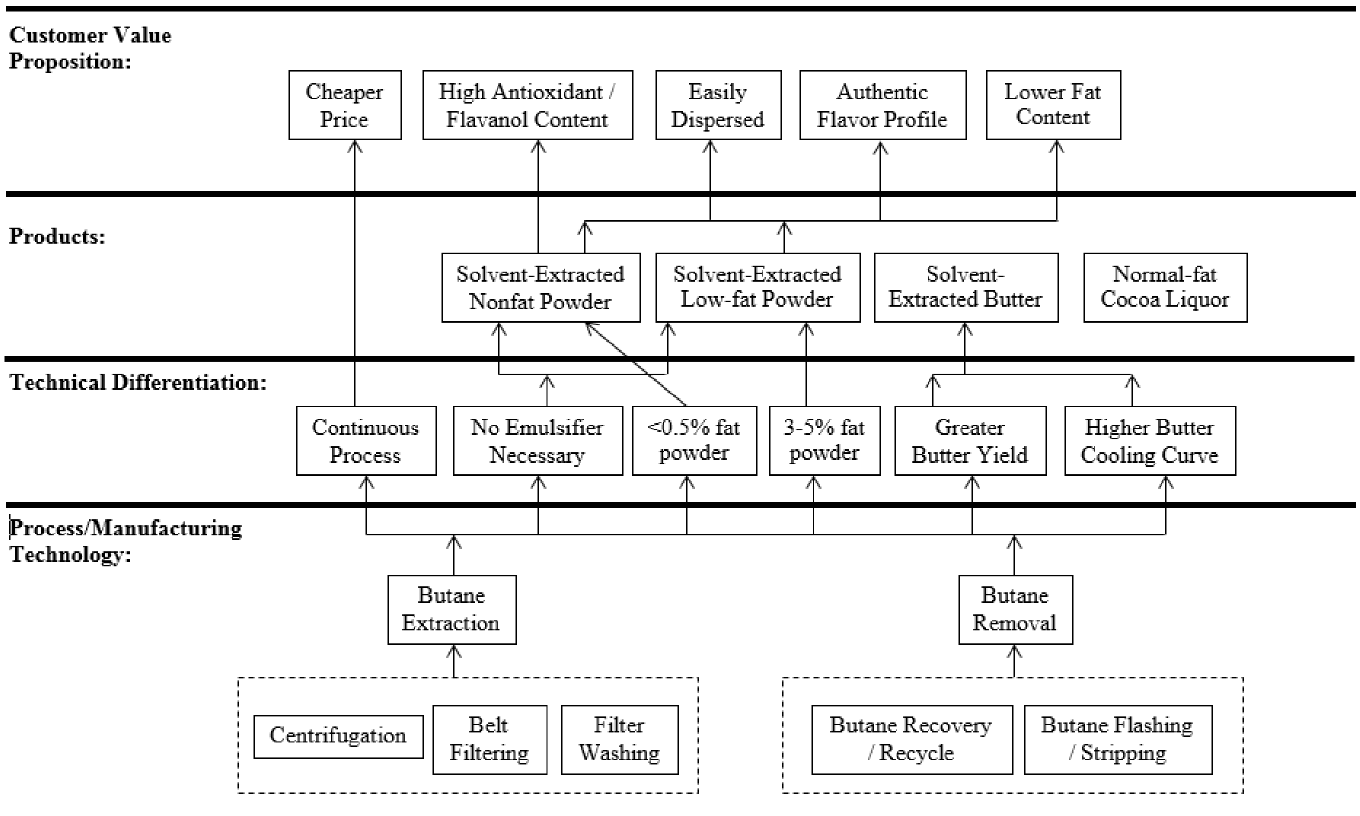


Figure 1. Innovation Map for Cocoa Liquor, Butter, and Powder Production from Solvent-Extraction Process

Section 3: Concept Stage

3.1 Market Analysis

Cocoa beans are processed into three main products: cocoa liquor, cocoa powder, and cocoa butter. Cocoa liquor is solid, unsweetened baking chocolate made from ground cocoa nibs, which can be transformed into cocoa powder and cocoa butter. Cocoa butter is the fat of the cocoa nib, and may be used in lotions and pharmaceutical products (Spiegel, 2014). It is also the main ingredient in white chocolate. Cocoa powder is the solid product of the cocoa nib and can be processed to have varying fat content. The powder is used in beverages, baking, and frequently as a dye. Chocolate is produced by combining both cocoa powder and butter with milk and sugar. With diverse applications for cocoa liquor, butter, and powder, cocoa bean processing is a complex undertaking that incorporates all corners of the world: farms largely in Africa and Central America, cocoa processing facilities concentrated in the Netherlands, and confectionaries all over the world.

China, India, and Brazil are emerging cocoa markets as recent years have given way to more disposable income. Chocolate products are becoming more popular in these countries. India is the fastest growing market for chocolate, at a rate of 17% since 2010 compared to a 9% growth rate in China (Pham, 2016). Lastly, in Brazil, by 2020, the premium chocolate market will grow 26% (Pekic, 2014).

The popular kinds of cocoa products in each country are different. Pastries and flavored milk are central to the Chinese market as displayed in Figure 2. Specifically, demand for chocolate flavored milk drinks is on the rise, where cocoa powder is the key ingredient. Alternatively, chocolate confectionery is central to the world market and India alike. Liquor is used to make the different varieties of chocolate products that target these markets.

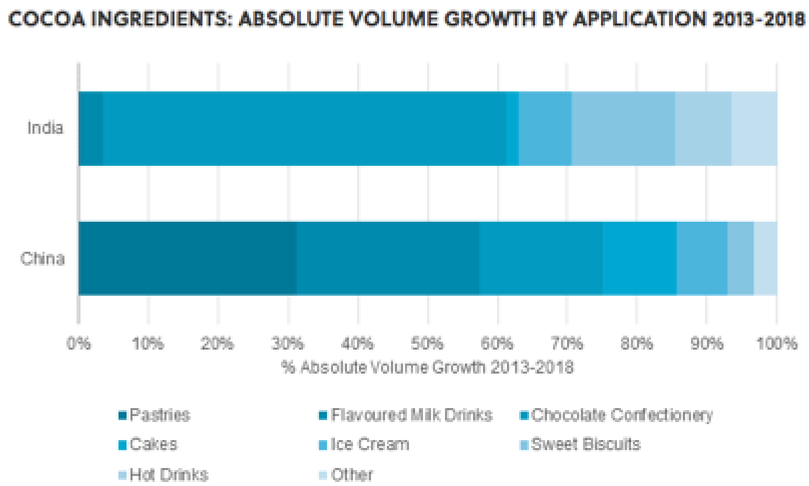


Figure 2. Cocoa Ingredients by absolute volume growth for 8 applications in China and India for 2013-2018 (Euromonitor)

Cocoa powder is the predominant cocoa ingredient in China, with 60% volume share (Euromonitor, 2014). Figure 3 also illustrates the resemblance between the cocoa market in India and the world market, with cocoa liquor having the largest percentage volume, followed by cocoa butter.

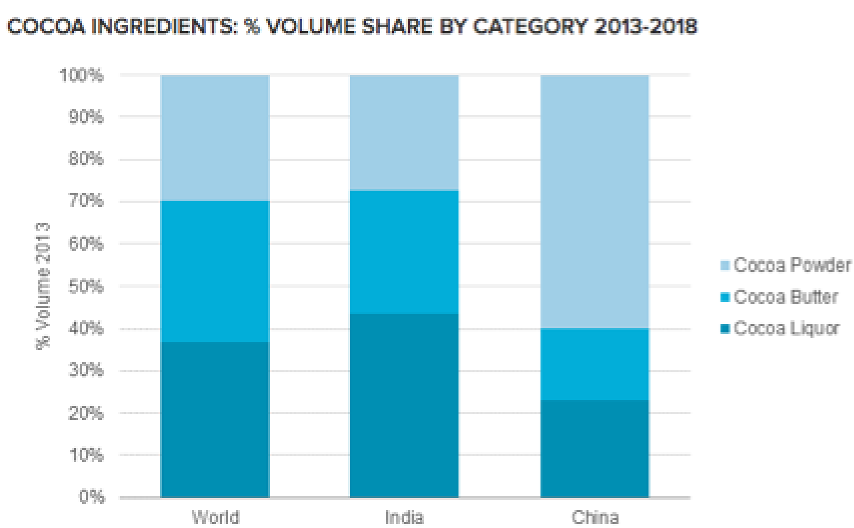


Figure 3. Cocoa Ingredients by percent volume share in three categories, Cocoa Powder, Butter, and Liquor in 2013-2018 for India, China as compared to the rest of the world (Euromonitor)

For cocoa processing, addressing the cultural needs of these emerging markets will be key to the successful growth of the cocoa business in the future. The plant's cocoa powder and butter will be enticing products to manufacturers for these largely untapped markets.

On a per person basis, chocolate consumption in emerging markets is still relatively small compared to the rest of the world. China and India consume less than 2% of the world's largest chocolate markets, which are Western Europe and the United States (Pham, 2016). Assuming labeling regulations in Europe do not change during the lifespan of this processing facility, Mr. Todd Gusek suggested that solvent extracted cocoa powder and butter will be prohibited in these markets. However, cocoa liquor from the facility will meet the requirements to be sold in these countries.

Western Europe and the United States are dominating chocolate consumption, thus acknowledging their unique patterns is important when considering the production of cocoa liquor in the plant. In the Western Europe and US markets, there has been a shift in demand for healthier products. Chocolate companies are aware of health conscious consumers, and are targeting this market with low fat and sugar free options. Dark chocolate became a popular choice because of its high antioxidant levels and ability to lower blood pressure (DeNoon, 2003). Consumers are also seeking sugar free options. Hershey and Godiva sell sugar free chocolate while Bensdorp has Acticoa™, a cocoa powder with cocoa flavanols that benefit the cardiovascular system and the body's blood circulation (Acticoa.com).

Also, sustainability is becoming more important to chocolate consumers. The documentary *The Dark Side of Chocolate* exposed the terrible implications of unregulated chocolate production in the form of child slavery. Thus, confectionaries are playing closer attention to their suppliers of cocoa products, in two respects - labor regulation and cocoa crop methods. The Fair Trade movement sources cocoa beans ethically, from small farmers that grow cocoa trees with limited chemical exposure. Its chocolate is sold at a premium due to the organic nature of the product and the regulation needed to support its system (Equal Trade, 2016).

Alkalization is the process of treating roasted cocoa nibs, or grounded cocoa liquor, with an alkalizing salt. Cocoa that has been treated with an alkalizing salt is also referred to as Dutch cocoa.

Alkalization raises the pH of the cocoa to 6.8 - 8.1, depending on reaction time and the concentration of alkaline (Miller et al). Not only does alkalization improve the taste of the cocoa by neutralizing the acidic bitterness of natural cocoa but, it also brings out a deep red or brown color in the powder. Due to these changes in taste and appearance, alkalized cocoa is preferred over natural cocoa.

3.2 Competitive Analysis

Cocoa processing facilities are spread out all over the world. Currently, there are no plants using solvent extraction to produce fat-free cocoa powder; however, there are a number of cocoa processing plants in Ghana. Barry Callebaut (67,000 tonnes/year capacity) and Cargill (65,000 tonnes/year) lead cocoa processing in Ghana. Overall, the Netherlands leads the world's grinding capacity with 530,000 tonnes/year, followed by the Ivory Coast with 440,000 tonnes/year, and United States with 405,000 tonnes/year (Nicholson et al, 2013).

The proposed facility, with an annual capacity of 120,000 tonnes of cocoa products will be the leading grinding facility in Ghana. To put this into perspective however, Olam, who recently acquired Archer Daniels Midland's cocoa business, now has a combined processing capacity of 700 MT (McFarlane and Hunt, 2015). Olam is an agri-business that focuses on supply chain management, processing and trading of soft commodities and Archer Daniels Midland is an agricultural processor. Barry Callebaut focuses on cocoa and chocolate manufacturing while Cargill is a provider of food, agriculture, financial and industrial products and services.

3.3 Customer Requirements

The leading confectionery customers are Mars, followed by Mondelez, Nestle, Meiji, Ferrero and Hershey (Market Research Academic, 2014). Their needs for cocoa butter, liquor and powder vary depending on the chocolate products they sell. However, there is a common trend that appeals to the increasingly health conscious consumer. Cocoa beverages, snacks, and candies all are moving towards fat free or low fat modifications.

The solvent extraction process for cocoa beans includes a number of confectionary requirements. In their current state, cocoa products contain much lecithin. Lecithin is a fatty substance that is widely used by confectionaries to make cocoa powder more soluble. In a candy bar, it keeps the cocoa and cocoa butter from separating. Lecithin is an expensive ingredient for both confectioneries and this facility, and is less desirable by the final consumers as it increases the fat content of cocoa powder.

An overall reduction in costs is possible using solvent extraction as will be outlined in the report. As this decrease in costs flows down the supply chain, this will ultimately allow chocolate products to profitably expand in developing and established markets.

Lastly, taste and chocolate performance are important factors in consumer’s chocolates of choice. Solvent extracted cocoa powder and butter is higher performing than traditional cocoa powder and butter, and taste profile remains the same.

3.4 Preliminary Process Synthesis

Different decision pathways were evaluated in the design of this process. Because the solvent extraction of cocoa butter from cocoa liquor is the innovative and most critical aspect of this process, a traditional approach to the upstream processing was taken. In this manner, the preprocessing units were chosen to be similar to those of any large-scale cocoa processing plant.

One of the most important decisions was choosing a specific type of cocoa bean to use in the process. There are three main varieties of cocoa: Forastero, Criollo, and Trinitario. Forastero beans were chosen for this process because they comprise roughly 95% of the world cocoa market, they can be grown in numerous equatorial locations, they are more disease-resistant than Criollo beans, and they are less expensive than Trinitario beans.

Another key decision was the starting point at which the process would begin to operate on the beans. Cocoa beans must be fermented and roasted. Typical cocoa farming practices, especially those in Ghana, tend to lead towards fermenting the bean on-site, before selling it to either a private buyer or a government-controlled entity (Vigneri et al, 2007). Any large cocoa processor would need to purchase its feed from one of these intermediate entities. Ghana grows its cocoa beans in a primary, main season from September to March, and then alternately during a secondary, mid-season from May to August (ICCO, 2016). To have some influence on cocoa prices, these intermediates store the harvested cocoa year-round. Thus, it is assumed that a large-scale cocoa processing plant would be able to purchase its required fermented cocoa bean throughput at regular, two-week intervals throughout the year. While farmers have historically used jute bags to transport their product, bulk methods are becoming more popular. It is assumed that a “mega-bulk” transportation method, where beans are placed directly in the cargo holds of trucks and ships, may be employed in order to save on up to 33% of debagging and shipping costs (ICCO, 2016).

Uses for the process waste streams were also considered. The used solvent, approximately 43,164 kg/hr of butane, could potentially have been deemed a waste stream and dealt with as such. Economic analyses dictated that purifying and reclaiming the solvent for a recycle stream would create the most cost-effective outcome. This decision was made due to the large quantity of solvent required for the process, and the need to separate the butter from the used solvent for product, which already made up the most expensive portion of the recovery cycle. This choice left the cocoa shells as the principal source of process waste. Certain sources indicated that these shells could be sold as mulch, or even ground into a mock-cocoa powder of sorts; however, these avenues did not possess significant economic value at the scale of this process. Many processors choose to burn the shells in order to generate heating utilities; that choice is mirrored here, as this combustion had the potential to generate 25,900 kg/hr of medium pressure steam, which was quite valuable for both heating and electric needs (Buhler).

The key choices regarding the downstream cocoa processing involved cocoa alkalization levels, solvent selection, and solvent removal. Profitability analyses were performed to determine whether or not the cocoa powder should be alkalized, and, if so, how much alkalization should occur. The significant factors in this decision were the costs of alkalization, the size of the potential increase in profit margin, and the market's need for alkalized powder. The point of alkalization was also carefully chosen. The process could have opted either for nib alkalization, which would occur before the grinding and milling stages, or for liquor alkalization, which would take place after these stages. Liquor alkalization was determined to be the more effective choice, as the alkalization reagent, a 10% by mass potassium carbonate solution fed in a 3:100 ratio with the cocoa, was much more likely to mix well with a slurry rather than a solid stream. Complete mixing was especially important in this scenario due to the relatively small amount of alkalizing agent, and the need for uniform flavor throughout the cocoa.

Patent literature stated that straight-chain alkanes with molecular weights less than 75 g/mol are best suited for this application. Butane and propane were mentioned as most effective, with butane appearing to be the more desirable of the two (Gusek et al). In order to choose from these two solvents, recovery costs were evaluated for each one, with equal efficacy in cocoa separation assumed. This analysis led to the choice of butane, as propane needed approximately 40ºC of additional cooling to condense after being flashed away from the cocoa butter. Only pure solvents were considered as solvent mixtures would incur greater energy demands for separation.

Multistage operations were required for separating the cocoa and removing the solvent,. To separate the powder from the dissolved butter, stages were set up in such a way to decrease the quantity being separated while also increasing the rigor of the separation. The first stage was chosen to be a large centrifuge, which would remove most of the dissolved butter. Subsequent belt filtering stages were added to finish the more difficult portion of the separation. The filter, with the countercurrent solvent washing, was the most effective choice for this task, as confirmed by patent literature (Gusek et al). To remove the solvent from the cocoa butter, volatility differences were exploited. Because butane is much more volatile than cocoa butter, a flash vessel was chosen as the first separation unit. This unit operation was selected as a cheap and effective way to take advantage of the significant volatility difference. To perform the smaller, more rigorous portion of the separation, a steam-based stripping column was chosen. Steam was selected for many reasons. Primarily, steam would allow for the least energy-intensive recovery of butane. Steam would be easy to acquire, and would minimize the introduction of air into the process (Dziugys et al).

3.5 Assembly of Database

Simulation Specifications

Thermophysical and transport property data for most of the continuous processes was obtained from Aspen Plus v8.8. These processes include mixing, centrifugation, filtering, flash evaporation, heat exchange, and steam stripping. The NRTL-RK thermodynamic model was used for these processes because the liquid and vapor mixtures formed are non-ideal. For the alkalizing process, the ELECNRTL model was chosen due to the formation of electrolyte solutions in water.

Additionally, cocoa butter is not chemically uniform, but rather composed of a variety of triglycerides and a negligible percentage free fatty acids. In Aspen Plus cocoa butter was modeled by its three main constituent triglycerides: POP, SOS, and POS. These triglycerides were assumed to have the largest effect on vapor and liquid mixture interactions because they make up over 80% by weight, of the cocoa butter ("Chocolate and Cocoa Manual", 2009). Sensitivities in Aspen Plus were performed with additional triglycerides to determine deviations in thermophysical behavior, especially freezing point. They were found to have a negligible effect on the liquid properties of the cocoa butter.

Raw Material Costs

The cost of cocoa beans for this facility was obtained from the daily price listing on the International Cocoa Organization's website for March 11, 2016, which was $3,120.08/MT. Although cocoa bean prices are highly volatile, this price was within the range of $2000-3500/MT, as suggested by Mr. Vincent Schoot Uiterkamp. Butane was priced using the OPIS North America LPG Report. The price on April 5, 2016 was $0.25/kg. The price of ethylene glycol was obtained from the ICIS Chemical Business price report provided by Ms. Leela Landress. The price reported was $493.96/MT. A price estimate for bulk regular grade potassium carbonate was obtained from Armand Products Company at $2359/MT.The price of Bunker C fuel oil used to combust shell waste product was priced at $180/MT according to Platt's Marine.

Utility and process water costs were also obtained from Dr. Warren Seider's profitability spreadsheet. Process water for the aqueous potassium carbonate solution costs \$0.27/m^3. A value of \$0.07 per kWh of electricity was used. The cost of cooling water was reported as \$0.027/m^3. The cost of refrigerating the ethylene glycol solution at 10°F was determined to be \$5.50/GJ. Process and utility steam at 150 psig was determined to cost \$15.30/1000kg.

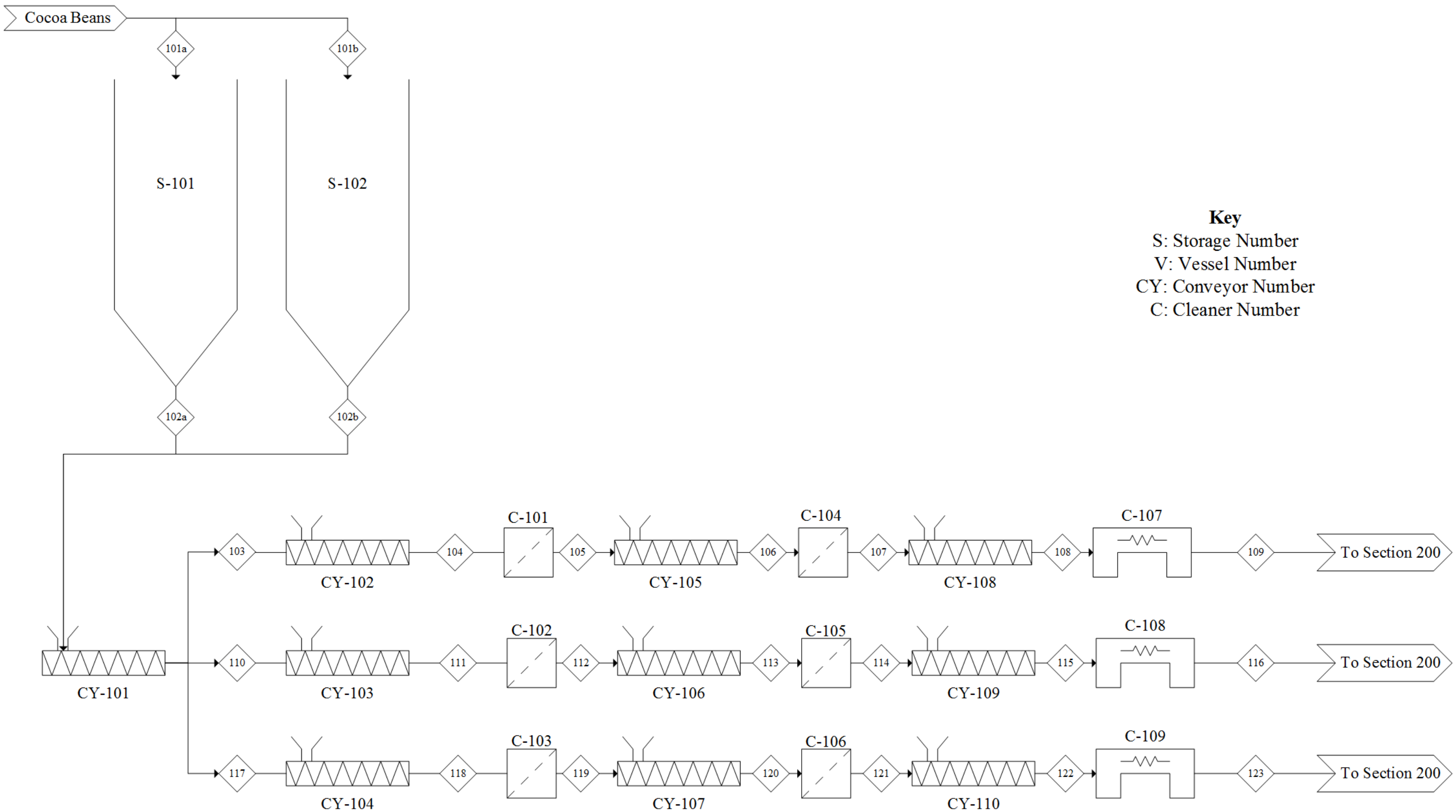
Section 4: Process Descriptions, Flow Diagrams, and Material Balances

The overall process diagrams for the proposed cocoa processing facility are shown in Figures 4-9 (Sections 100-600). All processes are continuous and Section 100 shows bean storage and the initial bean cleaning process in three parallel trains. The roasting, sterilizing, and winnowing unit operations are presented in Section 200. Processing of cocoa nibs into cocoa liquor is shown in Section 300. Section 400 demonstrates the alkalization of cocoa liquor. Solvent extraction of cocoa butter from cocoa liquor is shown in Section 500. Lastly, Section 600 shows the purification of the butter and recovery of the solvent for recycle. Tables 1-6 show the material balance flows for all process streams. Component flows, stream temperatures, and pressures are also indicated.

4.1 Section 100

Trucks with a 40,000lb capacity arrive with hourly shipments of loose bulk cocoa beans. These shipments are transferred to a 570 m^3 stainless steel cone bottom storage silo (S-101 or 102). Three storage silos are required for the plant: an operational tank, standby tank, and spare tank. The cocoa beans from this silo are fed directly into a screw conveyor (CY-101) to be transported 50 feet to the process. Due to equipment capacity constraints, the cocoa bean flow rate is split into three equal streams. Screw conveyors in each parallel train are used to transport the cocoa beans to a separator and classifier unit (C-101-103), which removes coarse debris via air aspiration. From the coarse cleaning, the beans are conveyed to a second air aspiration unit (C-104-106), or fine cleaner, to remove finer debris. Then, the beans are sent to a destoning unit to remove high density materials such as stones and metal pieces (C-107-109).

Section 100



Key
S: Storage Number
V: Vessel Number
CY: Conveyor Number
C: Cleaner Number

Figure 4. Process Flow Diagram for all bean cleaning operations including silo bean storage, coarse cleaning, fine cleaning, and destoning.

Table 1.1 Stream Summary Table for Section-100. *The mass of beans fed to the silos is a kg/batch quantity as beans are supplied batch-wise every hour. Only one silo is used to feed into the process, thus either 102a or 102b will be the stream into the process.

STREAM ID:	101a/b*	102a/b	103	104	105	106	107	108	109	110	111	112
Temperature (C)	21	21	21	21	21	21	21	21	21	21	21	21
Pressure (bar)	1	1	1	1	1	1	1	1	1	1	1	1
Total Flows (kg/hr)	492001	20500	6834	6834	6834	6834	6834	6834	6834	6834	6834	6834
Component Flows (kg/hr)												
Water	24108	1004	335	335	335	335	335	335	335	335	335	335
Fat	214020	8918	2973	2973	2973	2973	2973	2973	2973	2973	2973	2973
Protein	55990	2333	778	778	778	778	778	778	778	778	778	778
Starch	23616	984	328	328	328	328	328	328	328	328	328	328
Cellulose	61500	2563	854	854	854	854	854	854	854	854	854	854
Ash	18106	754	251	251	251	251	251	251	251	251	251	251
Other	94661	3944	1315	1315	1315	1315	1315	1315	1315	1315	1315	1315

Table 1.2 Stream Summary Table for Section-100. *The mass of beans fed to the silos is a kg/batch quantity as beans are supplied batch-wise every hour. Only one silo is used to feed into the process, thus either 102a or 102b will be the stream into the process.

STREAM ID:	113	114	115	116	117	118	119	120	121	122	123
Temperature (C)	21	21	21	21	21	21	21	21	21	21	21
Pressure (Bar)	1	1	1	1	1	1	1	1	1	1	1
Total Flows (kg/hr)	6834	6834	6834	6834	6834	6834	6834	6834	6834	6834	6834
Component Flows (kg/hr)											
Water	335	335	335	335	335	335	335	335	335	335	335
Fat	2973	2973	2973	2973	2973	2973	2973	2973	2973	2973	2973
Protein	778	778	778	778	778	778	778	778	778	778	778
Starch	328	328	328	328	328	328	328	328	328	328	328
Cellulose	854	854	854	854	854	854	854	854	854	854	854
Ash	251	251	251	251	251	251	251	251	251	251	251
Other	1315	1315	1315	1315	1315	1315	1315	1315	1315	1315	1315

4.2 Section 200

The parallel roasters (R-200-202) were each maintained at 170ºC by 581 kW of medium pressure steam produced by shell combustion. The steam heats up air flowing in a heat exchanger attached to the roaster. The heated air heats up the cocoa beans via countercurrent convection to produce the desired Maillard reaction flavor compounds and aromatics. Due to the complexity of the Maillard reaction mechanism, it was assumed that any changes in the fats and solids compositions were negligible. Changes in the water content of the cocoa bean to below 2% of the total weight were accounted for as steam evaporation.

Beans are conveyed from the roasters to the steam sterilization units (SZ-200-202). Low pressure process steam is used to sterilize the beans so that bacteria counts are 500 colony forming units per gram. Minimal moisture intake only on shell occurs. In addition, winnowing units (U-200-202) are necessary to remove the shells from the desired cocoa nib material needed for cocoa liquor.

Section 200

Key
R: Reactor Number
CY: Conveyor Number
SZ: Sterilizer Number
W: Winnower Number

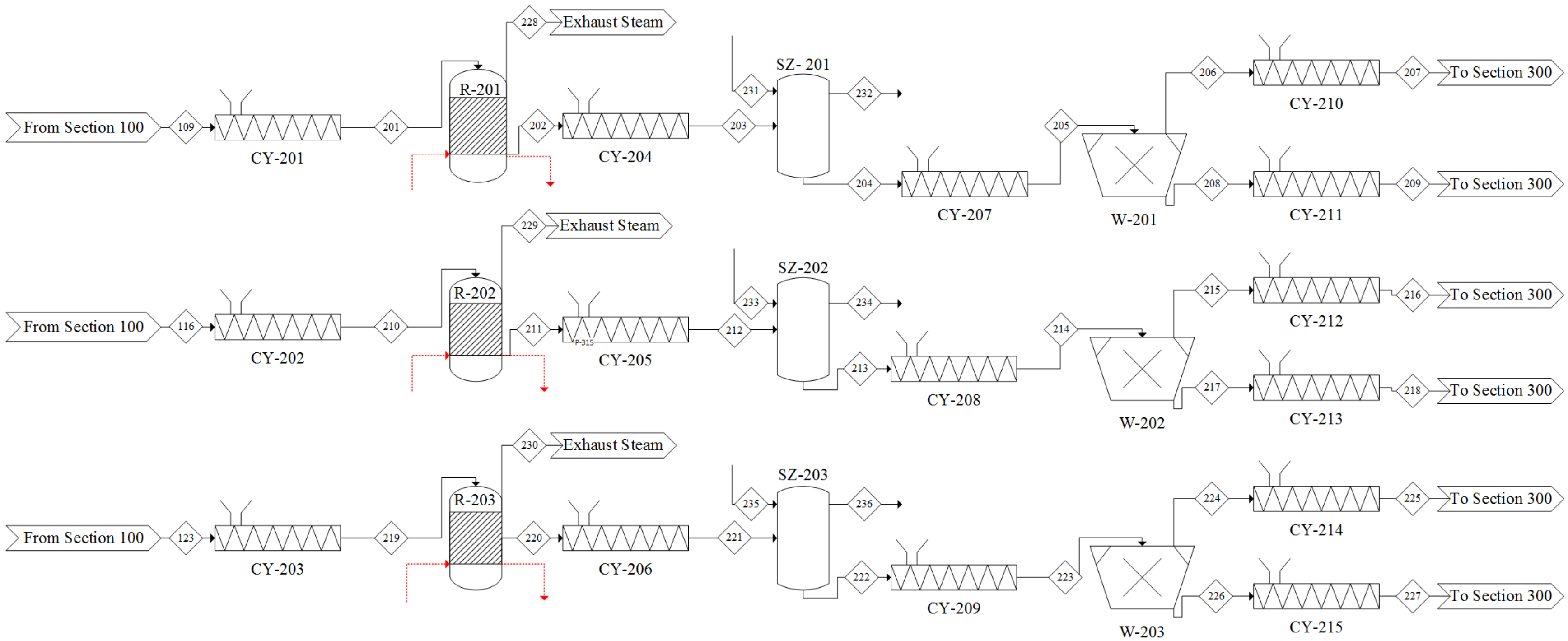


Figure 5. Process Flow Diagram for bean processing including roasting, sterilizing and winnowing.

Table 2.1 Stream Summary Table for Section-200.

STREAM ID:	201	202	203	204	205	206	207	208	209	210	211
Temperature (C)	21	121	121	138	138	23	23	23	23	21	121
Pressure (bar)	1	1	1	2.50	2.50	1	1	1	1	1	1
Total Flows (kg/hr)	6834	6628	6628	6666	6666	1327	1327	5340	5340	6834	6628
Component Flows (kg/hr)											
Water	335	130	130	168	168	59	59	111	111	335	130
Fat	2973	2972	2972	2989	2989	20	20	2958	2958	2973	2972
Protein	778	778	778	778	778	145	145	633	633	778	778
Starch	328	328	328	330	330	0	0	328	328	328	328
Cellulose	854	854	854	848	848	352	352	500	500	854	854
Ash	251	251	251	250	250	106	106	145	145	251	251
Other	1315	1315	1315	1303	1303	645	645	665	665	1315	1315

Table 2.2 Stream Summary Table for Section-200.

STREAM ID:	212	213	214	215	216	217	218	219	220	221	222
Temperature (C)	121	138	138	23	23	23	23	21	121	121	138
Pressure (bar)	1	2.50	2.50	1	1	1	1	1	1	1	2.50
Total Flows (kg/hr)	6628	6666	6666	1327	1327	5340	5340	6834	6628	6628	6666
Component Flows (kg/hr)											
Water	130	168	168	59	59	111	111	335	130	130	168
Fat	2972	2989	2989	20	20	2958	2958	2973	2972	2972	2989
Protein	778	778	778	145	145	633	633	778	778	778	778
Starch	328	330	330	0	0	328	328	328	328	328	330
Cellulose	854	848	848	352	352	500	500	854	854	854	848
Ash	251	250	250	106	106	145	145	251	251	251	250
Other	1315	1303	1303	645	645	665	665	1315	1315	1315	1303

Table 2.3 Stream Summary Table for Section-200.

STREAM ID:	223	224	225	226	227	228	229	230	231	232	233	234	235	236
Temperature (C)	138	23	23	23	23	120	120	120	185	185	185	185	185	185
Pressure (bar)	2.50	1	1	1	1	1	1	1	10.30	1	10.30	1	10.30	1
Total Flows (kg/hr)	6666	1327	1327	5340	5340	205	205	205	928	894	928	894	928	894
Component Flows (kg/hr)														
Water	168	59	59	111	111	205	205	205	928	894	928	894	928	894
Fat	2989	20	20	2958	2958	0	0	0	0	0	0	0	0	0
Protein	778	145	145	633	633	0	0	0	0	0	0	0	0	0
Starch	330	0	0	328	328	0	0	0	0	0	0	0	0	0
Cellulose	848	352	352	500	500	0	0	0	0	0	0	0	0	0
Ash	250	106	106	145	145	0	0	0	0	0	0	0	0	0
Other	1303	645	645	665	665	0	0	0	0	0	0	0	0	0

4.3 Section 300

The cocoa shells are sent to an on-site packaged boiler room, where they are mixed with a bunker-C fuel oil. They are combined to create a fuel stream composed of 10% oil and 90% shells, and then combusted in a large furnace. The heat generated in this step is assumed to provide the latent heat of vaporization for approximately 25,900 kg/hr of steam at 150 psig, with 75% assumed efficiency in energy transfer.

Cocoa nibs are then conveyed (CY-210) to a coarse grinder (G-301). The cocoa mixture is pumped (P-301) to a second fine grinder (G-302) to produce the desired fluid cocoa liquor. The liquor is either pumped to the alkalization process or transferred to a blocking process for export. Because cocoa liquor possesses significant value even before it is separated into its constituents, a sizable portion of the liquor stream is sent to blocking. In accordance with the worldwide cocoa market, about 36% of the liquor is diverted for product.

Section 300

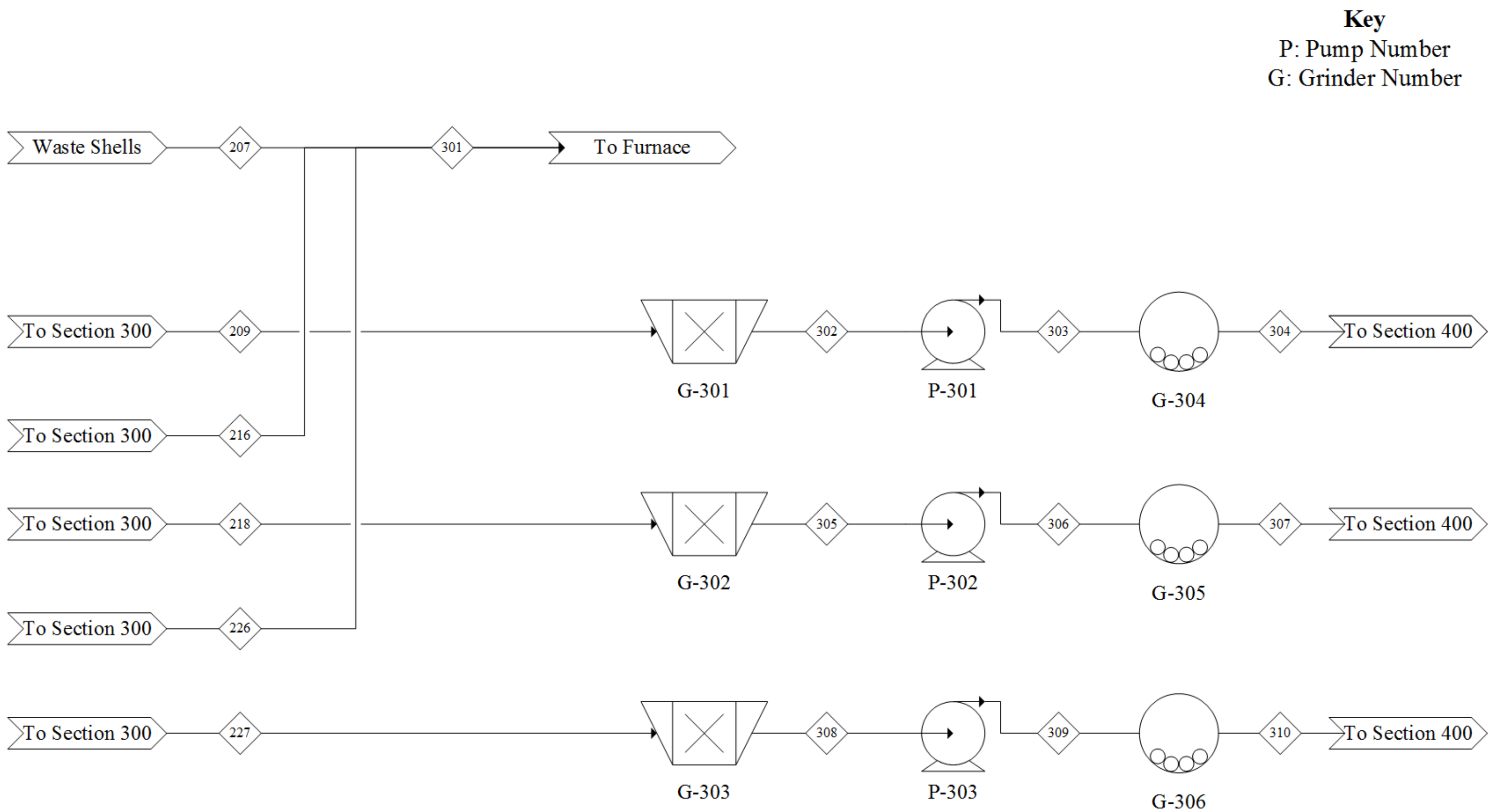


Figure 6. Process Flow Diagram for shell burning and cocoa nib grinding into cocoa liquor.

Table 3.1 Stream Summary Table for Section-300.

STREAM ID:	**301**	**302**	**303**	**304**	**305**	**306**	**307**	**308**	**309**	**310**
Temperature (C)	21	21	21	21	21	21	21	21	21	21
Pressure (bar)	1	1	1	1	1	1	1	1	1	1
Total Flows (kg/hr)	5340	5340	5340	5340	5340	5340	5340	5340	5340	5340
Component Flows (kg/hr)										
Water	111	111	111	111	111	111	111	111	111	111
Fat	2958	2958	2958	2958	2958	2958	2958	2958	2958	2958
Protein	633	633	633	633	633	633	633	633	633	633
Starch	328	328	328	328	328	328	328	328	328	328
Cellulose	500	500	500	500	500	500	500	500	500	500
Ash	145	145	145	145	145	145	145	145	145	145
Other	665	665	665	665	665	665	665	665	665	665

4.4 Section 400

The cocoa liquor is pumped (P-402) at 13,400 kg/hr to a reactor (R-401) that combines it with potassium carbonate and water for alkalization. The potassium carbonate is added to the water in a 1:10 ratio; this degree of dilution helps to achieve a well-mixed slurry during the reaction. Additionally, FDA regulations stipulate that the alkalizing reagent mass must be no more than 3% of the cocoa mass. Together, these criteria determine the mass of alkalizing solution that may be added to the cocoa mass. This solution is mixed into the cocoa mass for 30 minutes in a stainless steel vertical pressure vessel (R-401), which raises the pH of the cocoa mass from 6 to 7. The mixture is then transferred to a flash vessel (T-401) where the excess water is separated from the cocoa liquor by vaporization. The duty required for this stage is 3194 kW. The water enters a heat exchanger (E-401), then a vessel (V-401) and finally is pumped (P-405) as wastewater.

Section 400

Key
R: Reactor Number
P: Pump Number
T: Tower (Column) Number
E: Exchanger Number
V: Vessel Number

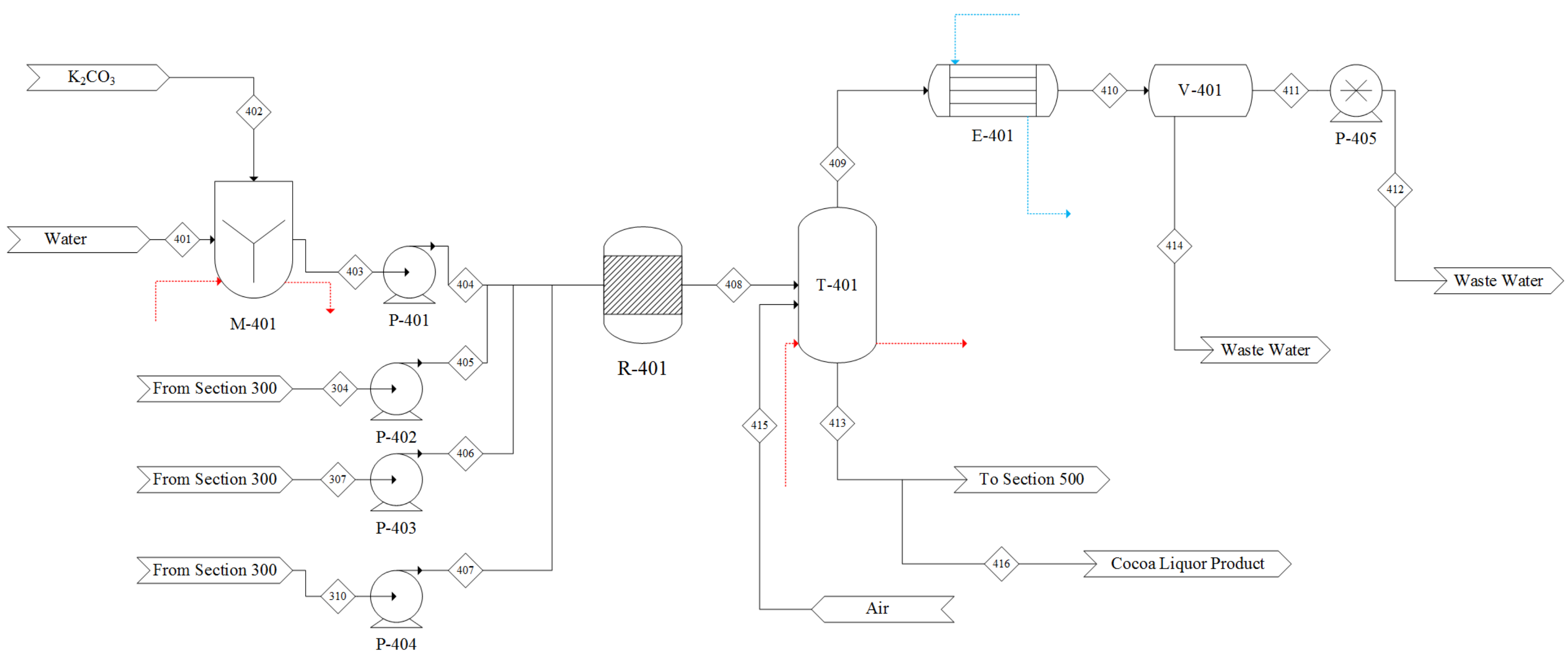


Figure 7. Process Flow Diagram for alkalization of cocoa liquor. Dashed red and blue lines indicate heat and cooling utility requirements.

Table 4.1 Stream Summary Table for Section-400. The term "powder" refers to cocoa solids with the following composition: The term "powder" refers to cocoa solids with the following compositions by weight: 12% protein, 6% starch, 9% cellulose, 3% ash, 12% other.

STREAM ID:	**401**	**402**	**403**	**404**	**405**	**406**	**407**	**408**	**409**	**410**	**411**	**412**
Temperature (C)	20	20	22	22	95	95	95	95	95	30	28	183
Pressure (bar)	1	1	1	1.50	1.50	1.50	1.50	1.50	0.30	0.30	0.30	1.05
Total Flows (kg/hr)	4806	481	5286	5286	5340	5340	5340	21306	4985	4985	0.008	0.008
Component Flows (kg/hr)												
Water	4806	0	4805	4805	160	160	160	5286	4985	4985	0.001	0.001
Fat	0	0	0	0	2883	2883	2883	8650	0	0	0	0
Powder	0	0	0	0	2296	2296	2296	6888	0	0	0	0
K^+	0	0	272	272	0	0	0	272	0	0	0	0
$CO3^{2-}$	0	0	209	209	0	0	0	209	0	0	0	0
K_2CO_3 (S)	0	481	0	0	0	0	0	0	0	0	0	0
N_2	0	0	0	0	0	0	0	0	0.02	0.02	0.006	0.006
O_2	0	0	0	0	0	0	0	0	0.007	0.007	0.001	0.001

Table 4.2 Stream Summary Table for Section-400.

STREAM ID:	**413**	**414**	**415**	**416**
Temperature (C)	95	28	20	95
Pressure (bar)	0.30	0.30	1	0.30
Total Flows (kg/hr)	16320	4985	0.029	2954
Component Flows (kg/hr)				
Water	301	4985	0	55
Fat	8650	0	0	1565
Powder	6888	0	0	1247
K^+	116	0	0	21
$CO3^{2-}$	89	0	0	16
K_2CO_3 (S)	275	0	0	50
N_2	0	0.02	0.02	0
O_2	0	0.006	0.007	0

4.5 Section 500

The alkalized liquor is pumped (P-501) at 13366 kg/hr to a mixer (M-501) to maintain the suspension of the cocoa solids in the butter. M-501 was sized with a residence time of 30 minutes; this duration allows for complete mixing, and also helps mitigate any deviations from steady state in the process. The liquor is then pumped (P-502) to a second mixer (M-502), which mixes it with 33,414 kg/hr of butane from the solvent recycle loop. This addition creates the 2.5:1 solvent to cocoa ratio necessary for the first separation stage as recommended by the patent literature. This mixture is then pumped (P-503) to a continuous centrifuge, where the stream's solids and liquids are separated. Meanwhile, the centrifuge is able to pull roughly 90% of the liquid out of the slurry. The liquid stream is pumped (P-504) to Section 600 for solvent recovery. This separation stage brings the fat content in the cocoa from 52% to 10%, as confirmed by Mr. Gusek.

The solid cake is conveyed (CY-501) to another mixer (M-503), where fresh butane from the recycle stream is added to bring the solvent to cocoa ratio back up to 1.8:1. The mixture is then filtered (FL-501) on a continuous vacuum belt. Once again, the solids remain entirely in the cake stream, while the butane is able to pull away approximately 69% of the fat and moisture content from the cocoa. The liquid stream is pumped (P-505) to Section 600. After this second stage, the fat content in the cocoa is lowered to 3.4%, while the moisture drops below 0.1%. A screw conveyor brings the low-fat cake to a splitter. Here, the cake can either be sent to a dryer (D-501), or alternately to a second mixer-filter (M-504, FL-502) to be processed into nonfat powder. The process equipment is sized so that the splitter may range from an 80-20 balance in favor of either fat content. Because the low-fat powder requires less energy to separate, retains its taste while adding health benefits, disperses without being dusty, and has wider market appeal, the splitter was set to produce 80% low-fat powder and 20% nonfat powder.

A more rigorous filtration step is required to bring the cocoa powder into the nonfat range. The last portion of fresh butane is sent down from the recycle loop in order to create a solvent to cocoa ratio of 1.2:1. However, this butane (Stream 627) is split in half before it reaches the mixer-filter; half of the stream is mixed with the solids, while the other half is used as a washing step at the end of the filter. This countercurrent washing and filtration is required to bring the fat content of the cocoa powder under 0.5%, as the filtration removes roughly 86% of the liquids present on the cake. In a manner similar to the low-fat case, the powder is conveyed (CY-505) to a dryer, where any excess butane is removed by dropping the pressure from 6 bar to 1.2 bar at constant temperature. Steam is used to maintain isothermal conditions in the dryers while the butane vaporizes. A residence time of 60 minutes is combined with thorough agitation to ensure that residual solvent levels do not exceed 1 PPM, the maximum tolerable level for the product.

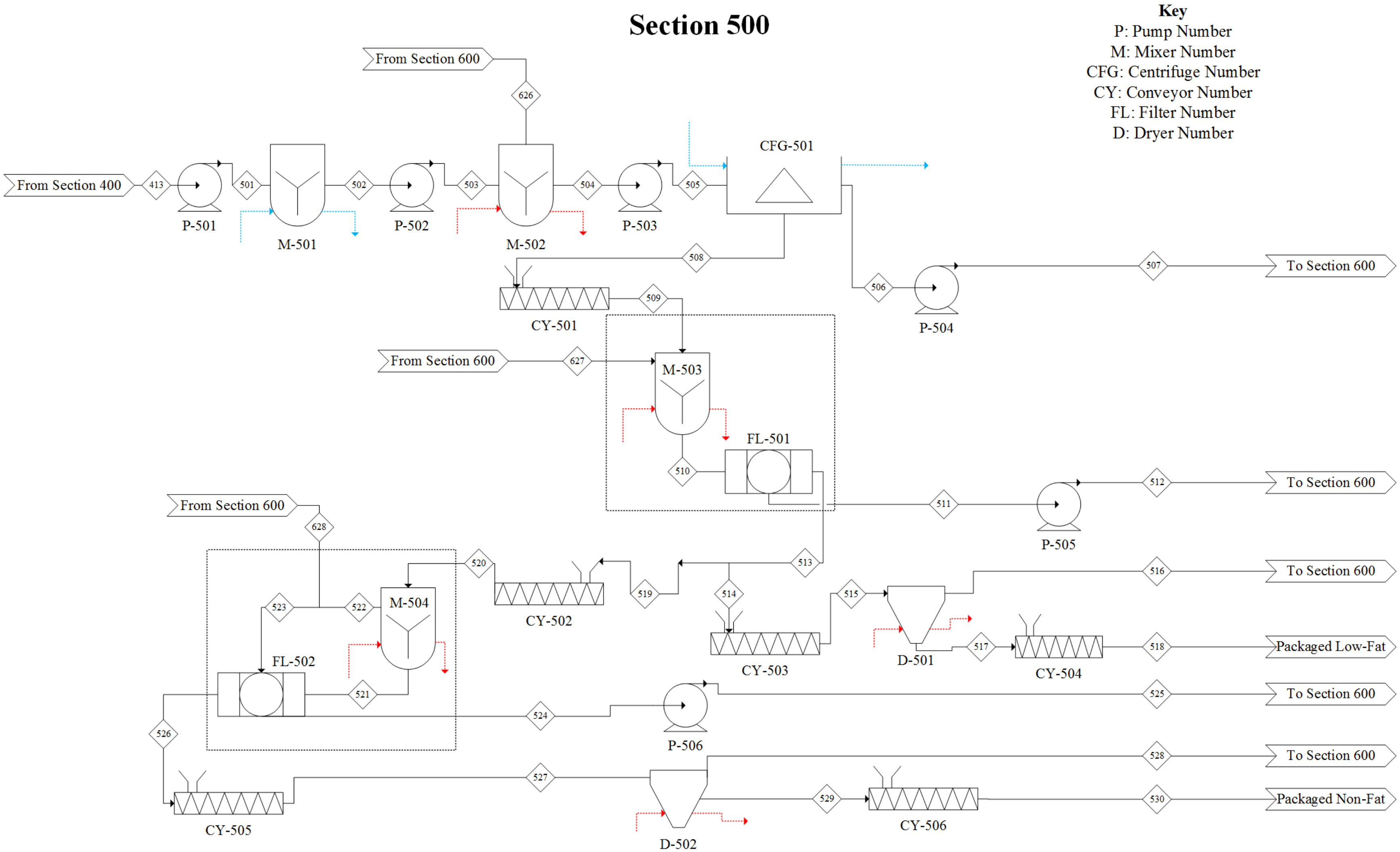


Figure 8. Process Flow Diagram for solvent extraction of cocoa butter from cocoa powder. Dashed boxes indicate mixer filter systems with or without wash stages.

Table 5.1 Stream Summary Table for Section-500. The term "powder" refers to cocoa solids with the following compositions by weight: 12% protein, 6% starch, 9% cellulose, 3% ash, 12% other.

STREAM ID:	**501**	**502**	**503**	**504**	**505**	**506**	**507**	**508**	**509**	**510**	**511**	**512**
Temperature (C)	95	50	50	50	50	50	50	50	50	50	50	50
Pressure (bar)	1.50	1.50	1.50	5	6	6	6	6	6	6	6	6
Total Flows (kg/hr)	13366	13366	13366	46780	46780	36588	36588	10192	10192	19182	9006	9006
Component Flows (kg/hr)												
Water	334	334	334	334	334	301	301	34	34	34	23	23
Fat	6905	6905	6905	6905	6905	6214	6214	690	690	690	476	476
Powder	5747	5747	5747	5747	5747	0	0	5747	5747	5747	0	0
Butane	0	0	0	33414	33414	30073	30073	3341	3341	12331	8507	8507
K_2CO_3 (S)	380	380	380	380	380	0	0	380	380	380	0	0

Table 5.2 Stream Summary Table for Section-500. The term "powder" refers to cocoa solids with the following compositions by weight: 12% protein, 6% starch, 9% cellulose, 3% ash, 12% other.

STREAM ID:	**513**	**514**	**515**	**516**	**517**	**518**	**519**	**520**	**521**	**522**	**523**	**524**
Temperature (C)	50	50	50	50	50	50	50	50	50	50	50	50
Pressure (bar)	6	6	6	1.20	1.20	1.20	6	6	6	6	6	6
Total Flows (kg/hr)	10176	8141	8141	3059	5082	5082	2035	2035	2415	380	380	1361
Component Flows (kg/hr)												
Water	11	9	9	0	9	9	2	2	2	0	0	2
Fat	214	171	171	0	171	171	43	43	43	0	0	37
Powder	5747	4598	4598	0	4598	4598	1149	1149	1149	0	0	0
Butane	3824	3059	3059	3059	0	0	765	765	1145	380	380	1322
K_2CO_3 (S)	380	304	304	0	304	304	76	76	76	0	0	0

Table 5.3 Stream Summary Table for Section-500. The term "powder" refers to cocoa solids with the following compositions by weight: 12% protein, 6% starch, 9% cellulose, 3% ash, 12% other.

STREAM ID:	**525**	**526**	**527**	**528**	**529**	**530**
Temperature (C)	50	50	50	50	50	50
Pressure (bar)	6	6	6	1.20	1.20	1.20
Total Flows (kg/hr)	1361	1434	1434	203	1231	1231
Component Flows (kg/hr)						
Water	2	0.28	0.28	0	0.28	0.28
Fat	37	6	6	0	6	6
Powder	0	1149	1149	0	1149	1149
Butane	1322	203	203	203	0	0
K_2CO_3 (S)	0	76	76	0	76	76

4.6 Section 600

The volatilized butane streams from the dryers are condensed in a heat exchanger (E-601) with a 70/30 water to ethylene glycol solution at 10^{o}F. The condensed liquid joins the extracted butter streams from centrifugation and mixing-filtering. The resulting stream at 48^{o}C is then heated to 65^{o}C by medium pressure steam in a second heat exchanger (E-602). The effluent mixture is then subjected to adiabatic flash evaporation (T-601) at 1.56 bar, resulting in 99.5% recovery of solvent overhead. The overhead vapor is completely condensed (T-606) in a 10:1 ratio of 10^{o}F refrigerant to solvent. The bottoms product of the flash vessel is heated to 75^{o}C before being introduced into the stripping column (T-602). The heat added to this stream is intended to promote removal of residual butane in cocoa butter. The steam stripping column deodorizes the cocoa butter feed and strips off remaining butane with medium pressure saturated steam. Residual butane concentrations do not exceed 500 PPB. The cocoa butter is cooled to 50^{o}C using the feed of the stripping column as the cold side fluid. The product is then sent to final packaging in cardboard boxes.

The overhead of the stripping column is completely condensed with refrigerant (E-605) and sent to the decanter to purify butane stream before recycle. The decanter, operating at 50^{o}C, is able to purge most of the water so that the residual water concentration in the recycled solvent is 2 PPM. The recycled solvent is then sent to a spherical solvent storage tank (V-602), where make-up solvent is added to account for losses in the decanter and final products. The throughput through this tank is recycled to Section 500 to be used for solvent extraction.

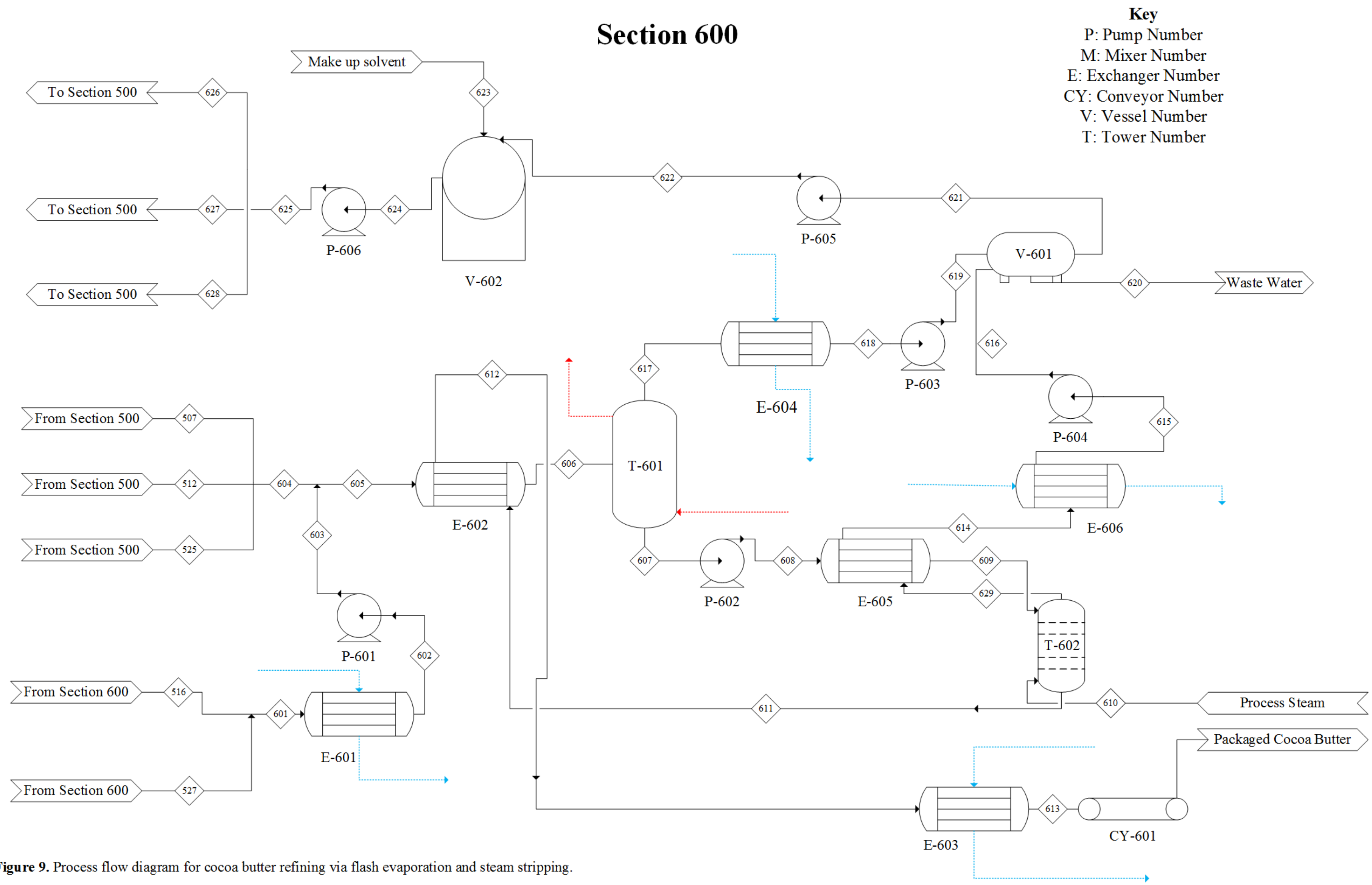


Figure 9. Process flow diagram for cocoa butter refining via flash evaporation and steam stripping.

Table 6.1 Stream Summary Table for Section-600.

STREAM ID:	**601**	**602**	**603**	**604**	**605**	**606**	**607**	**608**	**609**	**610**	**611**	**612**	**613**	**614**
Temperature (C)	53	4	4	47	47	52	57	57	59	149	149	80	50	77
Pressure (bar)	1.20	1.20	6	6	6	6	1.60	6	6	4.50	3.9	3.9	3.9	3.7
Total Flows (kg/hr)	3262	3262	3262	46955	50217	50217	6909	6909	6909	689	7402	7402	7402	196
Component Flows (kg/hr)														
Water	0	0	0	326	326	326	2	2	2	689	675	675	675	16
Butane	3262	3262	3262	39902	43164	43164	180	180	180	0	0	0	0	180
Fat	0	0	0	6727	6727	6727	6727	6727	6727	0	6727	6727	6727	0

Table 6.2 Stream Summary Table for Section-600.

STREAM ID:	**615**	**616**	**617**	**618**	**619**	**620**	**621**	**622**	**623**	**624**	**625**	**626**	**627**	**628**	**629**
Temperature (C)	32	32	57	10	10	50	50	50	50	50	50	50	50	50	101
Pressure (bar)	3.7	14	1.60	1.6	4	4	4	6	6	6	6	6	6	6	3.7
Total Flows (kg/hr)	196	196	43309	43309	43309	328	43176	43176	1	43177	43177	33398	9015	764	196
Component Flows (kg/hr)															
Water	16	16	325	325	325	327	13	13	0	13	13	10	3	0	16
Butane	180	180	42984	42984	42984	1	43163	43163	1	43164	43164	33387	9012	764	180
Fat	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Section 5: Energy Balance and Utility Requirements

5.1 Heat Integration Strategy

Heat integration was limited in this process design. Utilities were minimized, where possible, as streams were evaluated for their capacity to cool or heat other process streams. Adding more heat exchangers to process streams that required large amounts of cooling was found to be effective at minimizing utility costs. This was especially the case in Section 600. The effluent of the stripping column (T-602), which is at 149^{o}C, is used to partially vaporize the feed into the flash vessel (T-601). This transfer amounts to 355 kW and cools down the cocoa butter in this stream to 80^{o}C. Furthermore, this reduces the utilities needed to cool the stripping column's effluent to 50^{o}C for product packaging. An additional 7905 kg/hr of cooling water is necessary for this purpose.

Similarly, the bottoms product of the flash vessel in section 600 was used to cool down the overhead vapor of the stripping column. The bottoms stream reduces the temperature of the overhead vapor to 77^{o}C. Utility costs for chilled water are reduced by nearly 53% with this heat integration. The resulting arrangement of heat exchangers also meets the minimum utility requirements provided the minimum temperature approach of 5.56^{o}C.

Other streams in Section 600 could not be valued for their heating potential as there were more hot streams than cold streams available. The consequence of this is the use of refrigerant at 10^{o}F and cooling water to completely condense the butane vapor streams. Compressors were alternatively considered, as a means to reduce refrigerant amounts, but immediately ruled out, as they would incur significant capital and operating costs to the facility.

Waste products produced in this facility were considered to provide a majority of the heating requirements needed for this process. The shells from units W-200, W-201, and W-202, sent to the on-site packaged boiler room, were combusted. The shells made up the balance of a stream containing 10% Bunker C fuel oil by mass. The fuel oil was necessary for making the stream easy to both combust and handle. The higher heating value from this combustion was exploited in producing medium pressure steam, which was contained in a pressurized loop internal to the system and used for heat transfer and energy generation. For this steam, the only heat transfer occurring was assumed to be from the latent heat of vaporization. Because the furnace heat was only vaporizing pressurized, hot water, the unit generated 31,800 kg/hr of steam at 150 psig. This boiling was assumed to be 90% efficient (Woodbank). To minimize utility costs, this steam was sent to the roasters at roughly 2,820 kg/hr, where it heated inlet air, which then roasted the beans by convection. An efficiency of 75% was assumed during these heat transfer steps. Some of the medium pressure steam was also sent to the cocoa powder drying vessels; 591 kg/hr were sent to the low-fat drying vessel, and 157 kg/hr were sent to the nonfat drying vessel. These values ensured that the dryers operated isothermally as the butane evaporated from the product stream. Maximum values were used for each dryer. Depending on the cocoa powder product split fractions, the steam flows represent upper bounds. Another 13,350 kg/hr of the generated steam was sent to the process flash vessels, T-401 and T-601, again to ensure isothermal operation.

While some of the steam generated by the furnace was used in the process, the majority of it was converted to electricity. This conversion was executed by assuming that the excess steam was sold at $15.30/1000 kg and that the resulting capital was used to purchase electricity at $0.07/kWh, with a 40% efficiency in the transfer (Woodbank). In this manner, the furnace was able to generate approximately 1,273 kW of electricity using the surplus steam. After meeting the plant's electricity requirements, 583 kW of electricity remained. This electricity was sold at the aforementioned rate; the revenue of approximately $286,000/yr was put towards the purchase of cooling utilities such as refrigerant and cooling water.

5.2 Process Utilities

Tables 7 summarizes the utilities and electricity needed for each equipment item. Net energy requirements after heat integration are also shown. Table 8 summarizes the net utilities needed per kg of cocoa butter. Cocoa powder, both low fat and fat-free, was chosen as the main product for the economic analysis.

Table 7. Net Utility Requirements by Equipment Unit.

Utility	Equipment Unit	Quantity (kg/yr)
Cooling Water	E-401	841,000,000
	E-603	55,000,000
	CFG-501	95,565,381
	M-501	125,900,000
	Total	1,117,000
		Quantity (GJ/yr)
Refrigeration at 10°F	E-601	11,000
	E-604	144,000
	Total	155,000
		Quantity (kWh/year)
Electricity	CY-101	33,000
	CY-102 to 203	50,000
	CY-204 to 206	13,000
	CY-207 to 209	13,000
	CY-210,212,214	4,000
	CY-211,213,215	11,000
	CY-501	5,800
	CY-502	1,500
	CY-503	4,800
	CY-504	3,200
	CY-505	1,100
	CY-506	1,000
	C-101 to 103	4,900
	C-104 to 106	26,100
	C-107 to 109	2,500
	W-201 to 203	877,000
	G-301 to 303	141,000
	G-304 to 306	340,000
	P-301 to 303	2,500
	M-401	28,000
	P-401	3,200
	P-402 to 404	700
	P-501	9,500
	P-502	3,900
	P-503	3,500
	P-504	18,500
	P-505	6,100
	P-506	5,300
	P-601	39,800
	P-602	31,600
	P-603	110,000
	P-604	10,700
	P-605	103,000
	P-606	16,200
	CFG-501	1,800,000
	FL-501	385,700
	FL-502	385,700
	M-501	60,500
	M-502	27,900
	M-503	6,000

	M-504	3,000
	D-501	5,700
	D-502	5,700
	Subtotal	4,600,000
	Shell: Electricity	-4,600,000
	Net Utility Required	0
		Quantity (kg/yr)
Medium Pressure Steam	R-201 to 203	19,800,000
	D-501	5,900,000
	D-502	1,600,000
	T-401	40,400,000
	T-601	53,200,000
	Subtotal	120,800,000
	Shell: Medium Pressure Steam	-120,800,000
	Net Utility Required	0

Table 8. Utility Costs per kg of Cocoa Powder

Utility	Unit	Ratio (per kg of Cocoa Powder)	Utility Cost ($ per Unit)
Cooling Water	kg	21.6	$2.7x10^{-5}$
Chilled Water	GJ	$1.12x10^{-5}$	6.70
Refrigeration at 10°F	GJ	$1.55x10^{-3}$	5.50

Section 6: Equipment List & Unit Descriptions

6.1 Unit Descriptions

Silos

Two truncated cone silos, each with a maximum working volume of 819 m^3, are used to store cocoa beans when they are delivered in bulk to the processing facility. A third silo is necessary if any maintenance on the other two silos must be done. The cocoa beans are stored, at 21ºC and 3 psig, in stainless steel silos to meet Food Grade standards. There are two picking seasons for cocoa beans in Ghana, but a Licensed Buying Company in Ghana will supply this cocoa processing facility every hour. Mr. Stephen Tieri recommended this as an acceptable length of storage after determining reasonably sized storage units for the company's product requirements and accounting for variations in the supply of raw materials. The combined bare module cost for the silos is $191,511.

Cleaners

Three types of cleaners were used in the preprocessing of the cocoa beans coarse cleaners, fine cleaners, and destoners. Based on industry-reported capacities, this process called for three parallel cleaning streams (Buhler). For each of these units, the mass balances remain unchanged, as the waste percentage present in the dried, fermented beans is assumed to be negligibly low. All of these units were constructed with stainless steel and designed to run at room temperature and atmospheric pressure. Coarse cleaners were modeled as vibrating screens with 2 decks. The top deck was designed to filter out large pieces of debris and let cocoa beans through to the second screen, which would only allow finer sand grains and jute fibers through to a waste drawer. A load heuristic of 0.86 tons/hr-m^2-mm was observed; assuming 20-mesh screens, an area of 11 m^2 was required (Rao).

Fine cleaners were installed as the next step in the cleaning process; these units were designed to remove lighter dust particles from the cocoa beans. These units were modeled and costed according to the cyclone units in Seider, et. al. Specifications obtained from the cocoa preprocessing industry indicated that air intake could be calculated based on an air to cocoa mass ratio of 1:2.34 (Buhler). This heuristic called for an air intake of 2,041 m^3/hr. Typical cyclone parameters dictated that a motor of approximately 3.75 kW would be necessary to achieve this intake (Pentz).

The final cleaning step was comprised of three destoners in parallel. These units, which contain both a vibrating screen and an air intake system, were specified using an industry brochure which may be found in Appendix D. These industry specifications called for an active area of 0.78 m^2, a pressure gradient of 12 mbar across the screen, and 70 m^3/min of aspiration. These cleaning steps have a power demand of approximately 14.5 kW, and a total bare module cost of $319,300 as calculated by the equations given in Seider, et. al.

Roasters

A roaster was present in each of the three preprocessing streams. These reactors were modeled as convection-heated, stainless steel vessels in which the fermented beans would undergo a series of Maillard reactions. The Maillard reactions, which are largely responsible for the flavors and aromas inherent to cocoa, require a temperature of 120ºC and a residence time of 30 minutes (Buhler). Because the pressure of this vessel remained approximately atmospheric, a height to diameter ratio of 1:1 was determined to be safely permissible; the residence time defined the height and diameter as 1.67 m (Buhler). The roasters were also designed to reduce the moisture content in the beans; they were heated such that 205 kg/hr of water would be boiled out of the solids stream.

In order to heat the roasters, medium pressure saturated steam was sent from the furnace at 941 kg/hr for each of the roasters. The heat released by the condensation of this steam was used to heat process air from 125ºC to 170ºC at roughly 41,000 kg air/hr for each roaster. This air was sent to contact the beans. As the air dropped back to 125ºC, the beans absorbed the heat convectively, rising to 120ºC and engaging the roasting process. These flow rates were calculated assuming a 75% efficiency of heat transfer; surplus steam is sent to the reactors to ensure that sufficient heating occurs. The bare module cost of these vessels was calculated to total $537,400.

Sterilizers

Three sterilizers were required for this process. The sterilizers were designed as a final cleaning step for the cocoa beans, maintaining bacterial counts below 500 colony forming units per gram ("Cocoa", 2016). The sterilizers were modeled as vertical, stainless steel pressure vessels. A residence time of 5 min was assumed to find a maximum working volume of 1.25m^3. Medium pressure process steam at 927.92 kg/hr is added to the vessel. Bean moisture intake was assumed to be minimal and only on the shell. A 3:1 height to diameter aspect ratio was used to determine the dimensions of each sterilizer. Furthermore, the height is 2.27m and the diameter is 0.76m. The total bare module costs for the sterilizers is $325,19.

Winnowers

A winnowing step was required after each of the three sterilizers. This step was designed to take place after roasting occurred; pre-roasted beans allow the shell removal process to be less energy-intensive. Because air currents comprise the main component of the winnowing process, the winnowers were modeled as air cyclones. Shell separation patents maintained an acceptable range of 1,360-2,040 m^3/hr of air, linearly scaled to a range of 50-150 kg shells/hr (Kopp). An aspiration rate of 1,360 m^3/hr was chosen, as only 48 kg shells/hr were entering each winnower. Power requirements were extrapolated from a winnower manufacturer, who quoted a rate of 150 kW/(8000kg/hr) (Buhler). The total bare module cost of the winnowing machines was calculated to be $7,400 using the cyclone model presented by Seider, et. al.

Grinders

Like many other cocoa preprocessing arrangements, this process required two grinding steps: coarse and fine. Following the three parallel upstream flows, three grinders of each type were needed. The coarse grinders were characterized by an inlet flow of 5,340 kg/hr of cocoa nibs and a desired outlet particle diameter of 5 mm, thus dictating cone crushers as the most applicable choice for modeling purposes (Seider et al). This outlet particle size was ideal for feeding into the fine grinding steps, which brought the particles down to an average size of 10 μm (Buhler). In order to achieve such a small size, it was necessary to model the fine grinders as ball mills (Seider et al). The grinding steps required a power input of 206 kW, with a total bare module cost of $1,487,000.

Alkalizing Reactor

The reactor is required to alkalize cocoa liquor. The reaction is a neutralization reaction, resulting in a pH shift from 6 to 7 and improvements in taste and color of the cocoa mass. The alkalizing agent, potassium carbonate, is fed in a 3:97, potassium carbonate-to-cocoa mass ratio. The potassium carbonate was previously dissolved in a 1:10, potassium carbonate-to-water ratio. The reactor is constructed using stainless steel because it comes in contact with food, and is a closed vessel operating at 95°C and 1.5 bar. The residence time of the reactor is 30min. There is an associated heat duty of 667 kW.

Flash Evaporator Vessels

The purpose of isothermal flash evaporator T-401 is to reduce the moisture content of the alkalized cocoa liquor to 2% after having added 4805 kg/hr of water during the alkalization reaction. There is a pressure decrease from 1.50 bar to 0.30 bar, resulting in 4985 kg/hr of water being flashed off as vapor in the overhead. The bottoms stream is 16320 kg/hr of alkalized cocoa liquor. The evaporator operates at 95°C and has an associated heat duty of 3194 kW. The evaporator was constructed using stainless steel 304. The height is 3.7m and the diameter is 1m.

The purpose of T-601 is to isothermally vaporize most of the butane from the cocoa butter. The pressure is reduced from 6 to 1.6 bar, which results in 99.6% of the butane to flash off the cocoa butter. The flash vessel operates at 57ºC and has an associated heat duty of 4211 kW. The height of the vessel is 10 m and the diameter is 2.5 m.

Heat duty requirements of flash vessels T-401 and T-601 are serviced with 5761 kg/hr and 7595 kg/hr of steam, respectively.

Pumps

Nineteen pumps were required in this process; these pumps were mainly used to move slurry and liquid streams through the process. Pressure losses were assumed to be 0.4 bar through the pumps. Because the head values were relatively small, the pump size factors, calculated according to Seider, et. al., were all near the lower limits of the costing and power correlations. For pumps that fell below the lower limit of these correlations, costs were assumed to be equal to those at the limit; these values represent conservative estimates for the pump requirements. Both the pumps and motors were costed and analyzed according to Seider, et. al. All pumps were characterized as centrifugal, 3,600 rpm, VSC units. Each pump was constructed from stainless steel with a TEFC motor, in order to provide sufficient cleanliness and prevent the introduction of air into the process. The total bare module cost of the centrifugal pumps for this process is $313,500.

The Nash liquid ring pump is water sealed and has a suction volume of 1 ft3/min. The pumps are constructed from stainless steel 304, which is resistant to rust and easier to maintain at food grade quality levels than is carbon steel. The total bare module cost of the Nash liquid ring pump is $32,100.

Mixers

The purpose of the mixer included in the alkalization process was to dissolve potassium carbonate in a solution of water. Water was added in a 110, potassium carbonate-to-water ratio. The mixer was constructed using stainless steel 304 because the resulting alkalizing stream will come into contact with food material. The mixer was designed as a closed hopper and agitator at atmospheric pressure, with a residence time of 30 minutes. The bare module cost of this mixer was $123,900.

Section 500 required four mixers, which are each modeled as agitated, closed, vertical, stainless steel vessels. The mixers were sized with 30 minute residence times, in order to allow for proper mixing as well as disturbances to the steady-state process (Gusek). The first mixer, M-501, was required to maintain the suspension of the cocoa powder in the liquor stream. The power requirement was calculated using a heuristic of 0.75 kW/100 gal (Seider, et. al.). A turbine agitator was needed for this vessel, as the required power exceeded the limits of the propeller agitator. This mixer also required 17,960 kg/hr of cooling water to reduce the temperature of the liquor from 95ºC to 50ºC so that any butane added to the process would not vaporize. The final three mixers were all used for adding recycled butane to achieve desired solvent to cocoa ratios before the separation stages. For mixing the miscible butter and butane flows, a heuristic of 0.5 hp/1000 gal was employed; thus, propeller agitators were sufficient for these vessels (Seider, et. al.). The total bare module cost of the mixers in this section is $1,033,400.

<u>Filters</u>

Belt filters were used as the second and third stages for removing butter from the cocoa powder. The first filter, FL-501, was used to create the low fat powder, while the second filter, FL-502, was used for the production of fat-free powder. The process was designed such that varying amounts of each type of powder could be produced; potential low fat-free production ratios may range from 41 to 14, depending on market conditions. To allow versatility in these ratios, FL-502 was sized to accommodate up to 80% of the powder entering Section 500. While the filters are sized similarly, Fl-502 is unique due to the implementation of its washing machinery. Patent literature dictated that a stage modeled as a mixer and filter and series would be sufficient for reducing the fat content in the powder down to a range of 3-5%. However, to bring the fat content below this range, countercurrent solvent washing was necessary. FL-501 requires a solvent to cocoa mass ratio of 1.81:1 to reduce the fat content to 3.4%. FL-502 requires a ratio of 1.21, with the butane split equally between the inlet stream and the wash, to bring the fat content under 0.5% (Gusek).

BHS Sonthofen was instrumental in outlining the unit specifications and operating conditions; Mr. Barry Perlmutter provided these parameters in a unit quotation, which is given in Appendix D. Each filter has an active area of 98 m^2, requires 55 kW for operation, and moves at approximately 10 m/min (BHS Sonthofen). These filters operate at 50ºC and 6 bar in order to maintain butane in the liquid state. Mr. Perlmutter quoted a bare module cost of $900,000 for each filter before the addition of any optional equipment pieces; purchase costs were modeled as a vacuum belt filter, as outlined in Seider, et. al.

Like the centrifuge, the filters produce both wet cake and liquid streams. Again, powder and potassium carbonate were assumed to solely exist in the cake, while the filtration was assumed to significantly lower the proportions of butter, water, and solvent present. FL-501 had an inlet of 19,180 kg/hr of slurry; the filter was able to remove 69% of the liquid content, leaving 10,180 kg/hr of cake to be split between the low fat and fat-free processing streams. With the process set to create 20% of its powder at the fat-free specification, FL-502 removed 87% of the liquids from a 2,800 kg/hr inlet stream. Of the 1525 kg/hr of butane in this inlet stream, 380 kg/hr was mixed into the inlet, and another 380 kg/hr was used as the wash.

Centrifuge

The centrifuge was used as the first stage in separating the cocoa powder from the solvent and butter mixture. This process unit was modeled as a food-grade horizontal decanter, running continuously. The centrifuge takes on a 46,780 kg/hr flow of alkalized cocoa liquor and solvent, separating the inlet into liquid and cake outlets. The cocoa powder and potassium carbonate were assumed to exist solely in the cake phase, while the water, butter, and butane were assumed to comprise both the liquid phase and the cake fluid, as stated by Mr. Tieri. Based on Cargill's patent literature and Mr. Gusek's advice, this stage was expected to remove roughly 90% of the inlet liquid phase, bringing the fat content of the cocoa from 52% to 10% with an inlet solvent to cocoa mass ratio of 2.51 (Purtle et al, 2003). This separation produced 10,190 kg/hr of cake and 36,590 kg/hr of liquids.

The Alfa Laval Foodec 800 was used as a reference for this unit, as recommended by Mr. Ivan Gottberg of Alfa Laval. This model has a 480 mm diameter bowl constructed from duplex stainless steel, turning at a maximum of 3,500 rpm (Alfa Laval). Mr. Gottberg stated that a centrifuge of this size was appropriate given the inlet flow, and provided a bare module cost of approximately $300,000. The purchase cost was obtained using the costing of a continuous scroll solid bowl, as given in Seider, et. al.

Because centrifuging butane pressurized to 6 bar posed a significant risk for vaporization, a jacket of cooling water was added to the unit. The Foodec 800 requires 250 kW; this wattage was assumed to enter the process stream completely, as recommended by Mr. Richard Bockrath. To ensure isothermal centrifuging at 50ºC, cooling water was sent to the unit at 13,630 kg/hr.

Conveyors

There are 32 screw conveyors required in this process design. It was assumed that conveyor troughs were 30% full, and the screw was rotating at 50 rpm (Seider, et al). The screw diameters range from 15cm to 36 cm. Screw conveyors CY-503 and CY-505 were assumed to be completely full so as to maintain the back pressure of belt filters FL-501 and FL-502. This was recommended by Professor Len Fabiano so that the linear velocity of the powder entering the dryer could be controlled. The total bare module cost for these conveyors is $207,000.

Dryers

The dryers were modeled similarly to the mixers; both were vertical, closed, stainless steel vessels with propeller agitators. The vessels were sized to allow a 60 minute residence time; patent literature stated that agitation and pressure drop for this time period would be sufficient to vaporize the butane present with little need for temperature increase (Purtle et al., 2003). The dryers were maintained at 50ºC and 1.2 bar; medium pressure steam was used to hold the vessels at this temperature by offsetting the enthalpy requirements of the butane vaporization. Cargill's patent dictated that this method would be able to create a product with a butane mass fraction of 1 PPM (Purtle et al., 2003). This fraction was recommended by Mr. Tieri to be the safe limit for food products. The total bare module cost of these vessels is $513,000.

Heat Exchangers

There are 7 stainless steel heat exchangers in this process. All heat exchangers are countercurrent, shell and tube vessels with floating heads. Two of the heat exchangers are heat integrated, and the other exchangers have cooling water, chilled water, or refrigerant requirements. The combined bare module cost of these heat exchangers $1,368,586.

Decanters

There are two decanters in this process, both of which discharge wastewater. V-401 is required to induce a phase split between the water liquid and vapor that had been removed from the cocoa liquor in T-401. The decanter operates at 30°C and 0.3 bar. The liquid bottoms is 4985 kg/hr of water that is discharged as waste. The overhead is a 0.008 kg/hr vapor stream of water and air that is fed to the Nash liquid ring pump. The decanter is constructed using carbon steel because the decanter only contacts waste, and not food material. The height is 12 ft and the column diameter is 3.5 ft.

Similarly, V-601 is required to purge water from the solvent recycle stream. The decanter operates at 50ºC and 4 bar. The resulting concentration of water to outlet stream 621 is 301 PPM, making the decanter 96% efficient at purging water from recycle. The decanter is constructed as a stainless-steel. The length of the decanter is 7.30m and the diameter is 1.50m. The combined bare module costs for both decanters is $222,745.

Stripping Column

The stripping column's purpose was to remove residual butane from cocoa butter using 689 kg/hr of medium pressure process steam. The column was a modeled as a stainless-steel multi-stage tray tower with 3 theoretical stages and operating at 3.7 bar. The tray efficiency was assumed to be 70%; therefore, 5 actual trays were used for the column. The cocoa butter stream (609) entered above the top tray while steam entered on the bottom stage. The final cocoa butter product, the liquid bottoms of this column, has less than

500 PPB of butane. The height of the stripping column is 4.27m and the column diameter is 1.83m. The total bare module cost for the stripping column is $672,972.

6.2 Unit Specification Sheets

Section 100:

SILO 1			
Identification:	Item Item No. No. Required		*Silo* S-101 or 102 2
Function:	Storage and transition from batch to continuous		
Operation:	Batch in and continuous out		
Type:	Truncated Conical Silo		
Stream ID	**Inlet**	**Outlet**	
	101a/b	102a/b	
Temperature (C)	21	21	
		Flowrate (kg/hr)	20500
Composition (kg/batch)			
		Water	1004
	492001	Fat	8918
		Protein	2333
		Starch	984
		Cellulose	2563
		Ash	754
		Other	94661
Design Data:	Construction Material		Stainless Steel
	Max working volume (m^3)		819
	Hours of storage (max)		24
Total Purchase Cost:		$	59,427
Bare Module Cost:		$	63,837
Comments:	Bin and tank made of stainless steel. Volume of tank is 805 m^3 and volume of bin is 14 m^3. Pressure of tank is 3 psig.		

CONVEYOR 1		
Identification:	Item Item No. No. Required	*Conveyor* CY-101 1
Function:	To transport cocoa beans from the silo into the process	
Operation:	Continuous	
Type:	Screw Conveyor	
Stream ID	**Inlet**	**Outlet**
	102a/b	103,110,117
Flow rate (kg/hr)	20500	20500
Water	1004	1004
Fat	8918	8918
Protein	2333	2333
Starch	984	984
Cellulose	2563	2563
Ash	754	754
Other	3944	3944
Temperature (C)	21	21
Pressure (bar)	1	1
Design Data: Length (m)		16
Diameter (cm)		36
Velocity (m/s)		0.08
Total Purchase Cost:	$	9,925
Equipment Bare Module Cost:	$	17,164
Comments:	Cost doesn't include motor, drive, lid. Trough is 30% full and screw is rotating at 50 rpm.	

CONVEYOR 2			
Identification:		Item Item No. No. Required	*Conveyor* CY-102 until 110 9
Function:		To transport cocoa beans between upstream units	
Operation:		Continuous	
Type:		Screw Conveyor	
Stream ID		**Inlet**	**Outlet**
		103,110,117,105,112,119,107,114,121	104,111,118,106,113,120,108,115,122
Flow rate (kg/hr)		6834	6834
Water		335	335
Fat		2973	2973
Protein		778	778
Starch		328	328
Cellulose		854	854
Ash		251	251
Other		1315	1315
Temperature (C)		21	21
Pressure (bar)		1	1
Design Data:	Length (m)		5
	Diameter (cm)		26
	Velocity (m/s)		0.05
Total Purchase Cost:		$	3,619
Equipment Bare Module Cost:		$	6,259
Comments:		Cost doesn't include motor, drive, lid. Trough is 30% full and screw is rotating at 50 rpm.	

FINE CLEANER 1		
Identification:	Item Item No. No. Required	*Cleaner* C-104 until 106 3
Function:	To fine clean the cocoa beans	
Operation:	Continuous	
Type:	Cyclone Separator	

Stream ID	**Inlet**	**Outlet**
	106,113,120	107,114,121
Flow rate (kg/hr)	6834	6834
Water	335	335
Fat	2973	2973
Protein	778	778
Starch	328	328
Cellulose	854	854
Ash	251	251
Other	1315	1315
Temperature (C)	21	21
Pressure (bar)	1	1

Design Data:		
Airflow (m^3/hr)		2041
Total Purchase Cost:	$	2,672
Equipment Bare Module Cost:	$	2,871
Utilities Required/Year (kWh)		26147

COARSE CLEANER 1		
Identification:	Item	*Cleaner*
	Item No.	C-101 until 103
	No. Required	3
Function:	To coarse clean the cocoa beans	
Operation:	Continuous	
Type:	Vibrating Screen - 2 Deck	
Stream ID	**Inlet**	**Outlet**
	104,111,118	105,112,119
Flow rate (kg/hr)	6834	6834
Water	335	335
Fat	2973	2973
Protein	778	778
Starch	328	328
Cellulose	854	854
Ash	251	251
Other	1315	1315
Temperature (C)	21	21
Pressure (bar)	1	1
Design Data:	Screen Area (m^2)	11
	Load (Metric tonnes/hr-m^2-mm)	0.86
	Screen Type	20-Mesh
Total Purchase Cost:	$	49,387
Equipment Bare Module Cost:	$	91,779
Utilities Required/Year (kWh)		4909

DESTONER 1		
Identification:	Item Item No. No. Required	*Destoner* C-107 until 109 3
Function:	To destone the cocoa bean mixture	
Operation:	Continuous	
Type:	Vibrating Screen - 1 Deck	
Stream ID	**Inlet**	**Outlet**
	108,115,122	109,116,123
Flow rate (kg/hr)	6834	6834
Water	335	335
Fat	2973	2973
Protein	778	778
Starch	328	328
Cellulose	854	854
Ash	251	251
Other	1315	1315
Temperature (C)	21	21
Pressure (bar)	1	1
Design Data:	Screen Area (cm²)	7800
	Air Pressure (mBar)	12
	Aspiration (m³/min)	70.00
Total Purchase Cost:	$	6,342
Equipment Bare Module Cost:	$	11,785
Utilities Required/Year (kWh)		2454
Comments:	Screen model - MTSD-65/120	

Section 200:

WINNOWER 1			
Identification:	Item Item No. No. Required		*Winnower* W-201 until 203 3
Function:	To separate the cocoa nibs from the cocoa shells		
Operation:	Continuous		
Type:	Cyclone Separator		
Stream ID	**Inlet**	**Outlet**	
	205,214,223	206,215,224	208,217,226
Flow rate (kg/hr)	6666	1327	5340
Water	168	59	111
Fat	2989	20	2958
Protein	778	145	633
Starch	330	0	328
Cellulose	848	352	500
Ash	250	106	145
Other	1303	645	665
Temperature (C)	21	23	
Pressure (bar)	1	1	
Design Data:			
Airflow (m^3/hr)			1360
Total Purchase Cost:		$	2,291
Equipment Bare Module Cost:		$	2,461
Utilities Required/Year (kWh)			876512

ROASTER 1			
Identification:	Item		*Roaster*
	Item No.		R-201 until 203
	No. Required		3
Function:	To roast the cocoa beans		
Operation:	Continuous		
Type:	Vessel		
Stream ID	**Inlet**	**Outlet**	
	201,210,219	202,211,220	
Flow rate (kg/hr)	6834	6628	
Water	335	130	
Fat	2973	2972	
Protein	778	778	
Starch	328	328	
Cellulose	854	854	
Ash	251	251	
Other	1315	1275	
Temperature (C)	21	121	
Pressure (bar)	1	1	
Design Data:	Residence time (min)		30
	Diameter (m)		2
	Height (m)		2
Utilities Required/Year (kg)			6598908
Total Purchase Cost:		$	40,086
Equipment Bare Module Cost:		$	179,132
Comments:	205 kg/hr of steam is boiled off.		

STERILIZER 1		
Identification:	Item Item No. No. Required	*Cleaner* SZ-201 until 203 3
Function:	To sterilize the cocoa beans	
Operation:	Continuous	
Type:	Vessel	
Stream ID	**Inlet**	**Outlet**
	203,212,221	204,213,222
Flow rate (kg/hr)	6628	6666
Water	130	168
Fat	2972	2989
Protein	778	778
Starch	328	330
Cellulose	854	848
Ash	251	250
Other	1315	1303
Temperature (C)	121	138
Pressure (bar)	1	2.50
Design Data:	Residence time (min)	5
	Steam Flow rate (kg/hr)	928
	Diameter (m)	0.76
	Height (m)	2
Total Purchase Cost:	$	24,257
Equipment Bare Module Cost:	$	108,397
Comments:	34 kg/hr of steam condenses into the process stream.	

CONVEYOR 1			
Identification:	Item Item No. No. Required		*Conveyor* CY-201 until 203 3
Function:	To transport cocoa beans between upstream units		
Operation:	Continuous		
Type:	Screw Conveyor		
Stream ID	**Inlet**		**Outlet**
	109,116,123		201,210,219
Flow rate (kg/hr)	6834		6834
Water	335		335
Fat	2973		2973
Protein	778		778
Starch	328		328
Cellulose	854		854
Ash	251		251
Other	1315		1315
Temperature (C)	21		21
Pressure (bar)	1		1
Design Data:	Length (m)		5
	Diameter (cm)		26
	Velocity (m/s)		0.05
Total Purchase Cost:		$	3,619
Equipment Bare Module Cost:		$	6,259
Comments:	Cost doesn't include motor, drive, lid. Trough is 30% full and screw is rotating at 50 rpm.		

CONVEYOR 2		
Identification:	Item Item No. No. Required	*Conveyor* CY-204 until 206 3
Function:	Convey roasted beans to sterilizing units	
Operation:	Continuous	
Type:	Screw Conveyor	

Stream ID	**Inlet**	**Outlet**
	202,211,220	203,212,221
Flow rate (kg/hr)	6628	6628
Water	130	130
Fat	2,972	2,972
Protein	778	778
Starch	328	328
Cellulose	854	854
Ash	251	251
Other	1,315	1,315
Temperature (C)	121	121
Pressure (bar)	1	1

Design Data:	Length (m)	5
	Diameter (cm)	26
	Velocity (m/s)	0.05
Total Purchase Cost:	$	3,619
Equipment Bare Module Cost:	$	6,259
Comments:	Cost doesn't include motor, drive, lid. Trough is 30% full and screw is rotating at 50 rpm.	

CONVEYOR 3		
Identification:	Item Item No. No. Required	*Conveyor* CY-207 until 209 3
Function:	Convey sterilized beans to winnower	
Operation:	Continuous	
Type:	Screw Conveyor	

Stream ID	**Inlet**	**Outlet**
	204,213,222	205,214,223
Flow rate (kg/hr)	6666	6666
Water	168	168
Fat	2,989	2,989
Protein	778	778
Starch	330	330
Cellulose	848	848
Ash	250	250
Other	1,303	1,303
Temperature (C)	138	138
Pressure (bar)	2.50	2.50

Design Data:	Length (m)		5
	Diameter (cm)		26
	Velocity (m/s)		0.05
Total Purchase Cost:		$	3,619
Equipment Bare Module Cost:		$	6,259
Comments:	Cost doesn't include motor, drive, lid. Trough is 30% full and screw is rotating at 50 rpm.		

CONVEYOR 4		
Identification:	Item Item No. No. Required	*Conveyor* CY-210,212,214 3
Function:	To convey the shells to the furnace	
Operation:	Continuous	
Type:	Screw Conveyor	
Stream ID	**Inlet**	**Outlet**
	206,215,224	207,216,225
Flow rate (kg/hr)	1327	1327
Water	59	59
Fat	20	20
Protein	145	145
Starch	0	0
Cellulose	352	352
Ash	106	106
Other	645	645
Temperature (C)	23	23
Pressure (bar)	1	1
Design Data: Length (m)		5
Diameter (cm)		16
Velocity (m/s)		0.03
Total Purchase Cost:	$	2,172
Equipment Bare Module Cost:	$	3,756
Comments:	Cost doesn't include motor, drive, lid. Trough is 30% full and screw is rotating at 50 rpm.	

CONVEYOR 5		
Identification:	Item Item No. No. Required	*Conveyor* CY-211,213,215 3
Function:	To convey the cocoa nibs to Section 300	
Operation:	Continuous	
Type:	Screw Conveyor	
Stream ID	**Inlet**	**Outlet**
	208,217,226	209,218,227
Flow rate (kg/hr)	5340	5340
Water	111	111
Fat	2,958	2,958
Protein	633	633
Starch	328	328
Cellulose	500	500
Ash	145	145
Other	665	665
Temperature (C)	23	23
Pressure (bar)	1	1
Design Data:	Length (m)	5
	Diameter (cm)	23
	Velocity (m/s)	0.05
Total Purchase Cost:	$	3,257
Equipment Bare Module Cost:	$	5,633
Comments:	Cost doesn't include motor, drive, lid. Trough is 30% full and screw is rotating at 50 rpm.	

Section 300:

PUMP 1		
Identification:	Item Item No. No. Required	*Pump* P-301 until 303 3
Function:	Pump coarsely ground cocoa to fine grinder	
Operation:	Continuous	
Type:	**Centrifugal, 3600 RPM, VSC, 75 Hp**	
Stream ID	**Inlet**	**Outlet**
	302,305,308	303,306,309
Pressure (bar)	1	1
Design Data:	Flow Rate (kg/hr)	5340
	Brake Power (kW)	0.15
	Pump Head (m)	1
	Motor Efficiency	0.75
	Construction Material	Stainless Steel
Utilities required/year:	(kWh)	3964
Purchase Cost:	$	2,900
Bare Module Cost:	$	13,395
Associated Costs:	Motor $	407
Total Bare Module Cost:	$	13,802
Comments:	TEFC Enclosure. Costed with lower limit of size factor correlation; cost is an upper estimate.	

COARSE GRINDER 1		
Identification:	Item Item No. No. Required	*Grinder* G-301 until 303 3
Function:	To coarse grind the cocoa beans	
Operation:	Continuous	
Type:	Cone Crusher	
Stream ID	**Inlet**	**Outlet**
	209,218,228	302,305,308
Flow rate (kg/hr)	5340	5340
Water	111	111
Fat	2958	2958
Protein	633	633
Starch	328	328
Cellulose	500	500
Ash	145	145
Other	665	665
Temperature (C)	23	23
Pressure (bar)	1	1
Design Data:		
	Outlet particle size (mm)	5
Total Purchase Cost:	$	11,575
Equipment Bare Module Cost:	$	17,282
Utilities Required/Year (kWh)		141195
Comments:	The cone crusher is small enough to fit into the ball mill of the fine grinder.	

FINE GRINDER 1		
Identification:	Item Item No. No. Required	*Grinder* G-304 until 306 3
Function:	To fine grind the cocoa beans	
Operation:	Continuous	
Type:	Ball Mill	
Stream ID	**Inlet**	**Outlet**
	303,306,309	304,307,310
Flow rate (kg/hr)	5340	5340
Water	111	111
Fat	2958	2958
Protein	633	633
Starch	328	328
Cellulose	500	500
Ash	145	145
Other	665	665
Temperature (C)	21	21
Pressure (bar)	1	1
Design Data:		
	Outlet particle size (mm)	0.01
Total Purchase Cost:	$	193,642
Equipment Bare Module Cost:	$	478,424
Utilities Required/Year (kWh)		339914

Section 400:

PUMP 1		
Identification:	Item Item No. No. Required	*Pump* P-401 1
Function:	To pump potassium carbonate solution to R-401	
Operation:	Continuous	
Type:	Centrifugal	
Stream ID	**Inlet**	**Outlet**
	403	404
Pressure (bar)	1	1.50
Design Data:	Flow Rate (kg/hr)	5286
	Brake Horsepower (kW)	0.27
	Pump Head (m)	5
	Efficiency	0.75
	Construction Material	Stainless Steel
Utilities Required/Year (kWh)		3230
Purchase Cost:	$	3,300
Bare Module Cost:	$	14,100
Associated Costs:	Motor $	1,600
Total Bare Module Cost:	$	15,700
Comments:	Enclosure Type	

PUMP 2			
Identification:	Item Item No. No. Required		*Pump* P-402 1
Function:	Pump Cocoa Liquor to Alkalization Reactor		
Operation:	Continuous		
Type:	Centrifugal		
Stream ID	**Inlet**		**Outlet**
	304		405
Pressure (bar)	1		1.50
Design Data:	Flow Rate (kg/hr)		5340
	Brake Horsepower (kW)		0.0337
	Pump Head (m)		2
	Efficiency		0.75
	Construction Material		Stainless Steel
Utilities Required/Year (kWh)			700
Purchase Cost:		$	4,400
Bare Module Cost:		$	20,400
Associated Costs:	Motor	$	200
Total Bare Module Cost:		$	20,600
Comments:	Enclosure Type		

PUMP 3			
Identification:	Item Item No. No. Required		*Pump* P-403 1
Function:	Pump Cocoa Liquor to Alkalization Reactor		
Operation:	Continuous		
Type:	Centrifugal		
Stream ID	**Inlet**		**Outlet**
	307		406
Pressure (bar)	1		1.50
Design Data:	Flow Rate (kg/hr)		5340
	Brake Horsepower (kW)		0.0337
	Pump Head (m)		2
	Efficiency		0.75
	Construction Material		Stainless Steel
Utilities Required/Year (kWh)			700
Purchase Cost:		$	4,400
Bare Module Cost:		$	20,400
Associated Costs:	Motor	$	200
Total Bare Module Cost:		$	20,600
Comments:	Enclosure Type		

PUMP 4			
Identification:	Item Item No. No. Required		*Pump* P-404 1
Function:	Pump Cocoa Liquor to Alkalization Reactor		
Operation:	Continuous		
Type:	Centrifugal		
Stream ID	**Inlet**	**Outlet**	
	310	407	
Pressure (bar)	1	1.50	
Design Data:	Flow Rate (kg/hr)		5340
	Brake Horsepower (kW)		0.0337
	Pump Head (m)		2
	Efficiency		0.75
	Construction Material		Stainless Steel
Utilities Required/Year (kWh)			700
Purchase Cost:		$	4,400
Bare Module Cost:		$	20,400
Associated Costs:	Motor	$	200
Total Bare Module Cost:		$	20,600
Comments:	Enclosure Type		

PUMP 5			
Identification:	Item Item No. No. Required		*Pump* P-405 1
Function:	Vacuum Pull Wator Vapor		
Operation:	Continuous		
Type:	Liquid Ring, Water Sealed		
Stream ID	**Inlet**	**Outlet**	
	411	412	
Pressure (bar)	0.30	1.05	
Design Data:	Flow Rate (kg/hr)		0.008
	Efficiency		0.8
	Construction Material		Stainless Steel
Utilities Required/Year (kWh)			0.679
Purchase Cost:		$	10,000
Bare Module Cost:		$	32,100
Total Bare Module Cost:		$	32,100
Comments:	Suction Volume of 1 ft^3/min		

MIXER 1			
Identification:	Item Item No. No. Required		*Mixer* M-401 1
Function:	Mix water and potassium carbonate to form solution		
Operation:	Continuous		
Type:	Vertical Pressure Vessel		
Stream ID	**Inlet**	**Inlet**	**Outlet**
	401	402	403
Quantity (kg/hr)	4805	481	5286
Composition (kg/hr)			
Potassium Carbonate	0	481	0
Water	4805	0	4805
K+	0	0	272
CO3--	0	0	209
Temperature (C)	20	20	21.6
Pressure (bar)	1.01	1.01	1.01
Design Data:			
Construction Material			Stainless Steel
Utilities Required/Year (kWh)			27822
Purchase Cost:		$	26,800
Bare Module Cost:		$	121,000
Associated Costs:	Agitator ($/year)	$	1,700
	Hopper	$	1,300
Total Bare Module Cost:		$	124,000
Comments:	Closed Vessel at Atmospheric Pressure		

REACTOR 1			
Identification:	Item Item No. No. Required		*Reactor* R-401 1
Function:	To alkalize Cocoa Liquor		
Operation:	Continuous		
Type:	Vertical Tower		
Stream ID	**Inlet**		**Outlet**
	404	405,406,407	408
Flow rate (kg/hr)	5286	16020	21306
Water	4805	480	5286
Fat	0	8649	8650
Powder	0	6888	6888
K+	272	0	272
CO_3--	209	0	209
Temperature (C)	22	95	95
Pressure (bar)	1.50	1.50	1.50
Design Data:	Residence Time (min)		30
	Diameter (m)		1
	Height (m)		4
	Volume (m^3)		3
	Heat Duty (kW)		667
	Construction Material		Stainless Steel
Purchase Cost:		$	37,500
Toal Bare Module Cost:		$	161,300
Comments:	Closed Vessel		

H2O EVAPORATOR 1				
Identification:		Item		*Distillation Column*
		Item No.		T-401
		No. Required		1
Function:		To remove water from Cocoa Liquor		
Operation:		Continuous		
Type:		Flash Vessel		
Stream ID	**Feed**		**Bottoms**	**Overhead**
	408	415	413	409
Flow rate (kg/hr)	21306	0.029	16320	4168
Water	5286	0	301	4985
Fat	8650	0	8650	0
Powder	6888	0	6888	0
Potassium Carbonate	0	0	275	0
K+	272	0	116	0
CO_3--	209	0	89	0
N_2	0	0.022	0	0.022
O_2	0	0.007	0	0.007
Temperature (C)	95	20	95	95
Pressure (bar)	1.50	1	0.30	0.30
Design Data:	Height (m)			4
	Column Diameter (m)			1
	Heat Duty (kW)			3194
Purchase Cost:			$	21,900
Bare Module Cost:			$	91,300
Comments:		Closed Vessel Below Atmospheric Conditions		

DECANTER 1			
Identification:	Item Item No. No. Required		*Decanter* V-401 1
Function:	Phase Split Between Water Liquid and Vapor		
Operation:	Continuous		
Type:	Condenser		
Stream ID	**Feed**	**Bottoms**	**Overhead**
	410	414	411
Flow rate (kg/hr)	4985	4985	0.008
Water	4985	4985	0.001
N_2	0	0.021	0.006
O_2	0	0.006	0.001
Temperature (C)	30	28	28
Pressure (bar)	0.3	0.3	0.3
Design Data:	Height (m)		4
	Column Diameter (m)		1
Purchase Cost:		$	37,500
Bare Module Cost:		$	156,200
Comments:	Closed Vessel below Atmospheric Conditions		

HEAT EXCHANGER 1			
Identification:		Item Item No. No. Required	*Heat Exchanger* E-401 1
Function:		Condenses feed 409 to 410	
Operation:		Continuous	
Type:		Floating Head, Shell and Tube	
Stream ID	**Tube Side**		**Shell Side**
Inlet	Ethylene Glycol/Water (30:70)		409
Outlet	Ethylene Glycol/Water (30:70)		410
Flow rate (kg/hr)	120000		4985
Inlet Temperature (C)	25		95
Outlet Temperature (C)	46		30
Design Data:	Surface Area (m^2)		44
	Length (m)		3
	U (W/m^2-C)		2.38
	Fouling Resistance (m^2-C/W)		0.00053
	LMTD (C)		32
	Heat Duty (kW)		2852
	Construction Materials		Stainless Steel 304
Utilities Required/Year (kWh)			19986816
Purchase Cost:		$	21,000
Bare Module Cost:		$	157,200

Section 500:

MIXER 1		
Identification:	Item Item No. No. Required	*Mixer* M-501 1
Function:	Agitate cocoa liquor to maintain solid suspension	
Operation:	Continuous	
Type:	Vertical pressure vessel	
Stream ID	**Inlet**	**Outlet**
	501	502
Quantity (kg/hr)	16320	16320
Composition (kg/hr)		
Fat	8650	8650
Powder	6888	6888
Potassium Carbonate	480	480
Water	301	301
Butane	0	0
Temperature (C)	95	50
Pressure (bar)	1.50	2
Design Data:		
	Construction Material	Stainless Steel
	Diameter (m)	1.23
	Height (m)	3.69
Purchase Cost:	$	44,612
Bare Module Cost:	$	199,358
Associated Costs:	turbine agitator $	15,701
Total Bare Module Cost:	$	215,059
Utilities Required/Year:		125960510
Cooling Water (kg)		125900000
Electricity (kWh)		60510
Comments:	Closed vessel	

MIXER 2			
Identification:	Item		*Mixer*
	Item No.		M-502
	No. Required		1
Function:	Mix liquid butane with cocoa liquor		
Operation:	Continuous		
Type:	Vertical pressure vessel		
Stream ID	**Inlet**		**Outlet**
	503	626	504
Quantity (kg/hr)	16320	30460	46780
Composition (kg/hr)			
Fat	8650	0	8650
Powder	6888	0	6888
Potassium Carbonate	480	0	480
Water	301	0	301
Butane	0	30460	30460
Temperature (C)	50	50	50
Pressure (bar)	2	6	5
Design Data:			
	Construction Material		Stainless Steel
	Diameter (m)		2.58
	Height (m)		7.74
Purchase Cost:		$	125,896
Bare Module Cost:		$	562,587
Associated Costs:	propeller agitator	$	4,712
Total Bare Module Cost:		$	567,299
Utilities Required/Year:			
Electricity (kWh)			27890
Comments:	Closed vessel		

MIXER 3			
Identification:	Item Item No. No. Required		*Mixer* M-503 1
Function:	Create solvent:cocoa ratio of 1.8:1 with fresh butane		
Operation:	Continuous		
Type:	Vertical pressure vessel		
Stream ID	**Inlet**		**Outlet**
	509	627	510
Quantity (kg/hr)	10192	8990	19182
Composition (kg/hr)			
Fat	690	0	690
Powder	5747	0	5747
Potassium Carbonate	380	0	380
Water	34	0	34
Butane	3341	8990	12331
Temperature (C)	50	50	50
Pressure (bar)	6	6	6
Design Data:			
	Construction Material		Stainless Steel
	Diameter (m)		1.55
	Height (m)		4.64
Purchase Cost:	$		58,404
Bare Module Cost:	$		260,998
Associated Costs:	propeller agitator $		3,631
Total Bare Module Cost:	$		264,629
Utilities Required/Year:			
Electricity (kWh)			6021
Comments:	Closed vessel, part of first mixer-filter separation		

MIXER 4			
Identification:	Item		*Mixer*
	Item No.		M-504
	No. Required		1
Function:	Create solvent:cocoa ratio of 1.2:1 with fresh butane		
Operation:	Continuous		
Type:	Vertical pressure vessel		
Stream ID	**Inlet**		**Outlet**
	520	522	521
Quantity (kg/hr)	2035	380	2415
Composition (kg/hr)			
Fat	43	0	43
Powder	1149	0	1149
Potassium Carbonate	76	0	76
Water	2	0	2
Butane	765	380	1145
Temperature (C)	50	50	50
Pressure (bar)	6	6	6
Design Data:			
	Construction Material		Stainless Steel
	Diameter (m)		1.22
	Height (m)		3.67
Purchase Cost:	$		44,334
Bare Module Cost:	$		198,113
Associated Costs:	propeller agitator $		3,321
Total Bare Module Cost:	$		201,434
Utilities Required/Year:			
Electricity (kWh)			2977
Comments:	Closed vessel, part of second mixer-filter separation		

DRYER 1			
Identification:	Item		*Dryer*
	Item No.		D-501
	No. Required		1
Function:	Vaporize butane off of low fat cocoa powder		
Operation:	Continuous		
Type:	Vertical pressure vessel		
Stream ID	**Inlet**	**Outlet (vap)**	**Outlet (liq)**
	515	516	517
Quantity (kg/hr)	8141	3059	5082
Composition (kg/hr)			
Water	9	0	9
Powder	4598	0	4598
Butane	3059	3059	0
Fat	171	0	171
Potassium Carbonate	304	0	304
Temperature (C)	50	50	50
Pressure (bar)	6	1.20	1.20
Design Data:	Diameter (m)		1.52
	Height (m)		5
	Residence Time (min)		60
	Construction Material		Stainless Steel
Purchase Cost:		$	56,992
Bare Module Cost:		$	254,680
Associated Costs:	propeller agitator	$	3,593
Total Bare Module Cost:		$	258,273
Utilities Required/Year:			
Steam	(kg)		5873000
Electricity	(kWh)		5661
Comments:	Closed vessel, isothermal		

DRYER 2			
Identification:	Item Item No. No. Required		*Dryer* D-502 1
Function:	Vaporize butane off of nonfat cocoa powder		
Operation:	Continuous		
Type:	Vertical pressure vessel		
Stream ID	**Inlet**	**Outlet (vap)**	**Outlet (liq)**
	527	528	529
Quantity (kg/hr)	1434	203	1231
Composition (kg/hr)			
Water	0	0	0
Powder	1149	0	1149
Butane	203	203	0
Fat	6	0	6
Potassium Carbonate	76	0	76
Temperature (C)	50	50	50
Pressure (bar)	6	1.20	1.20
Design Data: Diameter (m)			1.52
Height (m)			5
Residence Time (min)			60
Construction Material			Stainless Steel
Purchase Cost:		$	56,992
Bare Module Cost:		$	254,680
Associated Costs:	propeller agitator	$	3,593
Total Bare Module Cost:		$	258,273
Utilities Required/Year:			
Steam (kg)			1557000
Electricity (kWh)			5661
Comments:	Closed vessel, isothermal		

FILTER 1			
Identification:	Item Item No. No. Required		*Filter* FL-501 1
Function:	Filter butter and solvent from powder cake		
Operation:	Continuous		
Type:	Rubber belt vacuum filter		
Stream ID	**Inlet**	**Outlet (cake)**	**Outlet (liq)**
	510	513	511
Quantity (kg/hr)	19182	10176	9006
Composition (kg/hr)			
Fat	690	214	476
Powder	5747	5747	0
Potassium Carbonate	380	380	0
Water	34	11	23
Butane	12331	3824	8507
Temperature (C)	50	50	50
Pressure (bar)	6	6	6
Design Data:			
Amount of solids in feed			6127
Filter Area (m^2)			98
Belt Speed (m/min)			10
Purchase Cost:		$	697,790
Bare Module Cost:		$	900,000
Utilities Required/Year:	(kWh)		385700
Comments:	BHS Sonthofen filter		

FILTER 2			
Identification:	Item Item No. No. Required		*Filter* FL-502 1
Function:	Wash remaining butter from powder cake		
Operation:	Continuous		
Type:	Rubber belt vacuum filter		
Stream ID	**Inlet**	**Outlet (cake)**	**Outlet (liq)**
	521, 523	526	524
Quantity (kg/hr)	2795	1434	1361
Composition (kg/hr)			
Fat	43	6	37
Powder	1149	1149	0
Potassium Carbonate	76	76	0
Water	2	0	2
Butane	1525	203	1322
Temperature (C)	50	50	50
Pressure (bar)	6	6	6
Design Data:			
Amount of solids in feed			1225
Filter Area (m^2)			98
Belt Speed (m/min)			10
Purchase Cost:		$	697,790
Bare Module Cost:		$	900,000
Utilities Required/Year:	(kWh)		385700
Comments:	BHS Sonthofen filter. 380 kg/hr of solvent enters as wash in stream 523		

CENTRIFUGE 1			
Identification:	Item Item No. No. Required		*Centrifuge* CFG-501 1
Function:	Separate powder from butter dissolved in solvent		
Operation:	Continuous		
Type:	Food-grade horizontal decanter		
Stream ID	**Inlet**	**Outlet (cake)**	**Outlet (liq)**
	505	508	506
Quantity (kg/hr)	46780	10192	36588
Composition (kg/hr)			
Powder	5747	5747	0
Butane	33414	3341	30073
Water	334	34	300
Fat	6905	690	6215
Potassium Carbonate	380	380	0
Temperature (C)	50	50	50
Pressure (bar)	6	6	6
Design Data:			
Amount of solids in feed (kg/hr)			6127
Motor Speed (rpm)			3477
Bowl Material			Duplex Stainless Steel
Bowl Diameter (mm)			480
Purchase Cost:		$	125,130
Bare Module Cost:		$	300,000
Utilities Required/Year:			
Cooling Water (kg)			95565000
Electricity (kWh)			1753200
Comments:	Continuous scroll solid bowl, Alfa Laval Foodec 800		

PUMP 1			
Identification:	Item Item No. No. Required		*Pump* P-501 1
Function:	Pump alkalized liquor to cooling/agitation vessel		
Operation:	Continuous		
Type:	**Centrifugal, 3600 RPM, VSC, 75 Hp**		
Stream ID	**Inlet**	**Outlet**	
	413	501	
Pressure (bar)	0.30	1.50	
Design Data:	Flow Rate (kg/hr)		13366
	Brake Power (kW)		0.60
	Pump Head (m)		7
	Motor Efficiency		0.79
	Construction Material		Stainless Steel
Utilities Required/Year:	(kWh)		9495
Purchase Cost:		$	2,900
Bare Module Cost:		$	13,395
Associated Costs:	Motor	$	474
Total Bare Module Cost:		$	13,869
Comments:	TEFC Enclosure. Costed with lower limit of size factor correlation; cost is an upper estimate.		

PUMP 2			
Identification:	Item Item No. No. Required		*Pump* P-502 1
Function:	Pump liquor to solvent mixing vessel		
Operation:	Continuous		
Type:	**Centrifugal, 3600 RPM, VSC, 75 Hp**		
Stream ID	**Inlet**		**Outlet**
	502		503
Pressure (bar)	1.50		1.50
Design Data:	Flow Rate (kg/hr)		13366
	Brake Power (kW)		0.24
	Pump Head (m)		3
	Motor Efficiency		0.76
	Construction Material		Stainless Steel
Utilities Required/Year:	(kWh)		3872
Purchase Cost:		$	2,900
Bare Module Cost:		$	13,395
Associated Costs:	Motor	$	431
Total Bare Module Cost:		$	13,826
Comments:	TEFC Enclosure. Costed with lower limit of size factor correlation; cost is an upper estimate.		

PUMP 3			
Identification:	Item		*Pump*
	Item No.		P-503
	No. Required		1
Function:	Pump solvent and liquor to centrifuge		
Operation:	Continuous		
Type:	**Centrifugal, 3600 RPM, VSC, 75 Hp**		
Stream ID	**Inlet**		**Outlet**
	504		505
Pressure (bar)	5		6
Design Data:	Flow Rate (kg/hr)		46780
	Brake Power (kW)		3
	Pump Head (m)		17
	Motor Efficiency		0.84
	Construction Material		Stainless Steel
Utilities Required/Year:	(kWh)		49379
Purchase Cost:		$	3,637
Bare Module Cost:		$	16,801
Associated Costs:	Motor	$	747
Total Bare Module Cost:		$	17,548
Comments:	TEFC Enclosure		

PUMP 4			
Identification:	Item		*Pump*
	Item No.		P-504
	No. Required		1
Function:	Pump centrifuged liquids to recovery section		
Operation:	Continuous		
Type:	Centrifugal, 3600 RPM, VSC, 75 Hp		
Stream ID	**Inlet**	**Outlet**	
	506	507	
Pressure (bar)	6	6	
Design Data:	Flow Rate (kg/hr)		36588
	Brake Power (kW)		1
	Pump Head (m)		8
	Motor Efficiency		0.81
	Construction Material		Stainless Steel
Utilities Required/Year:	(kWh)		18520
Purchase Cost:		$	3,300
Bare Module Cost:		$	15,242
Associated Costs:	Motor	$	533
Total Bare Module Cost:		$	15,775
Comments:	TEFC Enclosure		

PUMP 5			
Identification:	Item		*Pump*
	Item No.		P-505
	No. Required		1
Function:	Pump filtered liquids to recovery section		
Operation:	Continuous		
Type:	Centrifugal, 3600 RPM, VSC, 75 Hp		
Stream ID	**Inlet**	**Outlet**	
	511	512	
Pressure (bar)	6	6	
Design Data:	Flow Rate (kg/hr)		9006
	Brake Power (kW)		0.38
	Pump Head (m)		8
	Motor Efficiency		0.78
	Construction Material		Stainless Steel
Utilities Required/Year:	(kWh)		6081
Purchase Cost:		$	2,900
Bare Module Cost:		$	13,395
Associated Costs:	Motor	$	451
Total Bare Module Cost:		$	13,846
Comments:	TEFC Enclosure. Costed with lower limit of size factor correlation; cost is an upper estimate.		

PUMP 6			
Identification:	Item		*Pump*
	Item No.		P-506
	No. Required		1
Function:	Pump filtered liquids to recovery section		
Operation:	Continuous		
Type:	Centrifugal, 3600 RPM, VSC, 75 Hp		
Stream ID	**Inlet**		**Outlet**
	524		525
Pressure (bar)	6		6
Design Data:	Flow Rate (kg/hr)		1361
	Brake Power (kW)		0.33
	Pump Head (m)		8
	Motor Efficiency		0.77
	Construction Material		Stainless Steel
Utilities Required/Year:	(kWh)		5275
Purhase Cost:		$	2,900
Bare Module Cost:		$	13,395
Associated Costs:	Motor	$	445
Total Bare Module Cost:		$	13,840
Comments:	TEFC Enclosure. Costed with lower limit of size factor correlation; cost is an upper estimate.		

CONVEYOR 1		
Identification:	Item	*Conveyor*
	Item No.	CY-501
	No. Required	1
Function:	Convey centrifuged solids to first mixer-filter	
Operation:	Continuous	
Type:	Screw Conveyor	

Stream ID	**Inlet**	**Outlet**
	508	509
Flow rate (kg/hr)	10192	10192
Water	34	34
Fat	690	690
Powder	5747	5747
Butane	3341	3341
K_2CO_3 (S)	380	380
Temperature (C)	50	50
Pressure (bar)	6	6

Design Data:	Length (m)	5
	Diameter (cm)	31
	Velocity (m/s)	0.05
Total Purchase Cost:	$	4,343
Equipment Bare Module Cost:	$	7,511
Comments:	Cost doesn't include motor, drive, lid. Trough is 30% full and screw is rotating at 50 rpm.	

CONVEYOR 2		
Identification:	Item Item No. No. Required	*Conveyor* CY-502 1
Function:	Convey low-fat cake to second mixer-filter	
Operation:	Continuous	
Type:	Screw Conveyor	
Stream ID	**Inlet**	**Outlet**
	519	520
Flow rate (kg/hr)	2035	2035
Water	2	2
Fat	43	43
Powder	1149	1149
Butane	765	765
K_2CO_3 (S)	76	76
Temperature (C)	50	50
Pressure (bar)	6	6
Design Data: Length (m)		5
Diameter (cm)		18
Velocity (m/s)		0.03
Total Purchase Cost:	$	2,533
Equipment Bare Module Cost:	$	4,382
Comments:	Cost doesn't include motor, drive, lid. Trough is 30% full and screw is rotating at 50 rpm.	

CONVEYOR 3		
Identification:	Item Item No. No. Required	*Conveyor* CY-503 1
Function:	Convey low fat cake to solvent dryer	
Operation:	Continuous	
Type:	Screw Conveyor	

Stream ID	**Inlet**	**Outlet**
	514	515
Flow rate (kg/hr)	8141	8141
Water	9	9
Fat	171	171
Powder	4598	4598
Butane	3059	3059
K_2CO_3 (S)	304	304
Temperature (C)	50	50
Pressure (bar)	6	6

Design Data:	Length (m)		5
	Diameter (cm)		28
	Velocity (m/s)		0.05
Total Purchase Cost:		$	3,981
Equipment Bare Module Cost:		$	6,885
Comments:	Cost doesn't include motor, drive, lid. Trough is 30% full and screw is rotating at 50 rpm.		

CONVEYOR 4			
Identification:	Item Item No. No. Required		*Conveyor* CY-504 1
Function:	Convey low fat powder to packaging units		
Operation:	Continuous		
Type:	Screw Conveyor		
Stream ID	**Inlet**		**Outlet**
	517		518
Flow rate (kg/hr)	5082		5082
Water	9		9
Fat	171		171
Powder	4598		4598
Butane	0		0
K_2CO_3 (S)	304		304
Temperature (C)	50		50
Pressure (bar)	1.20		1.20
Design Data:	Length (m)		5
	Diameter (cm)		23
	Velocity (m/s)		0.05
Total Purchase Cost:		$	3,257
Equipment Bare Module Cost:		$	5,633
Comments:	Cost doesn't include motor, drive, lid. Trough is 30% full and screw is rotating at 50 rpm.		

CONVEYOR 5		
Identification:	Item Item No. No. Required	*Conveyor* CY-505 1
Function:	Convey nonfat powder to solvent dryer	
Operation:	Continuous	
Type:	Screw Conveyor	

Stream ID	**Inlet**	**Outlet**
	526	527
Flow rate (kg/hr)	1434	1434
Water	0.28	0.28
Fat	6	6
Powder	1149	1149
Butane	203	203
K_2CO_3 (S)	76	76
Temperature (C)	50	50
Pressure (bar)	6	6

Design Data:		
	Length (m)	5
	Diameter (cm)	16
	Velocity (m/s)	0.03
Total Purchase Cost:	$	2,172
Equipment Bare Module Cost:	$	3,756
Comments:	Cost doesn't include motor, drive, lid. Trough is 30% full and screw is rotating at 50 rpm.	

CONVEYOR 6			
Identification:	Item Item No. No. Required		*Conveyor* CY-506 1
Function:	Convey nonfat powder to packaging units		
Operation:	Continuous		
Type:	Screw Conveyor		
Stream ID	**Inlet**	**Outlet**	
	529	530	
Flow rate (kg/hr)	1231	1231	
Water	0.28	0.28	
Fat	6	6	
Powder	1149	1149	
Butane	0	0	
K_2CO_3 (S)	76	76	
Temperature (C)	50	50	
Pressure (bar)	1.20	1.20	
Design Data:	Length (m)		5
	Diameter (cm)		16
	Velocity (m/s)		0.03
Total Purchase Cost:		$	2,172
Equipment Bare Module Cost:		$	3,756
Comments:	Cost doesn't include motor, drive, lid. Trough is 30% full and screw is rotating at 50 rpm.		

Section 600:

HEAT EXCHANGER 1		
Identification:	Item Item No. No. Required	*Heat Exchanger* E-601 1
Function:	Condenses feed 601 to 602	
Operation:	Continuous	
Type:	Floating Head, Shell and Tube	
Stream ID	**Tube Side**	**Shell Side**
Inlet	Ethylene Glycol/Water (30:70)	601
Outlet	Ethylene Glycol/Water (30:70)	602
Flow rate (kg/hr)	35750	3262
Inlet Temperature (C)	-12	53
Outlet Temperature (C)	0	4
Design Data:	Surface Area (m²)	140
	Length (m)	6
	U (W/m²-C)	315
	Fouling Resistance (m²-C/W)	0.00053
	LMTD (C)	31
	Heat Duty (kW)	423
	Construction Material	Stainless Steel 316
Utilities Required/Year (kWh)		2961581
Purchase Cost:	$	31,419
Bare Module Cost:	$	205,175

HEAT EXCHANGER 2			
Identification:		Item Item No. No. Required	*Heat Exchanger* E-602 1
Function:		Partially vaporizes feed into flash T-601	
Operation:		Continuous	
Type:		Floating Head, Shell and Tube	
Stream ID		**Tube Side**	**Shell Side**
Inlet		605	611
Outlet		606	612
Flow rate (kg/hr)		50217	7402
Inlet Temperature (C)		149	47
Outlet Temperature (C)		80	52
Design Data:	Surface Area (m²)		38
	Length (m)		5
	U (W/m²-C)		174
	LMTD (C)		59
	Fouling Resistance (m²-C/W)		0.0007
	Heat Duty (kW)		355
	Construction Materials		Stainless Steel 316
Utilities Required/Year (kWh)			0
Purchase Cost:		$	20,467
Bare Module Cost:		$	135,533

HEAT EXCHANGER 3		
Identification:	Item Item No. No. Required	*Heat Exchanger* E-603 1
Function:	Cools cocoa butter before packaging	
Operation:	Continuous	
Type:	Floating Head, Shell and Tube	
Stream ID	**Tube Side**	**Shell Side**
Inlet	Cooling Water	612
Outlet	Cooling Water	613
Flow rate (kg/hr)	7905	7402
Inlet Temperature (C)	32	80
Outlet Temperature (C)	48	50
Design Data:	Surface Area (m²)	28
	Length (m)	5
	U (W/m²-C)	256
	LMTD (C)	21
	Fouling Resistance (m²-C/W)	0.00053
	Heat Duty (kW)	144
	Construction Materials	Stainless Steel 316
Utilities Required/Year (kWh)		1009152
Purchase Cost:	$	19,271
Bare Module Cost:	$	127,069

HEAT EXCHANGER 4			
Identification:		Item Item No. No. Required	*Heat Exchanger* E-604 1
Function:		Condenses vapor effluent from T-601	
Operation:		Continuous	
Type:		Floating Head, Shell and Tube	
Stream ID	**Tube Side**		**Shell Side**
Inlet	Ethylene Glycol/Water (30:70)		617
Outlet	Ethylene Glycol/Water (30:70)		618
Flow rate (kg/hr)	400000		43308
Inlet Temperature (C)	-12		56.9
Outlet Temperature (C)	2		8.3
Design Data:	Surface Area (m²)		823
	Length (m)		6
	U (W/m²-C)		162
	LMTD (C)		17
	Fouling Resistance (m²-C/W)		0.00061
	Heat Duty (kW)		5670
	Construction Materials		Stainless Steel 316
Utilities Required/Year (kWh)			39735360
Purchase Cost:		$	91,880
Bare Module Cost:		$	635,819

HEAT EXCHANGER 5			
Identification:		Item	*Heat Exchanger*
		Item No.	E-605
		No. Required	1
Function:		Condenses overhead of stripping column	
Operation:		Continuous	
Type:		Floating Head, Shell and Tube	
Stream ID		**Tube Side**	**Shell Side**
Inlet		608	609
Outlet		609	614
Flow rate (kg/hr)		6909	196
Inlet Temperature (C)		57	101
Outlet Temperature (C)		59	77
Design Data:	Surface Area (m²)		3
	Length (m)		2.4
	U (W/m²-C)		122
	LMTD (C)		28
	Fouling Resistance (m²-C/W)		0.0007
	Heat Duty (kW)		8
	Construction Materials		Stainless Steel 316
Utilities Required/Year (kWh)			0
Purchase Cost:		$	18,075
Bare Module Cost:		$	132,630

HEAT EXCHANGER 6		
Identification:	Item Item No. No. Required	*Heat Exchanger* E-606 1
Function:	Completely condenses butane overhead from stripping column	
Operation:	Continuous	
Type:	Floating Head, Shell and Tube	
Stream ID	**Tube Side**	**Shell Side**
Inlet	Chilled Water	614
Outlet	Chilled Water	615
Flow rate (kg/hr)	3034	196
Inlet Temperature (C)	7	71
Outlet Temperature (C)	13	30
Design Data:	Surface Area (m^2)	4.1
	Length (m)	2.40
	U (W/m^2-C)	133
	LMTD (C)	44
	Fouling Resistance (m^2-C/W)	0.0007
	Heat Duty (kW)	23
	Construction Materials	Stainless Steel 316
Utilities Required/Year (kWh)		161184
Purchase Cost:	$	18,075
Bare Module Cost:	$	132,630

PUMP 1			
Identification:	Item Item No. No. Required		*Pump* P-601 1
Function:	To pump feed into E-602		
Operation:	Continuous		
Type:	Centrifugal Pump		
Stream ID	**Inlet**		**Outlet**
	602		603
Pressure (bar)	1.50		6
Design Data:	Flow Rate (kg/hr)		3262
	Brake Power (kW)		3
	Pump Head (m)		83
	Motor Efficiency		0.83
	Construction Material		Stainless Steel
Utilities Required/Year (kWh)			39805
Purchase Cost:		$	2,903
Bare Module Cost:		$	13,410
Associated Costs:	Motor	$	1,828
Total Bare Module Cost:		$	15,238
Comments:	Totally Enclosed, Fan cooled, 1 to 250 Hp, 3600 RPM		

PUMP 2			
Identification:	Item Item No. No. Required		*Pump* P-602 1
Function:	To pump flash liquid effluent to T-602		
Operation:	Continuous		
Type:	Centrifugal Pump		
Stream ID	**Inlet**	**Outlet**	
	607	608	
Pressure (bar)	1.60	6	
Design Data:	Flow Rate (kg/hr)		6909
	Brake Power (kW)		2
	Pump Head (m)		35
	Motor Efficiency		0.83
	Construction Material		Stainless Steel
Utilities Required/Year (kWh)			31606
Purchase Cost:		$	2,908
Bare Module Cost:		$	13,432
Associated Costs:	Motor	$	1,779
Total Bare Module Cost:		$	15,211
Comments:	Totally Enclosed, Fan cooled, 1 to 250 Hp, 3600 RPM		

PUMP 3			
Identification:	Item		*Pump*
	Item No.		P-603
	No. Required		1
Function:	To pump condensed butane to V-601		
Operation:	Continuous		
Type:	Centrifugal Pump		
Stream ID	**Inlet**		**Outlet**
	618		619
Pressure (bar)	1.60		4
Design Data:	Flow Rate (kg/hr)		43308
	Brake Power (kW)		7
	Pump Head (m)		42
	Motor Efficiency		0.86
	Construction Material		Stainless Steel
Utilities Required/Year (kWh)			109605
Purchase Cost:		$	3,939
Bare Module Cost:		$	18,195
Associated Costs:	Motor	$	3,396
Total Bare Module Cost:		$	21,591
Comments:	Totally Enclosed, Fan cooled, 1 to 250 Hp, 3600 RPM		

PUMP 4			
Identification:	Item		*Pump*
	Item No.		P-604
	No. Required		1
Function:	To pump overhead of T-602 to V-601		
Operation:	Continuous		
Type:	Centrifugal Pump		
Stream ID	**Inlet**	**Outlet**	
	615	616	
Pressure (bar)	3.70	4	
Design Data:	Flow Rate (kg/hr)		196
	Brake Power (kW)		0.76
	Pump Head (m)		5
	Motor Efficiency		0.80
	Construction Material		Stainless Steel
Utilities Required/Year (kWh)			10652
Purchase Cost:		$	2,900
Bare Module Cost:		$	13,395
Associated Costs:	Motor	$	473
Total Bare Module Cost:		$	13,868
Comments:	Totally Enclosed, Fan cooled, 1 to 250 Hp, 3600 RPM		

PUMP 5			
Identification:	Item Item No. No. Required		*Pump* P-605 1
Function:	To pump recycled butane to storage tank		
Operation:	Continuous		
Type:	Centrifugal Pump		
Stream ID	**Inlet**		**Outlet**
	621		622
Pressure (bar)	1.60		4
Design Data:	Flow Rate (kg/hr):		43176
	Brake Power (kW):		7
	Pump Head (m):		38
	Motor Efficiency		0.86
	Construction Material:		Stainless Steel
Utilities Required/Year (kWh)			103088
Purchase Cost:		$	3,939
Bare Module Cost:		$	18,195
Associated Costs:	Motor	$	3,396
Total Bare Module Cost:		$	21,591
Comments:	Totally Enclosed, fan cooled, 1 to 250 Hp, 3600 RPM		

PUMP 6		
Identification:	Item Item No. No. Required	*Pump* P-606 1
Function:	To pump recycled butane to section 500	
Operation:	Continuous	
Type:	Centrifugal Pump	
Stream ID	**Inlet**	**Outlet**
	624	625
Pressure (bar)	5.70	6
Design Data:	Flow Rate (kg/hr)	43176
	Brake Power (kW)	1
	Pump Head (m)	6
	Motor Efficiency	0.86
	Construction Material	Stainless Steel
Utilities Required/Year (kWh)		16195
Purchase Cost:	$	3,237
Bare Module Cost:	$	14,951
Associated Costs:	Motor $	1,477
Total Bare Module Cost:	$	16,428
Comments:	Totally Enclosed, Fan cooled, 1 to 250 Hp, 3600 RPM	

DECANTER 1				
Identification:	Item Item No. No. Required			*Decanter* V-601 1
Function:	To purge water from butane recycle			
Operation:	Continuous			
Type:	Horizontal Pressure Vessel			
Stream ID	**Inlet**		**Outlet**	
	619	616	621	620
Flow rate (kg/hr)	43308	196	43176	328
Water	324	15	13	327
Butane	42984	181	43163	1
Fat	Trace	Trace	0	0
Temperature (C)	9.90	32.30	50	50
Pressure (bar)	4	4	4	4
Design Data:	Length (m)			7.30
	Diameter (m)			1.50
	Material			Stainless Steel 316
Purchase Cost:			$	73,031
Bare Module Cost:			$	222,745

STORAGE TANK 1			
Identification:	Item Item No. No. Required		*Storage Tank* V-602 1
Function:	To add butane to recycle stream		
Operation:	Continuous		
Type:	Spherical (30-200 psig)		
Stream ID	**Inlet**		**Outlet**
	622	623	624
Flow rate (kg/hr)	43176	1	43177
Water	13	0	13
Butane	43163	1	43164
Fat	0	0	0
Temperature (C)	50	50	53
Pressure (bar)	6	6	6
Design Data:	Construction Material		Stainless Steel 316
	Max working volume (m³)		20
	Residence Time (min)		15
Purchase Cost:		$	37,521
Bare Module Cost:		$	40,305

STRIPPING COLUMN 1				
Identification:		Item Item No. No. Required		*Stripping Column* T-602 1
Function:		To desolventize residual butane from cocoa butter		
Operation:		Continuous		
Type:		Multi-stage Stripping Column		
Stream ID		**Top Feed**	**Bottoms**	**Overhead**
		609	611	629
Flow rate (kg/hr)		6909	7402	196
Water		1	675	15
Butane		181	0	181
Fat		6727	6727	Trace
Temperature (C)		59	149	101
Pressure (bar)		6	3.9	3.7

Design Data:	Height (m)	4.27	Tray Efficiency	0.7
	Column Diameter (m)	1.83	Tray Spacing (m)	0.61
	Number of Trays	5	Top Stage Pressure (bar)	3.7
	Feed Stage	1	Stage Pressure Drop (bar)	0.1
	Material	SS 316		
Medium Pressure Process Steam (kg/hr)				689
Purchase Cost:		$		150,598
Bare Module Cost:		$		672,972
Comments:		Steam entering process is accounted for in material balance		

FLASH EVAPORATOR COLUMN 1			
Identification:	Item Item No. No. Required		*Flash Vessel* T-601 1
Function:	To evaporate butane from cocoa butter product		
Operation:	Continuous		
Type:	Vertical Flash Vessel		
Stream ID	**Inlet**	**Outlet**	
	606	607	617
Flow rate (kg/hr)	50217	43309	6909
Water	326	325	2
Butane	43164	42984	180
Fat	6727	Trace	6727
Temperature (C)	52	57	57
Pressure (bar)	6	1.60	1.60
Utilities Required/Year (kWh)			29510688
Design Data:	Height (m)		10
	Column Diameter (m)		2.50
	Material		Stainless Steel 316
Purchase Cost:		$	156,214
Bare Module Cost:		$	698,069

Section 7: Equipment Cost Summary

Table 9 details the itemized and total bare module costs for all equipment units in the plant. The total bare module cost for this cocoa processing facility is $12.7M. The costs are a result of the stainless steel construction of all equipment units. This constraint must be set to reduce the risk of contamination in the plant, and ensure that the plant's products are of Food Grade quality.

The Pannevis filters were the greatest equipment costs in the process ($1.8M), accounting for 16% of the total bare module costs. The filters were essential in the solvent extraction technology exploited in this process. The packaged steam boiler had the second greatest equipment cost, but was necessary to reduce overall utility costs in this process.

Table 9. Equipment Cost Summary.

Unit Name	**C_p**	**F_{BM}**	**Associated Costs**	**C_{BM}**	**Quantity**	**Total CBM**
Storage Tanks						
Silos (S-101,102,Spare)	$59,427	1	$0	$63,837	3	$191,511
V-602	$37,521	1	$0	$40,305	1	$40,305
Subtotal						$231,816
Cleaners						
C-101-103	$49,387	1.86	$0	$91,779	3	$275,337
C-104-106	$2,672	1.07	$0	$2,871	3	$8,612
C-107-109	$6,342	1.86	$0	$11,785	3	$35,356
SZ-201-203	$24,257	4.47	$0	$108,397	3	$325,190
Subtotal						$644,495
Conveyors						
CY-101	$9,924	1.61	$0	$17,164	2	$34,328
CY-102-209	$3,619	1.61	$0	$6,259	18	$112,662
CY-210,212,214	$2,172	1.61	$0	$3,756	3	$11,268
CY-211,213,215	$3,257	1.61	$0	$5,633	3	$16,899
CY-501	$4,343	1.61	$0	$7,511	1	$7,511
CY-502	$2,533	1.61	$0	$4,382	1	$4,382
CY-503	$3,981	1.61	$0	$6,885	1	$6,885
CY-504	$3,257	1.61	$0	$5,633	1	$5,633
CY-505	$2,172	1.61	$0	$3,756	1	$3,756
CY-506	$2,172	1.61	$0	$3,756	1	$3,756
Subtotal					32	$207,080
Roasters						
R-201-203	$40,086	4.47	$0	$179,132	3	$537,396
Subtotal						$537,396
Winnowers and Grinders						
W-201-203	$2,291	1.07	$0	$2,461	3	$7,382
G-301-303	$11,575	1.49	$0	$17,282	3	$51,847
G-304-306	$193,642	2.47	$0	$478,424	3	$1,435,272
Subtotal						$1,494,501
Mixing Tanks						
M-401	$26,800	4.51	$3,000	$120,868	1	$123,868
M-501	$44,612	4.47	$15,701	$199,358	1	$215,059
M-502	$125,896	4.47	$4,712	$562,587	1	$567,299
M-503	$58,404	4.47	$3,631	$260,998	1	$264,629
M-504	$44,334	4.47	$3,321	$198,113	1	$201,434
Subtotal						$1,372,289
Reactor						
R-401	$37,500	4.3	$0	$161,250	1	$161,250
Subtotal						$161,250
Flash Vessels						
T-401	$21,900	4.17	$0	$91,323	1	$91,323
T-601	$156,214	4.3	$0	$698,069	1	$698,069
Subtotal						$789,392

Pumps						
P-301-303	$2,900	3.4	$407	$13,395	3	$41,406
P-401	$3,300	3.4	$1,600	$14,100	1	$15,700
P-402-404	$4,400	3.4	$200	$20,400	3	$61,800
P-405	$10,000	3.21	$0	$32,100	1	$32,100
P-501	$2,900	3.4	$474	$13,395	1	$13,869
P-502	$2,900	3.4	$431	$13,395	1	$13,826
P-503	$3,637	3.4	$747	$16,801	1	$17,548
P-504	$3,300	3.4	$533	$15,242	1	$15,776
P-505	$2,900	3.4	$451	$13,395	1	$13,846
P-506	$2,900	3.4	$445	$13,395	1	$13,840
P-601	$2,903	3.4	$1,828	$13,410	1	$15,238
P-602	$2,908	3.4	$1,779	$13,432	1	$15,211
P-603	$3,939	3.4	$3,396	$18,195	1	$21,591
P-604	$2,900	3.4	$473	$13,868	1	$14,341
P-605	$3,939	3.4	$3,396	$18,195	1	$21,591
P-606	$3,237	3.4	$1,477	$16,428	1	$17,905
Subtotal					20	$345,588
Heat Exchangers						
E-401	$21,100	3.17	$0	$157,155	1	$157,155
E-601	$31,419	3.17	$0	$205,175	1	$205,175
E-602	$20,467	3.17	$0	$135,533	1	$135,533
E-603	$19,271	3.17	$0	$127,069	1	$127,069
E-604	$91,880	3.17	$0	$635,819	1	$635,819
E-605	$18,075	3.17	$0	$132,630	1	$132,630
E-606	$18,075	3.17	$0	$132,360	1	$132,360
Subtotal						$1,368,586
Decanters						
V-401	$37,500	4.17	$0	$156,200	1	$156,200
V-601	$73,031	3.05	$0	$222,745	1	$222,745
Subtotal						$378,945

Filters						
FL-501-502	$697,790	1.29	$0	$900,000	2	$1,800,000
Subtotal						$1,800,000
Centrifuge						
CFG-501	$125,130	2.4	$0	$300,000	1	$300,000
Subtotal						$300,000
Dryers						
D-501-502	$56,992	4.47	$3,593	$254,680	2	$512,954
Subtotal						$512,954
Stripping Column						
T-602	$150,598	4.3	$0	$672,972	1	$672,972
Subtotal						$672,972
Furnace						
Packaged Steam Boiler	$351,628	2.35	$0	$827,205	1	$827,205
Subtotal						$827,205
Refrigerator						
Refrigerant Chiller	$519,491	2.35	$0	$1,220,803	1	$1,220,803
Subtotal						$1,220,803
TOTAL						$12,704,022

Section 8: Operating Cost - Cost of Manufacture

The plant's variable costs are broken down into raw materials, utility costs, labor costs, and other general expenses that scale with production. The general summary of all costs and investments is shown in the Economic Analysis section, Figure 11.

Section 9: Other Important Considerations

9.1 Plant Location, Layout and Startup

The solvent extraction processing facility will be built in Ghana. There were two considerations that led to this decision, labor cost and cocoa bean supply. Ghana and Brazil are two very different countries, excluding the fact that their environment makes them ideal locations for cocoa trees. In Ghana, cocoa is central to the economy; production accounts for around a sixth of the country's GDP (WorldAtlas, 2015).

Labor costs in Ghana and Brazil differ. In Ghana, a high skilled worker's pay is approximately $417/month whereas a high skilled worker's pay in Brazil is $891/month (GIPC, 2016). A low skilled worker's wage in Brazil is $265/month as compared to a salary of $165/month in Ghana for a semi-skilled worker (Trading Economics, 2016). The solvent extraction processing facility will hire 4-6 skilled workers to maintain the continuous process and 6-10 semi-skilled workers to manage loading, the control room, and other such tasks. In terms of labor costs, a facility in Ghana will cost less to operate.

Though Brazil is an up and coming market for chocolate, it is not yet ready to export chocolate. BMI Research conducted an analysis on the Brazilian market and concluded that Brazil will not reaffirm itself as a net exporter over the coming years because of limited production growth (BMI Research, 2016). Brazil is projected to collect 216,000 tonnes/year in 2023/24 (Pekic, 2014). This is a fourth of the amount that Ghana is estimated to collect this year (Dunn, 2016), who is the second largest producer to the Ivory Coast. Brazil has also experienced a recent depression that BMI concludes will influence future projections for local chocolate consumption. In 2020, the local consumption is expected to reach 270,000 tonnes (BMI Research, 2016). The solvent extraction processing facility will have a capacity of 120,000 tonnes per year. If it were to serve the Brazilian market, this would constitute a 44% share of the market which is too large to expect reasonable.

Logistically, farmers in Ghana sell their supply of cocoa beans to a Licensed Buying Company, which then distributes to processing companies. From them, the facility will be receiving a truckloads of cocoa beans to feed into the process. The plant will largely involve three streams in parallel with equipment spaced out 5 feet with 10-15 feet in between the three parallel units.

9.2 Water Management

To treat cocoa liquor with potassium carbonate as an alkalizing salt, a 10% solution of potassium carbonate dissolved in water is needed. With 401.8 kg/hr of potassium carbonate being added, a 4018 kg/hr stream of process water will be added without recycle. 4168 kg/hr of water vapor will be flashed off of the alkalized cocoa liquor product to be condensed. During the solvent recovery process, 150 kg/hr of 20 psig steam at 130°C will be added.

9.3 Filter Buildup

Both filters following centrifugation will be cleaned and maintained by plant personnel to prevent sediment buildup. The lifespan of each filtered will be monitored as well, with replacements occurring as needed.

9.4 Environmental Considerations

Butane added during the solvent extraction process will be recovered to mitigate the need for waste disposal or dumping of butane. For every 1 kg of butane added, 0.994 kg of butane will be recovered and recycled. Primary wastewater treatment will be employed on the recycle purge stream for this event before dumping. Cocoa shells will be burned as biofuel to generate steam. This steam will be used during the upstream sterilizing and roasting events. Excess steam will be sold to purchase electricity. While the burning of any fuel contributes to pollution, replacing some of the need for coal with cocoa bean shells will result in a net reduction of the plant’s carbon foot-print.

9.5 Process Controllability

During the centrifugation process to separate the powder product, heat is transferred to the liquor/butane slurry. If butane is heated in presence of air, there is a risk of explosion. As a safety precaution, the centrifuge was designed to maintain butane in the liquid state if the full wattage of the centrifuge was applied to the liquor/butane slurry. To perform this task cooling coils were incorporated into the centrifuge design. The cooling coils' energy removal was designed to be equal to the full wattage of the centrifuge.

Every piece of equipment that comes in contact with food material is constructed with Stainless Steel 304. This allows the machinery to be more easily cleaned and maintained, limiting contamination from rust or buildup of other foreign substances.

9.6 FDA and Good Manufacturing Practices

All plant personnel will be educated regarding maintaining a safe and clean working environment. Any person who is shown have, or appears to have, an illness, open lesion, or any other abnormal source of microbial contamination will be excluded from operations until conditions have normalized. All personnel will be expected to report any such conditions to their supervisor. Additionally, all personnel will be responsible for proper sanitation, removal of jewelry, and the wearing of garments such as hairnets and gloves, when appropriate, to prevent cross-contamination of food.

Grounds and plant vicinity will also be maintained according to FDA standards. Waste and litter will be properly removed. All roads, yards, and parking lots will be maintained to remove any sources of contamination in areas where food is exposed. All fermented cocoa beans will be inspected, sterilized, and covered. Lastly, sanitation stations and drinking water will be accessible in all areas of the plant.

9.7 Food Grade Quality

Following the FDA's regulations for food grade quality, all shipments of fermented cocoa beans will be inspected. A shipment of fermented cocoa will be considered defect, and excluded from operations, if more than 4% of beans are moldy, if more than 4% of bean beans are insect-infested or insect-damage, if more than 6% of beans are insect-infested or moldy, or if an average of at least 10 mg of mammalian excreta per pound is present. All percentages are based on total bean count, not mass.

Regarding the alkalization process, in accordance with FDA regulations the total neutralizing value of anhydrous potassium carbonate to cocoa will not exceed a 3:100 by mass ratio. No product containing more than 10% fat will be marketed as low fat. No product containing more than 0.5% fat will be marketed as fat-free.

Section 10: Economic Analysis

The economic analysis of this project is summarized in Tables 10-13. Based on the norm in the commodity food industry, a conservative plant life of 17 years was chosen. The net present value of the project turns positive in 6 years of plant startup. At the end of the plant life, the NPV is expected to be $29M with an IRR of 33.5%. Additionally, the ROI after the third production year is 33.7%. These values indicate that the proposed design is profitable and feasible. Sensitivity analyses were performed to determine the robustness of these profits.

10.1 Sensitivity Analyses

Multiple sensitivity analyses were performed during the economic evaluation of this project. A primary analysis was able to evaluate the approximate profitability of the process; initially, no differences in price were assumed between the low fat and fat-free powders. This assumption was made because the powders are often seen as different items, suited for individual purposes. Due to the steam and electricity provided by the combusted shells, additional production costs for the fat-free powder were initially assumed to be negligible. The initial analysis was performed assuming that 79% of the cocoa liquor would be sent for processing, leaving the other 21% to be packaged and sold as liquor. These values were chosen based on current industry practices ("Chocolate and Cocoa", 2016). This analysis showed great promise for the profitability of the plant; however, the return on investment was shown to be quite sensitive to the selling prices of the products. Conservative price estimates placed the ROI at approximately 34%, assuming sale prices of $2.82/kg, $3.20/kg, and $6.11/kg for cocoa powder, liquor, and butter respectively. The sensitivity analysis based around these points is given in Table 10.

Table 10. Sensitivity analysis of utility and commodity prices. The price of each item was changed by 1%, 5%, and 10% in each direction, while the resulting percent changes in ROI were monitored.

% change in price:	**1**	**5**	**10**
Powder	10%	49%	97%
Liquor	11%	58%	102%
Butter	45%	226%	500%
Bean	64%	324%	655%
Utilities	0%	1%	2%

While the commodity prices had very large impacts on the overall profitability, the required utilities showed a lower degree of sensitivity. Altering the utility requirements by 10% only produced a 1-2% change in ROI for the process.

A secondary sensitivity analysis was performed on the split fraction of cocoa liquor sent for additional processing. As designed, the process allows a capacity of up to 80% of the alkalized liquor to be sent for separation. This split fraction value was cycled through all possible values, and the resulting ROI values were recorded in Table 11.

Table 11. Sensitivity analysis of the portion of cocoa liquor sent for processing. A split fraction of 0.73 was set as a lower limit because any lower value would produce negative ROI. A fraction of 0.79 was set as a ceiling because the process equipment does not have sufficient capacity to handle more liquor.

Split Fraction:	0.73	0.74	0.75	0.76	0.77	0.78	0.79
ROI:	2%	8%	14%	20%	26%	28%	34%

Based on the above analysis, greatest profitability is achieved by separating the most cocoa liquor possible. Thus, the split fraction was chosen to be 79%. While greater profitability may be achieved by exceeding this fraction, a large plant would also need to consider its effect on the overall market. Current specifications show this process to produce approximately 3.5% of the total world grindings, in the average proportions of the world manufacturers (“Chocolate and Cocoa”, 2016). Further research may also be needed before choosing to increase the split fraction due to the inevitable increase in bare module costs.

Section 10.2: Economic Analysis

An economic analysis was used to determine the ratio of low fat to fat-free cocoa powder produced. Process equipment allows for up to a 4:1 ratio in favor of either type of powder. For the process mass balances, the ratio of low fat to fat-free powders was set at 4:1. This value was chosen because the low fat powder seems to be equally desirable given the current market conditions; the low fat powder presents both health benefits and superior dissolving properties. Mr. Todd Gusek noted that the fat-free cocoa powder had the potential disadvantages of being as dusty and bitter, thus the low-fat product was more favorable. This split fraction could change if the market dictated a higher selling price for the fat-free cocoa powder. Operating the additional filtration equipment required for the production of fat-free powder was costed at $54,620/yr for the necessary steam and electricity. However, because this technology is able to process 4924 kg/hr of fat-free powder, the marginal processing costs are less than $0.01/kg. Thus, the balance between the low fat and fat-free powders should simply be a function of market prices and rates of demand.

General Information

Process Title:	**Cocoa Liquor, Powder, and Butter Production**
Product:	**Low Fat Cocoa Powder**
Plant Site Location:	**Tema, Ghana**
Site Factor:	**0.92**
Operating Hours per Year:	**7008**
Operating Days Per Year:	**292**
Operating Factor:	**0.8000**

Product Information

This Process will Yield

5,080	kg	of Low Fat Cocoa Powder	per hour
121,918	kg	of Low Fat Cocoa Powder	per day
35,600,000	kg	of Low Fat Cocoa Powder	per year

Price **$2.82 /kg**

Chronology

Year	Action	Distribution of Permanent Investment	Production Capacity	Depreciation 5 year MACRS	Product Price
2017	Design		0.0%		
2018	Construction	100%	0.0%		
2019	Production	0%	45.0%	20.00%	$2.82
2020	Production	0%	67.5%	32.00%	$2.82
2021	Production	0%	90.0%	19.20%	$2.82
2022	Production		90.0%	11.52%	$2.82
2023	Production		90.0%	11.52%	$2.82
2024	Production		90.0%	5.76%	$2.82
2025	Production		90.0%		$2.82
2026	Production		90.0%		$2.82
2027	Production		90.0%		$2.82
2028	Production		90.0%		$2.82
2029	Production		90.0%		$2.82
2030	Production		90.0%		$2.82
2031	Production		90.0%		$2.82
2032	Production		90.0%		$2.82
2033	Production		90.0%		$2.82

Figure 10.1 Input Summary

Raw Materials

	Raw Material:	Unit:	Required Ratio:	Cost of Raw Material:
1	Cocoa Beans	kg	4.06 kg per kg of Low Fat Cocoa Pow	$3.380 per kg
2	Butane	kg	0.000197 kg per kg of Low Fat Cocoa Pow	$0.25 per kg
3	Potassium Carbonate	kg	0.095 kg per kg of Low Fat Cocoa Pow	$2.36 per kg
4	Process Steam	kg	0.688 kg per kg of Low Fat Cocoa Pow	$0.02 per kg
5	Process Water	kg	0.952 kg per kg of Low Fat Cocoa Pow	$0.00 per kg
6	Bunker C Fuel Oil	kg	0.088 kg per kg of Low Fat Cocoa Pow	$0.18 per kg
	Total Weighted Average:			$13.973 per kg of Low Fat Cocoa Powder

Byproducts

	Byproduct:	Unit:	Ratio to Product	Byproduct Selling Price
1	Cocoa Liquor	kg	0.705 kg per kg of Low Fat Cocoa Pow	$3.200 per kg
2	Cocoa Butter	kg	1.47 kg per kg of Low Fat Cocoa Pow	$6.110 per kg
3		kg	0.25 kg per kg of Low Fat Cocoa Pow	$3.290 per kg
	Total Weighted Average:			$12.060 per kg of Low Fat Cocoa Powder

Utilities

	Utility:	Unit:	Required Ratio	Utility Cost
1	High Pressure Steam	lb	0 lb per kg of Low Fat Cocoa Powd	$0.000E+00 per lb
2	Low Pressure Steam	lb	0 lb per kg of Low Fat Cocoa Powd	$0.000E+00 per lb
3	Process Water	kg	0 kg per kg of Low Fat Cocoa Pow	$0.000E+00 per kg
4	Cooling Water	kg	31.46 kg per kg of Low Fat Cocoa Pow	$2.700E-05 per kg
5	Electricity	kWh	0 kWh per kg of Low Fat Cocoa Po	$0.000E+00 per kWh
6	Refrigeration at 10 F	GJ	0.00435 GJ per kg of Low Fat Cocoa Pow	$6.700 per GJ
7	Chilled Water	GJ	0.0000163 GJ per kg of Low Fat Cocoa Pow	$5.50 per GJ

Figure 10.2 Input Summary

Variable Costs			
General Expenses:			
Selling / Transfer Expenses:		**1.00% of Sales**	
Direct Research:		**4.80% of Sales**	
Allocated Research:		**0.50% of Sales**	
Administrative Expense:		**2.00% of Sales**	
Management Incentive Compensation:		**1.25% of Sales**	

Working Capital			
Accounts Receivable	⇨	**30**	**Days**
Cash Reserves (excluding Raw Materials)	⇨	**0**	**Days**
Accounts Payable	⇨	**0**	**Days**
Low Fat Cocoa Powder Inventory	⇨	**4**	**Days**
Raw Materials	⇨	**2**	**Days**

Total Permanent Investment	
Cost of Site Preparations:	**5.00% of Total Bare Module Costs**
Cost of Service Facilities:	**5.00% of Total Bare Module Costs**
Allocated Costs for utility plants and related facilities:	**$0**
Cost of Contingencies and Contractor Fees:	**18.00% of Direct Permanent Investment**
Cost of Land:	**2.00% of Total Depreciable Capital**
Cost of Royalties:	**$0**
Cost of Plant Start-Up:	**10.00% of Total Depreciable Capital**

Figure 10.4 Input Summary

Fixed Costs		
Operations		
	Operators per Shift:	**4 (assuming 4 shifts)**
	Direct Wages and Benefits:	**$3 /operator hour**
	Direct Salaries and Benefits:	**15% of Direct Wages and Benefits**
	Operating Supplies and Services:	**6% of Direct Wages and Benefits**
	Technical Assistance to Manufacturing:	**$60,000.00 per year, for each Operator per Shift**
	Control Laboratory:	**$65,000.00 per year, for each Operator per Shift**
Maintenance		
	Wages and Benefits:	**3.50% of Total Depreciable Capital**
	Salaries and Benefits:	**25% of Maintenance Wages and Benefits**
	Materials and Services:	**100% of Maintenance Wages and Benefits**
	Maintenance Overhead:	**5% of Maintenance Wages and Benefits**
Operating Overhead		
	General Plant Overhead:	**7.10% of Maintenance and Operations Wages and Benefits**
	Mechanical Department Services:	**2.40% of Maintenance and Operations Wages and Benefits**
	Employee Relations Department:	**5.90% of Maintenance and Operations Wages and Benefits**
	Business Services:	**7.40% of Maintenance and Operations Wages and Benefits**
Property Taxes and Insurance		
	Property Taxes and Insurance:	**2% of Total Depreciable Capital**
Straight Line Depreciation		
Direct Plant:		8.00% **of Total Depreciable Capital, less 1.18 times the Allocated Costs for Utility Plants and Related Facilities**
Allocated Plant:		6.00% **of 1.18 times the Allocated Costs for Utility Plants and Related Facilities**
Other Annual Expenses		
	Rental Fees (Office and Laboratory Space):	**$0**
	Licensing Fees:	**$0**
	Miscellaneous:	**$0**
Depletion Allowance		
	Annual Depletion Allowance:	**$0**

Figure 10.5 Input Summary

Variable Cost Summary

Variable Costs at 100% Capacity:		
General Expenses		
Selling / Transfer Expenses:		$ 1,003,920
Direct Research:		$ 4,818,816
Allocated Research:		$ 501,960
Administrative Expense:		$ 2,007,840
Management Incentive Compensation:		$ 1,254,900
Total General Expenses		$ 9,587,436
Raw Materials	$13.973466 per kg of Low Fat	$497,455,400
Byproducts	$12.060200 per kg of Low Fat	($429,343,120)
Utilities	$0.030084 per kg of Low Fat	$1,070,993
Total Variable Costs		**$ 78,770,709**

Figure 11.1 Cost Summary

Fixed Cost Summary

Operations			
	Direct Wages and Benefits	$	86,528
	Direct Salaries and Benefits	$	12,979
	Operating Supplies and Services	$	5,192
	Technical Assistance to Manufacturing	$	960,000
	Control Laboratory	$	1,040,000
	Total Operations	**$**	**2,104,699**
Maintenance			
	Wages and Benefits	$	665,278
	Salaries and Benefits	$	166,319
	Materials and Services	$	665,278
	Maintenance Overhead	$	33,264
	Total Maintenance	**$**	**1,530,139**
Operating Overhead			
	General Plant Overhead:	$	66,108
	Mechanical Department Services:	$	22,347
	Employee Relations Department:	$	54,935
	Business Services:	$	68,902
	Total Operating Overhead	**$**	**212,292**
Property Taxes and Insurance			
	Property Taxes and Insurance:	$	380,159
Other Annual Expenses			
	Rental Fees (Office and Laboratory Space):	$	-
	Licensing Fees:	$	-
	Miscellaneous:	$	-
	Total Other Annual Expenses	**$**	**-**
Total Fixed Costs		**$**	**4,227,288**

Figure 11.2 Cost Summary

Investment Summary

Total Bare Module Costs:				
Fabricated Equipment	$	13,859,531		
Process Machinery	$	552,668		
Spares	$	-		
Storage	$	231,816		
Other Equipment	$	-		
Catalysts	$	-		
Computers, Software, Etc.	$	-		
Total Bare Module Costs:			**$**	**14,644,015**
Direct Permanent Investment				
Cost of Site Preparations:	$	732,201		
Cost of Service Facilities:	$	732,201		
Allocated Costs for utility plants and related facilities:	$	-		
Direct Permanent Investment			**$**	**16,108,417**
Total Depreciable Capital				
Cost of Contingencies & Contractor Fees	$	2,899,515		
Total Depreciable Capital			**$**	**19,007,932**
Total Permanent Investment				
Cost of Land:	$	380,159		
Cost of Royalties:	$	-		
Cost of Plant Start-Up:	$	1,900,793		
Total Permanent Investment - Unadjusted			$	21,288,884
Site Factor				0.92
Total Permanent Investment			**$**	**19,585,773**

Figure 11.3 Cost Summary

Working Capital

		2018		2019		2020
Accounts Receivable	$	3,713,129	$	1,856,564	$	1,856,564
Cash Reserves	$	-	$	-	$	-
Accounts Payable	$	-	$	-	$	-
Low Fat Inventory	$	495,084	$	247,542	$	247,542
Raw Materials	$	1,226,602	$	613,301	$	613,301
Total	**$**	**5,434,815**	**$**	**2,717,407**	**$**	**2,717,407**
Present Value at 15%	*$*	*4,725,926*	*$*	*2,054,750*	*$*	*1,786,740*
Total Capital Investment			**$**	**28,153,189**		

Figure 11.4 Cost Summary

Cash Flow Summary

Year	Percentage of Design Capacity	Product Unit Price	Sales	Capital Costs	Working Capital	Var Costs	Fixed Costs	Depreciation	Depletion Allowance	Taxible Income	Taxes	Net Earnings	Cash Flow	Cumulative Net Present Value at 15%
2017	0%		-	-	-	-	-	-	-	-	-	-	-	-
2018	0%		-	(19,585,800)	(5,434,800)	-	-	-	-	-	-	-	(25,020,600)	(21,757,000)
2019	45%	$2.82	45,176,400	-	(2,717,400)	(35,446,800)	(4,227,300)	(3,801,600)	-	1,700,700	(425,200)	1,275,500	2,359,700	(19,972,800)
2020	68%	$2.82	67,764,600	-	(2,717,400)	(53,170,200)	(4,227,300)	(6,082,500)	-	4,284,500	(1,071,100)	3,213,400	6,578,500	(15,647,300)
2021	90%	$2.82	90,352,800	-	-	(70,893,600)	(4,227,300)	(3,649,500)	-	11,582,400	(2,895,600)	8,686,800	12,336,300	(8,593,900)
2022	90%	$2.82	90,352,800	-	-	(70,893,600)	(4,227,300)	(2,189,700)	-	13,042,200	(3,260,500)	9,781,600	11,971,300	(2,642,100)
2023	90%	$2.82	90,352,800	-	-	(70,893,600)	(4,227,300)	(2,189,700)	-	13,042,200	(3,260,500)	9,781,600	11,971,300	2,533,500
2024	90%	$2.82	90,352,800	-	-	(70,893,600)	(4,227,300)	(1,094,900)	-	14,137,000	(3,534,300)	10,602,800	11,697,600	6,931,000
2025	90%	$2.82	90,352,800	-	-	(70,893,600)	(4,227,300)	-	-	15,231,900	(3,808,000)	11,423,900	11,423,900	10,665,500
2026	90%	$2.82	90,352,800	-	-	(70,893,600)	(4,227,300)	-	-	15,231,900	(3,808,000)	11,423,900	11,423,900	13,912,900
2027	90%	$2.82	90,352,800	-	-	(70,893,600)	(4,227,300)	-	-	15,231,900	(3,808,000)	11,423,900	11,423,900	16,736,700
2028	90%	$2.82	90,352,800	-	-	(70,893,600)	(4,227,300)	-	-	15,231,900	(3,808,000)	11,423,900	11,423,900	19,192,200
2029	90%	$2.82	90,352,800	-	-	(70,893,600)	(4,227,300)	-	-	15,231,900	(3,808,000)	11,423,900	11,423,900	21,327,400
2030	90%	$2.82	90,352,800	-	-	(70,893,600)	(4,227,300)	-	-	15,231,900	(3,808,000)	11,423,900	11,423,900	23,184,100
2031	90%	$2.82	90,352,800	-	-	(70,893,600)	(4,227,300)	-	-	15,231,900	(3,808,000)	11,423,900	11,423,900	24,798,700
2032	90%	$2.82	90,352,800	-	-	(70,893,600)	(4,227,300)	-	-	15,231,900	(3,808,000)	11,423,900	11,423,900	26,202,600
2033	90%	$2.82	90,352,800	-	10,869,600	(70,893,600)	(4,227,300)	-	-	15,231,900	(3,808,000)	11,423,900	22,293,500	28,585,000

Figure 12. Cash Flows

Profitability Measures

The Internal Rate of Return (IRR) for this project is 33.50%

The Net Present Value (NPV) of this project in 2017 is $ 28,585,000

ROI Analysis (Third Production Year)

Annual Sales	**90,352,800**
Annual Costs	**(75,120,926)**
Depreciation	**(1,566,862)**
Income Tax	**(3,416,253)**
Net Earnings	**10,248,759**
Total Capital Investment	**30,455,403**
ROI	**33.65%**

Figure 13. Profitability Measure

Section 11: Conclusions and Recommendations

Based on the profitability analysis, this process merits further research and development. Tema should be investigated as a probable plant location, as the return on investment value was calculated to be 33.7%. While the ROI was very sensitive to the commodity prices of cocoa, sensitivity analyses showed the separation process to be profitable, as long as at least 73% of the total amount of alkalized cocoa liquor is sent for separation. As designed, this process has a throughput of 52,000 tonnes/year of cocoa butter, 36,000 tonnes/year of low fat cocoa powder, 9,000 tonnes/year of fat-free cocoa powder, and 25,000 tonnes/year of cocoa liquor. All of these cocoa products are alkalized in order to appeal to a wide market.

The net present value of this project is expected to turn positive in 2023; this value is projected to grow to approximately $29M by the end of the project's lifespan; however, a few opportunities for increased profitability should be considered. Further research should be conducted regarding larger separation equipment, as throughput is positively correlated with profitability. Additional market research should also be performed with regards to the sale price of fat-free powder compared to low fat powder, as these markets determine the desired powder breakdown. With these additional opportunities in mind, it is recommended that this process undergo further investigation, with extensive research into the effectiveness of solvent extraction and removal.

Section 12: Acknowledgements

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Section 14: Appendices

Appendix A - Sample Calculations

Silo Capacity Calculation

The plant's capacity per day was calculated to determine the maximum working volume for a truncated cone silo. R_1, the radius of the cylindrical tank was 20 times larger the than the bottom radius of the small cone. The height of the cone was assumed to be 3 times the small cone radius.

$$\frac{20500\, kg * 24\, hours * 1\, m^3}{hour * day * 721\, kg} * 1.2 = 819\, m^3$$

Silo Volume = Cylindrical Storage Tank Volume + Truncated Cone Hopper Volume

$$819\, m^3 - (3.14 * R_1^{\,2} * H_1) - (0.33 * 3.14 * H_2)(R_1^{\,2} + R_1 * R_2 + R_2^{\,2}) = 0$$

where $R_1=20*R_2$ and $H_2=3*R_2$.

Screw Conveyor Calculations

Conveyor Diameter

From Sieder et al, the conveyor diameter was calculated when the screw conveyor trough was 30% full, and the auger was spinning at 50 rpm.

$$Conveyor\ Diameter = \left(Volumetric\ Flow\ Rate^{\frac{1}{3.06}}\right)$$

$$Conveyor\ Diameter \rightarrow \left(\frac{20500\, kg * 35.3147\, ft^3 * m^3 * hr}{hr * m^3 * 720.85\, kg * 627.182}\right)^{1/3.06} * \frac{12\, in}{1\, foot} = 14\, in$$

Conveyor Velocities

Example with CY-101:

$$\frac{Volumetric\ Flowrate}{Conveyor\ Cross-Sectional\ Area} = \frac{\frac{20500\, kg * m^3 * 1\, hr * 1\, min}{hr * 720.85\, kg * 60\, \text{min} * 60\, sec}}{3.14 * (0.11778^2)} = 0.08\, \frac{m}{s}$$

Pump Horsepower Calculations

For calculating the horsepower of pumps and pump motors the pump head was obtained from ASPEN
Example with P-501:

$$\frac{Volumetric\ Flowrate * Pump\ Head * Density}{33000 * Pump\ Efficiency} = \frac{\left(38.57\frac{gal}{min}\right) * (21.64\ ft) * \left(12.73\frac{lb}{gal}\right)}{33000 * (0.401)}$$

$$= 0.803\ Hp$$

Pump Motor Horsepower Calculation
Example with P-501:

$$\frac{Pump\ Horsepower}{Motor\ Efficiency} = \frac{0.802\ Hp}{0.793} = 1.01\ Hp$$

Horizontal Pressure Vessel Dimension Calculations
For calculating the dimensions of of horizontal pressure vessels a residence time of 5 minutes was assumed and an aspect ratio of 3 to 1 was used.

Example with T-601:

$$Volume = Volumetric\ Flowrate * Residence\ Time * 2 = (215.83m^3)(5min) * 2$$
$$= 35.97m^3$$

$$Diameter = \left(\frac{4}{3} * \frac{Volume}{\pi}\right)^{1/3} = \left(\frac{4}{3} * \frac{35.97m^3}{\pi}\right)^{1/3} = 2.48m$$

Furnace Calculations

$$Q = Weighted\ Avg\ HHV * (Mass\ of\ Shells + Mass\ of\ Fuel) * 1000 * \left(\frac{0.9}{3600}\right) =$$
$$\left(18.65\frac{MJ}{kg}\right) * (3979.81\ kg + 442.2\ kg) * 1000 * \left(\frac{0.9}{3600}\right) = 20617\ kW$$

Heat Exchanger Calculation
The surface area for the heat exchangers in this process were calculated using the heat duty and overall heat transfer coefficient from Aspen Plus Heat Exchanger Design and Rating. The inlet and outlet temperatures were determined from the simulation.

$$Q = UA\Delta T_{LM} = UA\frac{((T_{hi} - T_{co}) - (T_{ho} - T_{ci}))}{\ln\left(\frac{T_{hi} - T_{co}}{T_{ho} - T_{ci}}\right)}$$

For heat exchanger E-603,

U= 174 W/m^2-K

T_{hi}= 149^{o}C

T_{hi}= 80°C
T_{ci}= 47°C
T_{co}= 52°C

Therefore, from the parameters given:

A= 38m^2

Stripping Column Calculation

The diameter of the stripping column was determined from the column flooding velocity. The equations shown calculate the flooding velocity and diameter given the provided parameters. The actual velocity was determined to be 85% of the flooding velocity.

$$U_f = C_{SB} F_{ST} F_F F_{HA} \sqrt{\frac{\rho_L - \rho_V}{\rho_V}}$$

$$F_{LG} = \frac{L}{V} \sqrt{\frac{\rho_V}{\rho_L}}$$

$$C_{SB} - Determined\ according\ to\ Figure\ 19.4\ in\ Seider, et. al$$

$$F_{ST} = (\frac{\sigma}{20})^{0.2}$$

$$F_{HA} = 1.0$$

$$F_F = 1.0$$

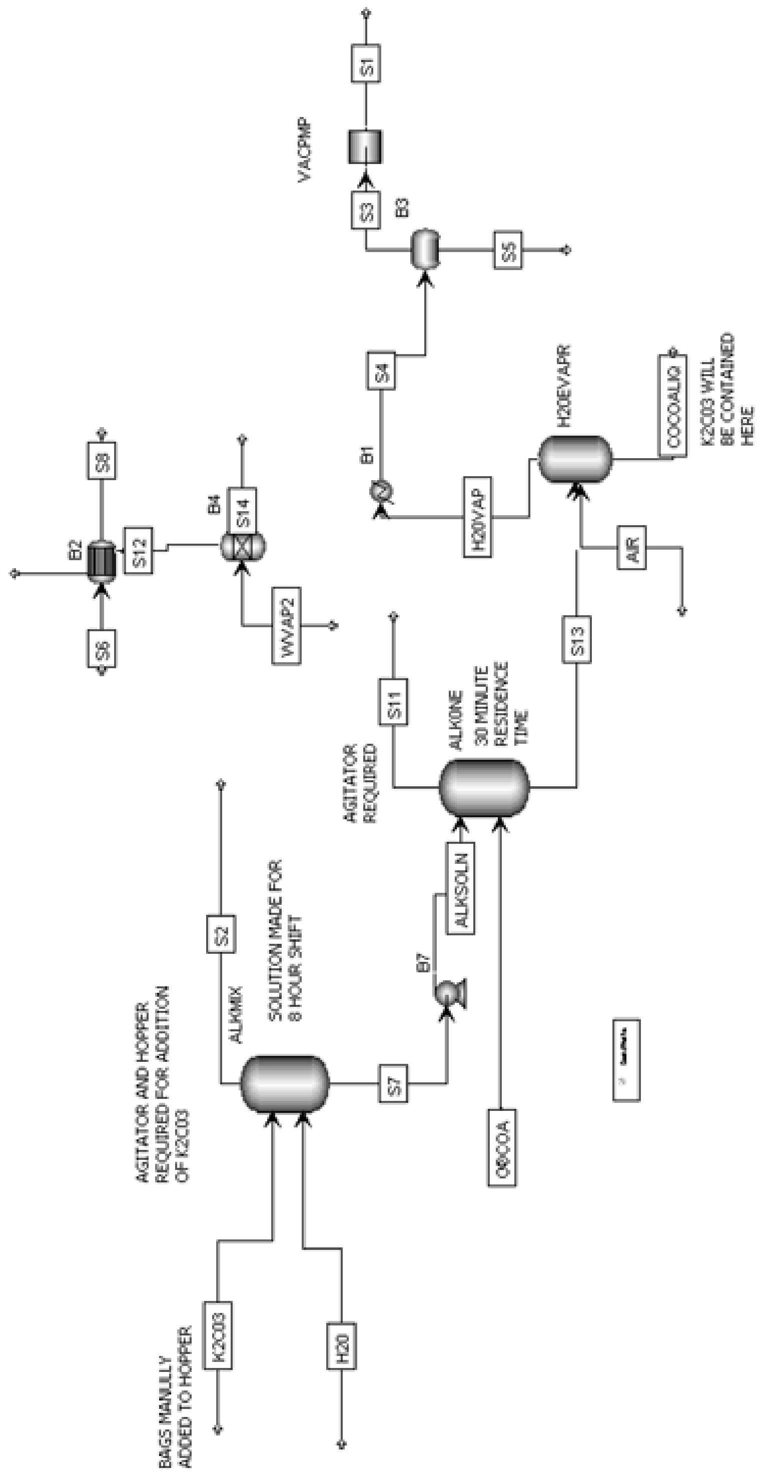
$$D = \sqrt{\frac{4V}{0.9 * \pi * \rho_V * U}}$$

For stripping column T-602,

σ = 8.40 dyne/cm
F_{-ST} = 0.841
F_{LG} = 3.71
C_{SB} = 0.06 ft/s for 2ft tray spacings
U_F = 2.26 ft/s
U= 0.85*U_F = 1.92 ft/s
D= 6ft= 1.83m

Appendix B - ASPEN Flowsheets, Input Summary, and Block Reports

Alkalization Flowsheet



Alkalization Input Summary

```
;Input Summary created by Aspen Plus Rel. 34.0 at 02:22:58 Tue Apr 12, 2016
;Directory \\base\root\homedir  Filename C:\Users\jmorales\AppData\Local\Temp\~apb9f4.txt

DYNAMICS
   DYNAMICS RESULTS=ON

IN-UNITS MET PRESSURE=bar TEMPERATURE=C DELTA-T=C PDROP=bar  &
      INVERSE-PRES='1/bar'

DEF-STREAMS MIXCISLD ALL

SIM-OPTIONS MASS-BAL-CHE=YES ATM-PRES=1.026675560

MODEL-OPTION

DATABANKS 'APV88 ASPENPCD' / 'APV88 AQUEOUS' / 'APV88 SOLIDS' &
       / 'APV88 INORGANIC' / 'APV88 BIODIESEL' /  &
      'NISTV88 NIST-TRC' / 'APV88 PURE32'

PROP-SOURCES 'APV88 ASPENPCD' / 'APV88 AQUEOUS' / 'APV88 SOLIDS' &
       / 'APV88 INORGANIC' / 'APV88 BIODIESEL' /  &
      'NISTV88 NIST-TRC' / 'APV88 PURE32'

COMPONENTS
   SOLVENT C6H14-1 /
   TAG-SOS C57H108O6-3 /
   TAG-POP C53H100O6-5 /
   TAG-POS C55H104O6-3 /
   POWDER SN /
   WATER H2O /
   "K2CO3(M)" K2CO3 /
   N2 N2 /
   O2 O2 /
   K+ K+ /
   "K2CO3(S)" K2CO3 /
   CO3-- CO3-2

CISOLID-COMPS POWDER "K2CO3(S)"

HENRY-COMPS GLOBAL O2 N2

HENRY-COMPS HC-1 N2 O2

SOLVE
   RUN-MODE MODE=SIM

CHEMISTRY GLOBAL
   PARAM GAMMA-BASIS=UNSYMMETRIC
   DISS "K2CO3(M)" CO3-- 1 / K+ 2
   SALT "K2CO3(S)" CO3-- 1 / K+ 2
   K-SALT "K2CO3(S)" A=-175.998001 B=17765.230469 C=21.686489  &
      D=0
```

```
FLOWSHEET
    BLOCK ALK0NE IN=ALKSOLN COCOA OUT=S11 S13
    BLOCK H20EVAPR IN=AIR S13 OUT=H20VAP COCOALIQ
    BLOCK ALKMIX IN=H20 K2C03 OUT=S2 S7
    BLOCK B7 IN=S7 OUT=ALKSOLN
    BLOCK B3 IN=S4 OUT=S3 S5
    BLOCK VACPMP IN=S3 OUT=S1
    BLOCK B1 IN=H20VAP OUT=S4
    BLOCK B2 IN=S12 S6 OUT=S10 S8
    BLOCK B4 IN=WVAP2 OUT=S12 S14

PROPERTIES ELECNRTL HENRY-COMPS=GLOBAL CHEMISTRY=GLOBAL  &
        FREE-WATER=STEAMNBS TRUE-COMPS=YES
    PROPERTIES ENRTL-SR / IDEAL / NRTL-RK / SOLIDS / SRK

STRUCTURES
    STRUCTURES TAG-POP C1 O2 S / O2 C3 S / C3 O4 D / C3  &
        C5 S / C5 C6 S / C6 C7 S / C7 C8 S / C8 C9  &
        S / C9 C10 S / C10 C11 S / C11 C12 S / C12 C13  &
        S / C13 C14 S / C14 C15 S / C15 C16 S / C16  &
        C17 S / C18 C19 S / C1 C20 S / C20 O21 S / O21  &
        C22 S / C22 O23 D / C24 C25 S / C25 C26 S /  &
        C26 C27 S / C27 C28 S / C28 C29 S / C29 C30 S /  &
        C30 C31 D / C31 C32 S / C32 C33 S / C33 C34 S /  &
        C34 C35 S / C35 C36 S / C36 C37 S / C37 C38 S /  &
        C38 C39 S / C20 C40 S / C40 O41 S / O41 C42 S /  &
        C42 O43 D / C42 C44 S / C44 C45 S / C45 C46 S /  &
        C46 C47 S / C47 C48 S / C48 C49 S / C49 C50 S /  &
        C50 C51 S / C51 C52 S / C52 C53 S / C53 C54 S /  &
        C54 C55 S / C55 C56 S / C56 C57 S / C57 C58 S
    STRUCTURES TAG-POS C1 O2 S / O2 C3 S / C3 O4 D / C3  &
        C5 S / C5 C6 S / C6 C7 S / C7 C8 S / C8 C9  &
        S / C9 C10 S / C10 C11 S / C11 C12 S / C12 C13  &
        S / C13 C14 S / C14 C15 S / C15 C16 S / C16  &
        C17 S / C18 C19 S / C1 C20 S / C20 O21 S / O21  &
        C22 S / C22 O23 D / C24 C25 S / C25 C26 S /  &
        C26 C27 S / C27 C28 S / C28 C29 S / C29 C30 S /  &
        C30 C31 D / C31 C32 S / C32 C33 S / C33 C34 S /  &
        C34 C35 S / C35 C36 S / C36 C37 S / C37 C38 S /  &
        C38 C39 S / C20 C40 S / C40 O41 S / O41 C42 S /  &
        C42 O43 D / C42 C44 S / C44 C45 S / C45 C46 S /  &
        C46 C47 S / C47 C48 S / C48 C49 S / C49 C50 S /  &
        C50 C51 S / C51 C52 S / C52 C53 S / C53 C54 S /  &
        C54 C55 S / C55 C56 S / C56 C57 S / C57 C58 S /  &
        C58 C59 S / C59 C60 S
    STRUCTURES TAG-SOS C1 O2 S / O2 C3 S / C3 O4 D / C3  &
        C5 S / C5 C6 S / C6 C7 S / C7 C8 S / C8 C9  &
        S / C9 C10 S / C10 C11 S / C11 C12 S / C12 C13  &
        S / C13 C14 S / C14 C15 S / C15 C16 S / C16  &
        C17 S / C17 C18 S / C18 C19 S / C19 C20 S /  &
        C20 C21 S / C1 C22 S / C22 O23 S / O23 C24 S /  &
        C24 O25 D / C24 C26 S / C26 C27 S / C27 C28 S /  &
        C28 C29 S / C29 C30 S / C30 C31 S / C31 C32 S /  &
        C32 C33 S / C33 C34 D / C34 C35 S / C35 C36 S /  &
        C36 C37 S / C37 C38 S / C38 C39 S / C39 C40 S /  &
        C40 C41 S / C41 C42 S / C22 C43 S / C43 O44 S /  &
```

```
      O44 C45 S / C45 O46 D / C45 C47 S / C47 C48 S /  &
      C48 C49 S / C49 C50 S / C50 C51 S / C51 C52 S /  &
      C52 C53 S / C53 C54 S / C54 C55 S / C55 C56 S /  &
      C56 C57 S / C57 C58 S / C58 C59 S / C59 C60 S /  &
      C60 C61 S / C61 C62 S / C62 C63 S

ESTIMATE ALL

PROP-DATA PCES-1
   IN-UNITS MET PRESSURE=bar TEMPERATURE=C DELTA-T=C PDROP=bar  &
      INVERSE-PRES='1/bar'
   PROP-LIST ZC / VB / RKTZRA / VLSTD / DGFORM / RGYR
   PVAL TAG-SOS .1359747040 / 682.7863210 / .1031860170 /  &
      320.7959360 / -1.0133515E+5 / 1.27116033E-9
   PVAL TAG-POP .1381455880 / 636.8003180 / .1043993550 /  &
      302.0326180 / -1.3615171E+5 / 1.23386352E-9
   PVAL TAG-POS .1369844490 / 661.5363710 / .1039441350 /  &
      312.4879070 / -1.3212955E+5 / 1.25671708E-9
   PROP-LIST TC / DHVLB / VLSTD
   PVAL POWDER 3808.986400 / 1.82873667E+5 / 0.0
   PROP-LIST RKTZRA / VLSTD
   PVAL "K2CO3(M)" .2918596200 / 298.9063450
   PVAL "K2CO3(S)" .2918596200 / 298.9063450

PROP-DATA DHVLWT-1
   IN-UNITS MET PRESSURE=bar TEMPERATURE=C DELTA-T=C PDROP=bar  &
      INVERSE-PRES='1/bar'
   PROP-LIST DHVLWT
   PVAL POWDER 1.82873667E+5 2599.850000 .3800000000 0.0  &
      2599.850000

PROP-DATA KLDIP-1
   IN-UNITS MET PRESSURE=bar TEMPERATURE=C DELTA-T=C PDROP=bar  &
      INVERSE-PRES='1/bar'
   PROP-LIST KLDIP
   PVAL TAG-SOS -3.954762758 .0277353126 -7.1975769E-5  &
      8.28421805E-8 -3.583321E-11 540.5892920 661.9410630
   PVAL TAG-POP -3.900779259 .0280167558 -7.4416988E-5  &
      8.76583747E-8 -3.880642E-11 527.6972860 647.7813660
   PVAL TAG-POS -3.917742515 .0278008098 -7.2976298E-5  &
      8.49559300E-8 -3.716939E-11 534.1885140 655.0009430
   PVAL POWDER -1.689294218 2.45223901E-3 -1.2410738E-6  &
      2.7549006E-10 -2.301472E-14 2599.850000 3768.165040

PROP-DATA MULAND-1
   IN-UNITS MET PRESSURE=bar TEMPERATURE=C DELTA-T=C PDROP=bar  &
      INVERSE-PRES='1/bar'
   PROP-LIST MULAND
   PVAL "K2CO3(M)" 81.17750888 -12127.32210 -10.25255770  &
      1126.850000 1706.850000
   PVAL "K2CO3(S)" 81.17753568 -12127.32210 -10.25255770  &
      1126.850000 1706.850000

PROP-DATA MUVDIP-1
   IN-UNITS MET PRESSURE=bar TEMPERATURE=C DELTA-T=C PDROP=bar  &
```

```
      INVERSE-PRES='1/bar'
   PROP-LIST MUVDIP
   PVAL TAG-SOS 8.52443691E-6 .9836995870 0.0 0.0 0.0  &
      6.850000000 826.8500000
   PVAL TAG-POP 8.86181224E-6 .9826356120 0.0 0.0 0.0  &
      6.850000000 826.8500000
   PVAL TAG-POS 8.67415723E-6 .9831844010 0.0 0.0 0.0  &
      6.850000000 826.8500000

PROP-DATA SIGDIP-1
   IN-UNITS MET PRESSURE=bar TEMPERATURE=C DELTA-T=C PDROP=bar  &
      INVERSE-PRES='1/bar'
   PROP-LIST SIGDIP
   PVAL TAG-SOS 15.21267550 1.222222220 -7.3253955E-9  &
      8.06112577E-9 -3.0009643E-9 540.5892920 652.4956980
   PVAL TAG-POP 16.94811190 1.222222210 4.52918561E-8  &
      -4.9850805E-8 1.85629697E-8 527.6972860 638.4790290
   PVAL TAG-POS 16.02907920 1.222222220 1.98528163E-8  &
      -2.1849025E-8 8.13483157E-9 534.1885140 645.6256810

PROP-DATA HOCETA-1
   IN-UNITS MET PRESSURE=bar TEMPERATURE=C DELTA-T=C PDROP=bar  &
      INVERSE-PRES='1/bar'
   PROP-LIST HOCETA
   BPVAL WATER WATER 1.700000000

PROP-DATA HENRY-1
   IN-UNITS MET PRESSURE=bar TEMPERATURE=C DELTA-T=C PDROP=bar  &
      INVERSE-PRES='1/bar'
   PROP-LIST HENRY
   BPVAL N2 SOLVENT 9.903673535 -275.5899960 -.2019300000  &
      -4.0560000E-3 -60.00000000 25.00000000 0.0
   BPVAL N2 WATER 164.9940745 -8432.770000 -21.55800000  &
      -8.4362400E-3 -.1500000000 72.85000000 0.0
   BPVAL O2 SOLVENT -84.86162646 3068.500000 14.19100000 0.0  &
      10.00000000 40.00000000 0.0
   BPVAL O2 WATER 144.4080745 -7775.060000 -18.39740000  &
      -9.4435400E-3 .8500000000 74.85000000 0.0

PROP-DATA NRTL-1
   IN-UNITS MET PRESSURE=bar TEMPERATURE=C DELTA-T=C PDROP=bar  &
      INVERSE-PRES='1/bar'
   PROP-LIST NRTL
   BPVAL SOLVENT WATER 0.0 1512.000000 .2000000000 0.0 0.0  &
      0.0 0.0 55.00000000
   BPVAL WATER SOLVENT 0.0 3040.000000 .2000000000 0.0 0.0  &
      0.0 0.0 55.00000000
   BPVAL N2 O2 -2.164500000 30.29660000 .1000000000 0.0 0.0  &
      0.0 -208.3142000 -157.1450000
   BPVAL O2 N2 2.238770000 13.59570000 .1000000000 0.0 0.0  &
      0.0 -208.3142000 -157.1450000

PROP-DATA VLCLK-1
   IN-UNITS MET PRESSURE=bar TEMPERATURE=C DELTA-T=C PDROP=bar  &
      INVERSE-PRES='1/bar'
```

```
    PROP-LIST VLCLK
    BPVAL K+ CO3-- 19.73097000 74.55601000

PROP-DATA GMELCC-1
    IN-UNITS MET PRESSURE=bar TEMPERATURE=C DELTA-T=C PDROP=bar  &
        INVERSE-PRES='1/bar'
    PROP-LIST GMELCC
    PPVAL WATER ( K+ CO3-- ) .7833727000
    PPVAL ( K+ CO3-- ) WATER .6027880000

PROP-DATA GMELCD-1
    IN-UNITS MET PRESSURE=bar TEMPERATURE=C DELTA-T=C PDROP=bar  &
        INVERSE-PRES='1/bar'
    PROP-LIST GMELCD
    PPVAL WATER ( K+ CO3-- ) 0.0
    PPVAL ( K+ CO3-- ) WATER -1173.117000

PROP-DATA GMENCC-1
    IN-UNITS MET PRESSURE=bar TEMPERATURE=C DELTA-T=C PDROP=bar  &
        INVERSE-PRES='1/bar'
    PROP-LIST GMENCC
    PPVAL WATER ( K+ CO3-- ) .7833727000
    PPVAL ( K+ CO3-- ) WATER .6027880000

PROP-DATA GMENCD-1
    IN-UNITS MET PRESSURE=bar TEMPERATURE=C DELTA-T=C PDROP=bar  &
        INVERSE-PRES='1/bar'
    PROP-LIST GMENCD
    PPVAL WATER ( K+ CO3-- ) 0.0
    PPVAL ( K+ CO3-- ) WATER -1173.117000

PROP-SET PS-1 TEMP KVL GAMMA KVL2 BETA MASSFRAC  &
        SUBSTREAM=MIXED COMPS=SOLVENT TAG-POS PHASE=V L1 L2

PROP-SET PS-2 TEMP KVL GAMMA KVL2 BETA MOLEFRAC  &
        SUBSTREAM=MIXED COMPS=SOLVENT TAG-SOS PHASE=V L1 L2

PROP-SET PS-3 TEMP KVL GAMMA KVL2 BETA MOLEFRAC  &
        SUBSTREAM=MIXED COMPS=SOLVENT TAG-SOS PHASE=V L1 L2

PROP-SET PS-4 TEMP KVL GAMMA KVL2 BETA MOLEFRAC  &
        SUBSTREAM=MIXED COMPS=SOLVENT TAG-POS PHASE=V L1 L2

PROP-SET PS-5 PL UNITS='psi' SUBSTREAM=MIXED COMPS=WATER  &
        PHASE=L

STREAM AIR
    SUBSTREAM MIXED TEMP=25. PRES=14.7 <psia>
    MOLE-FLOW N2 0.79 <mol/hr> / O2 0.21 <mol/hr>

STREAM ALKSOLN
    SUBSTREAM MIXED PRES=29.0075 <psi> VFRAC=0.  &
        MASS-FLOW=4419.58
    MASS-FLOW WATER 4017.8 / "K2CO3(M)" 401.78
```

```
STREAM COCOA
   SUBSTREAM MIXED TEMP=50. PRES=7.5 MASS-FLOW=16019.23
   MASS-FRAC TAG-SOS 0.1242 / TAG-POP 0.1782 / TAG-POS  &
      0.2376 / POWDER 0.43 / WATER 0.03

STREAM H20
   SUBSTREAM MIXED TEMP=20. PRES=14.7 <psi> MASS-FLOW=4017.8
   MASS-FLOW WATER 4017.8

STREAM K2C03
   SUBSTREAM MIXED TEMP=20. PRES=14.7 <psi> MASS-FLOW=401.78
   MASS-FRAC "K2CO3(S)" 1.

STREAM S6
   SUBSTREAM MIXED TEMP=25. PRES=65. <psia> MASS-FLOW=120000.
   MASS-FLOW WATER 1.

STREAM WVAP2
   SUBSTREAM MIXED TEMP=95. PRES=0.3 <atm>
   MASS-FLOW WATER 4200. / N2 0.02 / O2 0.007

BLOCK B4 SEP
   PARAM
   FRAC STREAM=S12 SUBSTREAM=MIXED COMPS=SOLVENT TAG-SOS  &
      TAG-POP TAG-POS POWDER WATER "K2CO3(M)" N2 O2 K+  &
      "K2CO3(S)" CO3-- FRACS=1. 1. 0. 0. 1. 1. 1. 1. 1.  &
      1. 1. 1.

BLOCK B1 HEATER
   PARAM TEMP=60. PRES=0. DPPARMOPT=NO

BLOCK ALK0NE FLASH2
   PARAM TEMP=95. PRES=1.5

BLOCK ALKMIX FLASH2
   PARAM PRES=0. <psi> DUTY=0.

BLOCK B3 FLASH2
   PARAM PRES=0. DUTY=0.
   PROPERTIES NRTL-RK HENRY-COMPS=HC-1 FREE-WATER=STEAMNBS  &
      SOLU-WATER=3 TRUE-COMPS=YES

BLOCK H20EVAPR FLASH2
   PARAM TEMP=95. PRES=4.5 <psi>

BLOCK B2 HEATX
   PARAM MIN-OUT-TAPP=10. <K> CALC-TYPE=DESIGN  &
      U-OPTION=PHASE F-OPTION=CONSTANT CALC-METHOD=SHORTCUT
   FEEDS HOT=S12 COLD=S6
   OUTLETS-HOT S10
   OUTLETS-COLD S8
   HOT-SIDE DP-OPTION=CONSTANT DPPARMOPT=NO
   COLD-SIDE DP-OPTION=CONSTANT DPPARMOPT=NO
   TQ-PARAM CURVE=YES
```

```
BLOCK B7 PUMP
   PARAM PRES=1.5 EFF=0.75

BLOCK VACPMP COMPR
   PARAM TYPE=ISENTROPIC PRES=15.3 <psia> SEFF=0.8 SB-MAXIT=30  &
      SB-TOL=0.0001

DESIGN-SPEC CTW-FLOW
   DEFINE CTWFLOW STREAM-VAR STREAM=S6 SUBSTREAM=MIXED  &
      VARIABLE=MASS-FLOW UOM="kg/hr"
   DEFINE VAPFRAC STREAM-VAR STREAM=S4 SUBSTREAM=MIXED  &
      VARIABLE=VFRAC
   SPEC "VAPFRAC" TO "0.01"
   TOL-SPEC "0.0001"
   VARY STREAM-VAR STREAM=S6 SUBSTREAM=MIXED VARIABLE=MASS-FLOW  &
      UOM="kg/hr"
   LIMITS "100000" "200000"

EO-CONV-OPTI

TRANSFER TS4
   SET STREAM WVAP2
   EQUAL-TO STREAM H20VAP

STREAM-REPOR MOLEFLOW MASSFLOW MASSFRAC

PROPERTY-REP PCES NOPARAM-PLUS

PROP-TABLE BINRY-1 FLASHCURVE
   IN-UNITS MET PRESSURE=psia TEMPERATURE=C DELTA-T=C PDROP=bar  &
      INVERSE-PRES='1/bar'
   PROPERTIES SRK FREE-WATER=STEAMNBS SOLU-WATER=3  &
      TRUE-COMPS=YES
   MASS-FLOW SOLVENT 1 /  TAG-POS  1
   STATE VFRAC=0.0
   VARY PRES
   RANGE LIST=14.69594878
   VARY MASSFRAC COMP=SOLVENT
   RANGE LOWER=0.0 UPPER=1.0 NPOINT= 100
   PARAM NPHASE=3
   TABULATE PROPERTIES=PS-1

PROP-TABLE BINRY-2 FLASHCURVE
   IN-UNITS MET PRESSURE=psia TEMPERATURE=C DELTA-T=C PDROP=bar  &
      INVERSE-PRES='1/bar'
   PROPERTIES SRK FREE-WATER=STEAMNBS SOLU-WATER=3  &
      TRUE-COMPS=YES
   MOLE-FLOW SOLVENT 1 /  TAG-SOS  1
   STATE VFRAC=0.0
   VARY PRES
   RANGE LIST=14.69594878
   VARY MOLEFRAC COMP=SOLVENT
   RANGE LOWER=0.0 UPPER=1.0 NPOINT= 51
   PARAM NPHASE=3
   TABULATE PROPERTIES=PS-2
```

```
PROP-TABLE BINRY-3 FLASHCURVE
   IN-UNITS MET PRESSURE=psia TEMPERATURE=C DELTA-T=C PDROP=bar  &
      INVERSE-PRES='1/bar'
   PROPERTIES SRK FREE-WATER=STEAMNBS SOLU-WATER=3  &
      TRUE-COMPS=YES
   MOLE-FLOW SOLVENT 1 /  TAG-SOS  1
   STATE VFRAC=0.0
   VARY PRES
   RANGE LIST=14.69594878
   VARY MOLEFRAC COMP=SOLVENT
   RANGE LOWER=0.0 UPPER=1.0 NPOINT= 51
   PARAM NPHASE=3
   TABULATE PROPERTIES=PS-3

PROP-TABLE BINRY-4 FLASHCURVE
   IN-UNITS MET PRESSURE=psia TEMPERATURE=C DELTA-T=C PDROP=bar  &
      INVERSE-PRES='1/bar'
   PROPERTIES SRK FREE-WATER=STEAMNBS SOLU-WATER=3  &
      TRUE-COMPS=YES
   MOLE-FLOW SOLVENT 1 /  TAG-POS  1
   STATE VFRAC=0.0
   VARY PRES
   RANGE LIST=14.69594878
   VARY MOLEFRAC COMP=SOLVENT
   RANGE LOWER=0.0 UPPER=1.0 NPOINT= 100
   PARAM NPHASE=3
   TABULATE PROPERTIES=PS-4

PROP-TABLE PURE-1 PROPS
   IN-UNITS MET PRESSURE=bar TEMPERATURE=C DELTA-T=C PDROP=bar  &
      INVERSE-PRES='1/bar'
   MOLE-FLOW WATER 1
   PROPERTIES ELECNRTL HENRY-COMPS=GLOBAL CHEMISTRY=GLOBAL  &
      FREE-WATER=STEAMNBS SOLU-WATER=3 TRUE-COMPS=YES
   VARY TEMP
   RANGE LOWER=0 UPPER=60. NPOINT= 50
   VARY PRES
   RANGE LIST=1.013250000
   PARAM
   TABULATE PROPERTIES=PS-5

DISABLE
   DESIGN-SPEC CTW-FLOW
```

Alkalization Block Reports

```
 BLOCK:  B1       MODEL: HEATER
 ------------------------------
   INLET STREAM:          H20VAP
   OUTLET STREAM:         S4
   PROPERTY OPTION SET:   ELECNRTL  ELECTROLYTE NRTL / REDLICH-KWONG
   HENRY-COMPS ID:        GLOBAL
   CHEMISTRY ID:          GLOBAL   - TRUE SPECIES
```

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(KMOL/HR)	232.987	232.987	0.00000
MASS(KG/HR)	4197.34	4197.34	0.216684E-15
ENTHALPY(CAL/SEC)	-0.370435E+07	-0.438027E+07	0.154310

*** CO2 EQUIVALENT SUMMARY ***

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

*** INPUT DATA ***

TWO PHASE TP FLASH
SPECIFIED TEMPERATURE C 60.0000
PRESSURE DROP BAR 0.0
MAXIMUM NO. ITERATIONS 30
CONVERGENCE TOLERANCE 0.000100000

*** RESULTS ***

OUTLET TEMPERATURE C 60.000
OUTLET PRESSURE BAR 0.31026
HEAT DUTY CAL/SEC -0.67592E+06
OUTLET VAPOR FRACTION 0.89664E-05

V-L PHASE EQUILIBRIUM :

COMP	F(I)	X(I)	Y(I)	K(I)
TAG-SOS	0.24765E-13	0.24766E-13	0.17954E-28	0.72495E-15
TAG-POP	0.13692E-12	0.13692E-12	0.42557E-27	0.31082E-14
TAG-POS	0.92954E-13	0.92955E-13	0.13954E-27	0.15011E-14
WATER	1.0000	1.0000	0.64453	0.64453
N2	0.33907E-05	0.78706E-06	0.29038	0.36895E+06
O2	0.90134E-06	0.31775E-06	0.65086E-01	0.20483E+06

BLOCK: B2 MODEL: HEATX

HOT SIDE:

INLET STREAM: S12
OUTLET STREAM: S10
PROPERTY OPTION SET: ELECNRTL ELECTROLYTE NRTL / REDLICH-KWONG
HENRY-COMPS ID: GLOBAL
CHEMISTRY ID: GLOBAL - TRUE SPECIES
COLD SIDE:

INLET STREAM: S6
OUTLET STREAM: S8
PROPERTY OPTION SET: ELECNRTL ELECTROLYTE NRTL / REDLICH-KWONG
HENRY-COMPS ID: GLOBAL
CHEMISTRY ID: GLOBAL - TRUE SPECIES

```
               ***  MASS AND ENERGY BALANCE  ***
                            IN            OUT       RELATIVE DIFF.
 TOTAL BALANCE
   MOLE(KMOL/HR )           6894.00        6894.00        0.00000
   MASS(KG/HR   )          124197.        124197.       0.285889E-13
   ENTHALPY(CAL/SEC )      -0.130097E+09   -0.130097E+09   -0.105631E-08

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

                  ***  INPUT DATA  ***

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 MIN OUTLET TEMP APPR
  SPECIFIED VALUE              C                  10.0000
  LMTD CORRECTION FACTOR                            1.00000

PRESSURE SPECIFICATION:
  HOT  SIDE PRESSURE DROP       BAR                  0.0000
  COLD SIDE PRESSURE DROP       BAR                  0.0000

HEAT TRANSFER COEFFICIENT SPECIFICATION:
  HOT LIQUID    COLD LIQUID      CAL/SEC-SQCM-K         0.0203
  HOT 2-PHASE   COLD LIQUID      CAL/SEC-SQCM-K         0.0203
  HOT VAPOR     COLD LIQUID      CAL/SEC-SQCM-K         0.0203
  HOT LIQUID    COLD 2-PHASE     CAL/SEC-SQCM-K         0.0203
  HOT 2-PHASE   COLD 2-PHASE     CAL/SEC-SQCM-K         0.0203
  HOT VAPOR     COLD 2-PHASE     CAL/SEC-SQCM-K         0.0203
  HOT LIQUID    COLD VAPOR       CAL/SEC-SQCM-K         0.0203
  HOT 2-PHASE   COLD VAPOR       CAL/SEC-SQCM-K         0.0203
  HOT VAPOR     COLD VAPOR       CAL/SEC-SQCM-K         0.0203

                 ***  OVERALL RESULTS  ***

STREAMS:
          --------------------------------------
          |                             |
S12    ----->|             HOT             |-----> S10
T=  9.5000D+01  |                             |      T=  5.5491D+01
P=  3.1026D-01  |                             |      P=  3.1026D-01
```

```
V=  1.0000D+00  |                              |      V=  5.8296D-06
             |                              |
S8       <-----|              COLD              |<----- S6
T=  4.5483D+01  |                              |      T=  2.5000D+01
P=  4.4816D+00  |                              |      P=  4.4816D+00
V=  0.0000D+00  |                              |      V=  0.0000D+00
             -------------------------------------

DUTY AND AREA:
  CALCULATED HEAT DUTY          CAL/SEC          681174.6446
  CALCULATED (REQUIRED) AREA     SQM                 121.3350
  ACTUAL EXCHANGER AREA          SQM                 121.3350
  PER CENT OVER-DESIGN                               0.0000

HEAT TRANSFER COEFFICIENT:
  AVERAGE COEFFICIENT (DIRTY)    CAL/SEC-SQCM-K          0.0203
  UA (DIRTY)                   CAL/SEC-K          24633.3166

LOG-MEAN TEMPERATURE DIFFERENCE:
  LMTD CORRECTION FACTOR                              1.0000
  LMTD (CORRECTED)              C                   27.6526
  NUMBER OF SHELLS IN SERIES                            1

PRESSURE DROP:
  HOTSIDE, TOTAL               BAR                  0.0000
  COLDSIDE, TOTAL              BAR                  0.0000

                 ***  ZONE RESULTS  ***

TEMPERATURE LEAVING EACH ZONE:

                            HOT
      -------------------------------------------------------------
      |                   |                   |
HOT IN  |          VAP           |          COND          | HOT OUT
------> |                      |                    |------>
 95.0  |                  69.9|                     |  55.5
      |                   |                   |
COLDOUT |          LIQ           |          LIQ           | COLDIN
<------ |                      |                    |<------
 45.5  |                  45.1|                     |  25.0
      |                   |                   |
      -------------------------------------------------------------
                            COLD

ZONE HEAT TRANSFER AND AREA:

ZONE      HEAT DUTY      AREA      LMTD      AVERAGE U      UA
         CAL/SEC        SQM        C        CAL/SEC-SQCM-K  CAL/SEC-K
  1     13255.609        1.8277     35.7233    0.0203        371.0631
  2    667919.035      119.5073     27.5291     0.0203      24262.2536

HEATX COLD-TQCU B2      TQCURV INLET
------------------------------------
PRESSURE PROFILE:     CONSTANT2
```

```
 PRESSURE DROP:        0.0        BAR
 PROPERTY OPTION SET:   ELECNRTL  ELECTROLYTE NRTL / REDLICH-KWONG
 HENRY-COMPS ID:        GLOBAL
 CHEMISTRY ID:          GLOBAL   - TRUE SPECIES

-----------------------------------------------------
! DUTY      ! PRES      ! TEMP      ! VFRAC     !
!           !           !           !           !
!           !           !           !           !
!           !           !           !           !
! CAL/SEC   ! BAR       ! C         !           !
!           !           !           !           !
!============!============!============!============!
!    0.0    !    4.4816 !    45.4832 !    0.0    !
! 3.2437+04 !    4.4816 !    44.5081 !    0.0    !
! 6.4874+04 !    4.4816 !    44.5081 !    0.0    !
! 9.7311+04 !    4.4816 !    43.5328 !    0.0    !
! 1.2975+05 !    4.4816 !    42.5576 !    0.0    !
!------------+------------+------------+------------!
! 1.6218+05 !    4.4816 !    41.5823 !    0.0    !
! 1.9462+05 !    4.4816 !    40.6069 !    0.0    !
! 2.2706+05 !    4.4816 !    39.6316 !    0.0    !
! 2.5950+05 !    4.4816 !    38.6561 !    0.0    !
! 2.9193+05 !    4.4816 !    37.6807 !    0.0    !
!------------+------------+------------+------------!
! 3.2437+05 !    4.4816 !    36.7052 !    0.0    !
! 3.5681+05 !    4.4816 !    35.7298 !    0.0    !
! 3.8924+05 !    4.4816 !    34.7543 !    0.0    !
! 4.2168+05 !    4.4816 !    33.7788 !    0.0    !
! 4.5412+05 !    4.4816 !    32.8033 !    0.0    !
!------------+------------+------------+------------!
! 4.8655+05 !    4.4816 !    31.8278 !    0.0    !
! 5.1899+05 !    4.4816 !    30.8523 !    0.0    !
! 5.5143+05 !    4.4816 !    29.8768 !    0.0    !
! 5.8386+05 !    4.4816 !    28.9014 !    0.0    !
! 6.1630+05 !    4.4816 !    27.9260 !    0.0    !
!------------+------------+------------+------------!
! 6.4874+05 !    4.4816 !    26.9506 !    0.0    !
! 6.8117+05 !    4.4816 !    25.9753 !    0.0    !
-----------------------------------------------------

HEATX HOT-TQCUR B2      TQCURV INLET
-----------------------------------
 PRESSURE PROFILE:      CONSTANT2
 PRESSURE DROP:        0.0        BAR
 PROPERTY OPTION SET:   ELECNRTL  ELECTROLYTE NRTL / REDLICH-KWONG
 HENRY-COMPS ID:        GLOBAL
 CHEMISTRY ID:          GLOBAL   - TRUE SPECIES

-----------------------------------------------------
! DUTY      ! PRES      ! TEMP      ! VFRAC     !
!           !           !           !           !
!           !           !           !           !
!           !           !           !           !
! CAL/SEC   ! BAR       ! C         !           !
!           !           !           !           !
```

```
!============!============!============!============!
!    0.0    !     0.3103 !    95.0000 !     1.0000 !
!  3.2437+04 !     0.3103 !    69.8502 !     0.9705 !
!  6.4874+04 !     0.3103 !    69.8502 !     0.9207 !
!  9.7311+04 !     0.3103 !    69.8502 !     0.8709 !
!  1.2975+05 !     0.3103 !    69.8502 !     0.8211 !
!------------+------------+------------+------------!
!  1.6218+05 !     0.3103 !    69.8502 !     0.7713 !
!  1.9462+05 !     0.3103 !    69.8501 !     0.7215 !
!  2.2706+05 !     0.3103 !    69.8501 !     0.6717 !
!  2.5950+05 !     0.3103 !    69.8501 !     0.6219 !
!  2.9193+05 !     0.3103 !    69.8501 !     0.5720 !
!------------+------------+------------+------------!
!  3.2437+05 !     0.3103 !    69.8501 !     0.5222 !
!  3.5681+05 !     0.3103 !    69.8501 !     0.4724 !
!  3.8924+05 !     0.3103 !    69.8500 !     0.4226 !
!  4.2168+05 !     0.3103 !    69.8500 !     0.3728 !
!  4.5412+05 !     0.3103 !    69.8500 !     0.3230 !
!------------+------------+------------+------------!
!  4.8655+05 !     0.3103 !    69.8499 !     0.2732 !
!  5.1899+05 !     0.3103 !    69.8498 !     0.2234 !
!  5.5143+05 !     0.3103 !    69.8497 !     0.1736 !
!  5.8386+05 !     0.3103 !    69.8495 !     0.1237 !
!  6.1630+05 !     0.3103 !    69.8489 !  7.3933-02 !
!------------+------------+------------+------------!
!  6.4874+05 !     0.3103 !    69.8462 !  2.4126-02 !
!  6.8117+05 !     0.3103 !    55.4912 !  5.8296-06 !
----------------------------------------------------

BLOCK:  B3       MODEL: FLASH2
------------------------------
  INLET STREAM:          S4
  OUTLET VAPOR STREAM:   S3
  OUTLET LIQUID STREAM:  S5
  PROPERTY OPTION SET:   NRTL-RK   RENON (NRTL) / REDLICH-KWONG
  HENRY-COMPS ID:        HC-1

                 ***  MASS AND ENERGY BALANCE  ***
                              IN             OUT        RELATIVE DIFF.
   TOTAL BALANCE
     MOLE(KMOL/HR )           232.987         232.987         0.00000
     MASS(KG/HR   )           4197.34         4197.34       -0.433368E-15
     ENTHALPY(CAL/SEC )      -0.438027E+07   -0.438027E+07   -0.627222E-12

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

                    ***  INPUT DATA  ***
  TWO    PHASE  PQ  FLASH
  PRESSURE DROP         BAR                             0.0
  SPECIFIED HEAT DUTY   CAL/SEC                         0.0
```

MAXIMUM NO. ITERATIONS 30
CONVERGENCE TOLERANCE 0.000100000

*** RESULTS ***

OUTLET TEMPERATURE C 58.684
OUTLET PRESSURE BAR 0.31026
VAPOR FRACTION 0.77879E-05

V-L PHASE EQUILIBRIUM :

COMP	F(I)	X(I)	Y(I)	K(I)
TAG-SOS	0.24765E-13	0.24766E-13	0.14070E-28	0.56811E-15
TAG-POP	0.13692E-12	0.13692E-12	0.33593E-27	0.24535E-14
TAG-POS	0.92954E-13	0.92955E-13	0.10975E-27	0.11806E-14
WATER	1.0000	1.0000	0.60640	0.60640
N2	0.33907E-05	0.87794E-06	0.32266	0.36751E+06
O2	0.90134E-06	0.34886E-06	0.70941E-01	0.20335E+06

BLOCK: B4 MODEL: SEP

INLET STREAM: WVAP2
OUTLET STREAMS: S12 S14
PROPERTY OPTION SET: ELECNRTL ELECTROLYTE NRTL / REDLICH-KWONG
HENRY-COMPS ID: GLOBAL
CHEMISTRY ID: GLOBAL - TRUE SPECIES

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(KMOL/HR)	232.987	232.987	0.00000
MASS(KG/HR)	4197.34	4197.34	0.176251E-11
ENTHALPY(CAL/SEC)	-0.370435E+07	-0.370435E+07	0.983026E-13

*** CO2 EQUIVALENT SUMMARY ***

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

*** INPUT DATA ***

FLASH SPECS FOR STREAM S12
TWO PHASE TP FLASH
PRESSURE DROP BAR 0.0
MAXIMUM NO. ITERATIONS 30
CONVERGENCE TOLERANCE 0.000100000

FLASH SPECS FOR STREAM S14
TWO PHASE TP FLASH
PRESSURE DROP BAR 0.0
MAXIMUM NO. ITERATIONS 30

CONVERGENCE TOLERANCE 0.000100000

FRACTION OF FEED
SUBSTREAM= MIXED
STREAM= S12 CPT= SOLVENT FRACTION= 1.00000

TAG-SOS	1.00000
TAG-POP	0.0
TAG-POS	0.0
POWDER	1.00000
WATER	1.00000
K2CO3(M)	1.00000
N2	1.00000
O2	1.00000
K+	1.00000
K2CO3(S)	1.00000
CO3--	1.00000

*** RESULTS ***

HEAT DUTY CAL/SEC -0.36392E-06

COMPONENT = TAG-SOS

STREAM	SUBSTREAM	SPLIT FRACTION
S12	MIXED	1.00000

COMPONENT = TAG-POP

STREAM	SUBSTREAM	SPLIT FRACTION
S14	MIXED	1.00000

COMPONENT = TAG-POS

STREAM	SUBSTREAM	SPLIT FRACTION
S14	MIXED	1.00000

COMPONENT = WATER

STREAM	SUBSTREAM	SPLIT FRACTION
S12	MIXED	1.00000

COMPONENT = N2

STREAM	SUBSTREAM	SPLIT FRACTION
S12	MIXED	1.00000

COMPONENT = O2

STREAM	SUBSTREAM	SPLIT FRACTION
S12	MIXED	1.00000

BLOCK: B7 MODEL: PUMP

INLET STREAM: S7
OUTLET STREAM: ALKSOLN
PROPERTY OPTION SET: ELECNRTL ELECTROLYTE NRTL / REDLICH-KWONG
HENRY-COMPS ID: GLOBAL
CHEMISTRY ID: GLOBAL - TRUE SPECIES

*** MASS AND ENERGY BALANCE ***

IN OUT RELATIVE DIFF.
TOTAL BALANCE
MOLE(KMOL/HR) 231.743 231.743 0.00000
MASS(KG/HR) 4419.58 4419.58 -0.205788E-15
ENTHALPY(CAL/SEC) -0.445961E+07 -0.445959E+07 -0.396152E-05

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

*** INPUT DATA ***
OUTLET PRESSURE BAR 1.50000
PUMP EFFICIENCY 0.75000
DRIVER EFFICIENCY 1.00000

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

*** RESULTS ***
VOLUMETRIC FLOW RATE L/MIN 68.4220
PRESSURE CHANGE BAR 0.48647
NPSH AVAILABLE M-KGF/KG 9.36761
FLUID POWER KW 0.055475
BRAKE POWER KW 0.073967
ELECTRICITY KW 0.073967
PUMP EFFICIENCY USED 0.75000
NET WORK REQUIRED KW 0.073967
HEAD DEVELOPED M-KGF/KG 4.60789

BLOCK: H20EVAPR MODEL: FLASH2

INLET STREAMS: AIR S13
OUTLET VAPOR STREAM: H20VAP
OUTLET LIQUID STREAM: COCOALIQ
PROPERTY OPTION SET: ELECNRTL ELECTROLYTE NRTL / REDLICH-KWONG
HENRY-COMPS ID: GLOBAL
CHEMISTRY ID: GLOBAL - TRUE SPECIES

*** MASS AND ENERGY BALANCE ***
IN OUT RELATIVE DIFF.
TOTAL BALANCE
MOLE(KMOL/HR) 326.527 323.692 0.868168E-02
MASS(KG/HR) 20438.8 20438.8 -0.124595E-14
ENTHALPY(CAL/SEC) -0.632528E+07 -0.568245E+07 -0.101628

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

UTILITIES CO2E PRODUCTION 0.00000 KG/HR
TOTAL CO2E PRODUCTION 0.00000 KG/HR

*** INPUT DATA ***

TWO PHASE TP FLASH	
SPECIFIED TEMPERATURE C	95.0000
SPECIFIED PRESSURE BAR	0.31026
MAXIMUM NO. ITERATIONS	30
CONVERGENCE TOLERANCE	0.000100000

*** RESULTS ***

OUTLET TEMPERATURE C	95.000
OUTLET PRESSURE BAR	0.31026
HEAT DUTY CAL/SEC	0.64282E+06
VAPOR FRACTION	0.88170

V-L PHASE EQUILIBRIUM :

COMP	F(I)	X(I)	Y(I)	K(I)
TAG-SOS	0.83307E-02	0.71551E-01	0.24765E-13	0.34612E-12
TAG-POP	0.12757E-01	0.10957	0.13692E-12	0.12496E-11
TAG-POS	0.16456E-01	0.14134	0.92954E-13	0.65767E-12
WATER	0.92997	0.53458	1.0000	1.8706
N2	0.29423E-05	0.63782E-11	0.33907E-05	0.53162E+06
O2	0.78212E-06	0.28123E-11	0.90134E-06	0.32049E+06
K+	0.21654E-01	0.95306E-01	0.0000	0.0000
CO3--	0.10827E-01	0.47653E-01	0.0000	0.0000

BLOCK: VACPMP MODEL: COMPR

INLET STREAM: S3
OUTLET STREAM: S1
PROPERTY OPTION SET: ELECNRTL ELECTROLYTE NRTL / REDLICH-KWONG
HENRY-COMPS ID: GLOBAL
CHEMISTRY ID: GLOBAL - TRUE SPECIES

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(KMOL/HR)	0.181448E-02	0.181448E-02	0.00000
MASS(KG/HR)	0.403418E-01	0.403418E-01	-0.172002E-15
ENTHALPY(CAL/SEC)	-17.5378	-16.9319	-0.345445E-01

*** CO2 EQUIVALENT SUMMARY ***

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

*** INPUT DATA ***

ISENTROPIC CENTRIFUGAL COMPRESSOR

OUTLET PRESSURE BAR 1.05490
ISENTROPIC EFFICIENCY 0.80000
MECHANICAL EFFICIENCY 1.00000

*** RESULTS ***

INDICATED HORSEPOWER REQUIREMENT KW 0.0025365
BRAKE HORSEPOWER REQUIREMENT KW 0.0025365
NET WORK REQUIRED KW 0.0025365
POWER LOSSES KW 0.0
ISENTROPIC HORSEPOWER REQUIREMENT KW 0.0020292
CALCULATED OUTLET TEMP C 213.865
ISENTROPIC TEMPERATURE C 183.347
EFFICIENCY (POLYTR/ISENTR) USED 0.80000
OUTLET VAPOR FRACTION 1.00000
HEAD DEVELOPED, M-KGF/KG 18,465.1
MECHANICAL EFFICIENCY USED 1.00000
INLET HEAT CAPACITY RATIO 1.35249
INLET VOLUMETRIC FLOW RATE , L/MIN 2.68518
OUTLET VOLUMETRIC FLOW RATE, L/MIN 1.15887
INLET COMPRESSIBILITY FACTOR 0.99852
OUTLET COMPRESSIBILITY FACTOR 0.99833
AV. ISENT. VOL. EXPONENT 1.35168
AV. ISENT. TEMP EXPONENT 1.35249
AV. ACTUAL VOL. EXPONENT 1.45635
AV. ACTUAL TEMP EXPONENT 1.45668

BLOCK: ALK0NE MODEL: FLASH2

INLET STREAMS: ALKSOLN COCOA
OUTLET VAPOR STREAM: S11
OUTLET LIQUID STREAM: S13
PROPERTY OPTION SET: ELECNRTL ELECTROLYTE NRTL / REDLICH-KWONG
HENRY-COMPS ID: GLOBAL
CHEMISTRY ID: GLOBAL - TRUE SPECIES

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(KMOL/HR)	326.526	326.526	0.00000
MASS(KG/HR)	20438.8	20438.8	0.00000
ENTHALPY(CAL/SEC)	-0.646947E+07	-0.632528E+07	-0.222878E-01

*** CO2 EQUIVALENT SUMMARY ***

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

*** INPUT DATA ***

TWO PHASE TP FLASH
SPECIFIED TEMPERATURE C 95.0000
SPECIFIED PRESSURE BAR 1.50000
MAXIMUM NO. ITERATIONS 30

CONVERGENCE TOLERANCE 0.000100000

*** RESULTS ***

OUTLET TEMPERATURE C	95.000
OUTLET PRESSURE BAR	1.5000
HEAT DUTY CAL/SEC	0.14419E+06
VAPOR FRACTION	0.0000

V-L PHASE EQUILIBRIUM :

COMP	F(I)	X(I)	Y(I)	K(I)
TAG-SOS	0.83307E-02	0.83307E-02	0.10647E-14	0.66826E-13
TAG-POP	0.12758E-01	0.12758E-01	0.58434E-14	0.23949E-12
TAG-POS	0.16456E-01	0.16456E-01	0.39821E-14	0.12653E-12
WATER	0.92997	0.92997	1.0000	0.56223
K+	0.21654E-01	0.21654E-01	0.0000	0.0000
CO3--	0.10827E-01	0.10827E-01	0.0000	0.0000

BLOCK: ALKMIX MODEL: FLASH2

INLET STREAMS: H20 K2C03
OUTLET VAPOR STREAM: S2
OUTLET LIQUID STREAM: S7
PROPERTY OPTION SET: ELECNRTL ELECTROLYTE NRTL / REDLICH-KWONG
HENRY-COMPS ID: GLOBAL
CHEMISTRY ID: GLOBAL - TRUE SPECIES

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(KMOL/HR)	225.929	231.743	-0.250891E-01
MASS(KG/HR)	4419.58	4419.58	0.205788E-15
ENTHALPY(CAL/SEC)	-0.445960E+07	-0.445961E+07	0.873179E-06

*** CO2 EQUIVALENT SUMMARY ***

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

*** INPUT DATA ***

TWO PHASE PQ FLASH

PRESSURE DROP BAR	0.0
SPECIFIED HEAT DUTY CAL/SEC	0.0
MAXIMUM NO. ITERATIONS	30
CONVERGENCE TOLERANCE	0.000100000

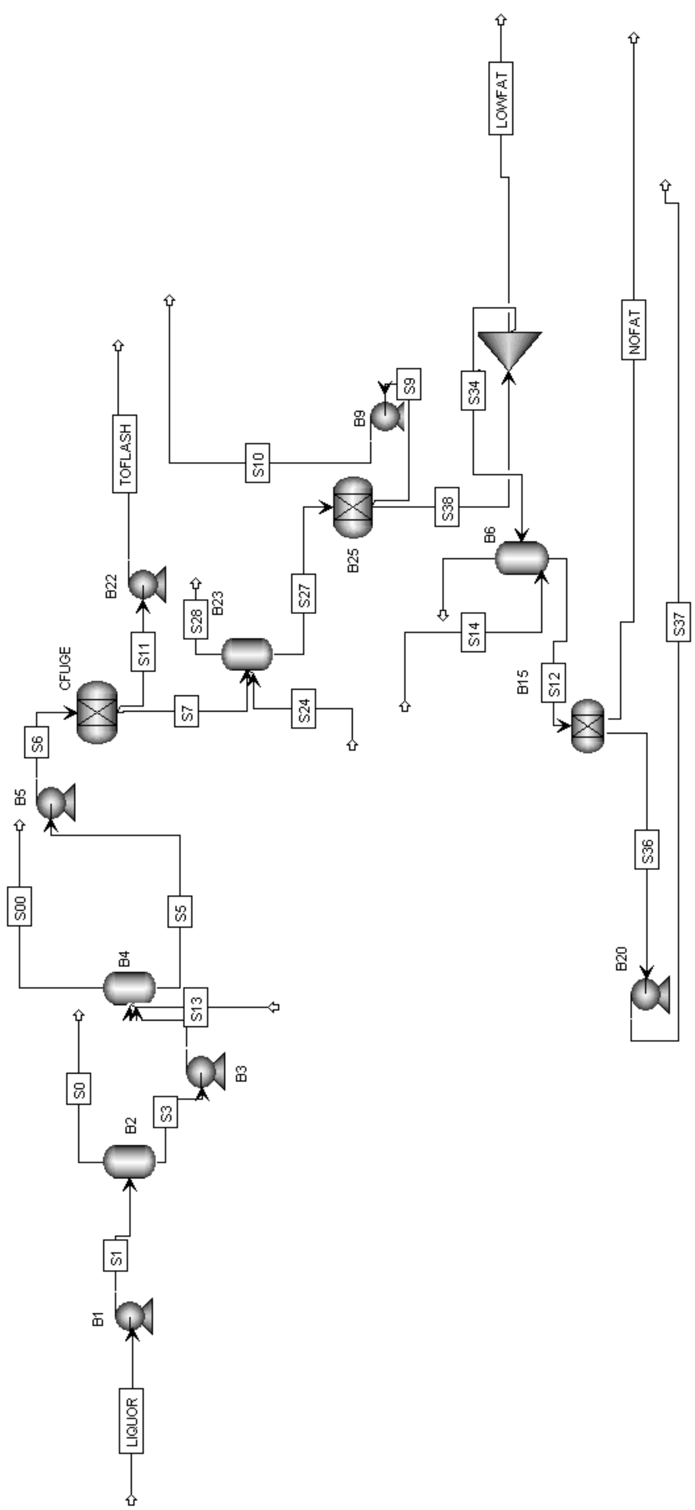
*** RESULTS ***

OUTLET TEMPERATURE C	21.643
OUTLET PRESSURE BAR	1.0135
VAPOR FRACTION	0.0000

V-L PHASE EQUILIBRIUM :

COMP	F(I)	X(I)	Y(I)	K(I)
WATER	1.0000	0.96237	1.0000	1.0391
K+	0.0000	0.25089E-01	0.0000	0.0000
CO3--	0.0000	0.12545E-01	0.0000	0.0000

Solvent Extraction Flowsheet


LIQUOR
B1
S1
B2
S0
S3
B3
S13
B4
S00
S5
B5
S6
CFUGE
S7
S11
B22
TOFLASH
S24
B23
S28
S27
B25
S38
S10
B9
S9
S34
LOWFAT
B6
S14
S12
B15
NOFAT
S36
B20
S37

Solvent Extraction Input Summary

```
;Input Summary created by Aspen Plus Rel. 34.0 at 02:52:28 Tue Apr 12, 2016
;Directory \\base\root\homedir  Filename C:\Users\jmorales\AppData\Local\Temp\~apba02.txt

DYNAMICS
   DYNAMICS RESULTS=ON

IN-UNITS MET PRESSURE=bar TEMPERATURE=C DELTA-T=C PDROP=bar  &
      INVERSE-PRES='1/bar'

DEF-STREAMS MIXCISLD ALL

SIM-OPTIONS MASS-BAL-CHE=YES NPHASE=3

MODEL-OPTION

DATABANKS 'APV88 PURE32' / 'APV88 SOLIDS' / 'APV88 BIODIESEL' &
       / 'NISTV88 NIST-TRC' / 'APV88 EOS-LIT' /  &
      'APV88 NRTL-SAC' / 'APV88 INORGANIC' / NOASPENPCD

PROP-SOURCES 'APV88 PURE32' / 'APV88 SOLIDS' / 'APV88 BIODIESEL' &
       / 'NISTV88 NIST-TRC' / 'APV88 EOS-LIT' /  &
      'APV88 NRTL-SAC' / 'APV88 INORGANIC'

COMPONENTS
   POS C55H104O6-3 /
   SOS C57H108O6-3 /
   POP C53H100O6-5 /
   PROPANE C3H8 /
   WATER H2O /
   POWDER SN /
   TAG-PLIS C55H102O6-3 /
   TAG-PLIP C53H98O6-5 /
   TAG-PPS C53H102O6-13 /
   TAG-PSS C55H106O6-11 /
   TAG-POS2 C55H104O6-3 /
   TAG-POP2 C53H100O6-5 /
   TAG-SOS2 C57H108O6-3 /
   BUTANE C4H10-1 /
   POTAS-01 K2CO3
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CISOLID-COMPS POWDER POTAS-01

SOLVE
    RUN-MODE MODE=SIM

FLOWSHEET
    BLOCK B9 IN=S9 OUT=S10
    BLOCK B2 IN=S1 OUT=S0 S3
    BLOCK B4 IN=S4 S13 OUT=S00 S5
    BLOCK B1 IN=LIQUOR OUT=S1
    BLOCK B3 IN=S3 OUT=S4
    BLOCK B5 IN=S5 OUT=S6
    BLOCK CFUGE IN=S6 OUT=S7 S11
    BLOCK B22 IN=S11 OUT=TOFLASH
    BLOCK B23 IN=S7 S24 OUT=S28 S27
    BLOCK B25 IN=S27 OUT=S9 S38
    BLOCK B8 IN=S38 OUT=LOWFAT S34
    BLOCK B15 IN=S12 OUT=NOFAT S36
    BLOCK B20 IN=S36 OUT=S37
    BLOCK B6 IN=S14 S34 OUT=S2 S12

PROPERTIES NRTL-RK
    PROPERTIES NRTL / PENG-ROB / UNIF-LL / UNIFAC

STRUCTURES
    STRUCTURES POP C1 O2 S / O2 C3 S / C3 O4 D / C3 C5  &
        S / C5 C6 S / C6 C7 S / C7 C8 S / C8 C9 S /  &
        C9 C10 S / C10 C11 S / C11 C12 S / C12 C13 S /  &
        C13 C14 S / C14 C15 S / C15 C16 S / C16 C17 S /  &
        C18 C19 S / C1 C20 S / C20 O21 S / O21 C22 S /  &
        C22 O23 D / C24 C25 S / C25 C26 S / C26 C27 S /  &
        C27 C28 S / C28 C29 S / C29 C30 S / C30 C31 D /  &
        C31 C32 S / C32 C33 S / C33 C34 S / C34 C35 S /  &
        C35 C36 S / C36 C37 S / C37 C38 S / C38 C39 S /  &
        C20 C40 S / C40 O41 S / O41 C42 S / C42 O43 D /  &
        C42 C44 S / C44 C45 S / C45 C46 S / C46 C47 S /  &
        C47 C48 S / C48 C49 S / C49 C50 S / C50 C51 S /  &
        C51 C52 S / C52 C53 S / C53 C54 S / C54 C55 S /  &
        C55 C56 S / C56 C57 S / C57 C58 S
    STRUCTURES POS C1 O2 S / O2 C3 S / C3 O4 D / C3 C5  &
        S / C5 C6 S / C6 C7 S / C7 C8 S / C8 C9 S /  &
        C9 C10 S / C10 C11 S / C11 C12 S / C12 C13 S /  &
        C13 C14 S / C14 C15 S / C15 C16 S / C16 C17 S /  &
        C18 C19 S / C1 C20 S / C20 O21 S / O21 C22 S /  &
        C22 O23 D / C24 C25 S / C25 C26 S / C26 C27 S /  &
        C27 C28 S / C28 C29 S / C29 C30 S / C30 C31 D /  &
        C31 C32 S / C32 C33 S / C33 C34 S / C34 C35 S /  &
        C35 C36 S / C36 C37 S / C37 C38 S / C38 C39 S /  &
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      C20 C40 S / C40 O41 S / O41 C42 S / C42 O43 D /  &
      C42 C44 S / C44 C45 S / C45 C46 S / C46 C47 S /  &
      C47 C48 S / C48 C49 S / C49 C50 S / C50 C51 S /  &
      C51 C52 S / C52 C53 S / C53 C54 S / C54 C55 S /  &
      C55 C56 S / C56 C57 S / C57 C58 S / C58 C59 S /  &
      C59 C60 S
   STRUCTURES SOS C1 O2 S / O2 C3 S / C3 O4 D / C3 C5  &
      S / C5 C6 S / C6 C7 S / C7 C8 S / C8 C9 S /  &
      C9 C10 S / C10 C11 S / C11 C12 S / C12 C13 S /  &
      C13 C14 S / C14 C15 S / C15 C16 S / C16 C17 S /  &
      C17 C18 S / C18 C19 S / C19 C20 S / C20 C21 S /  &
      C1 C22 S / C22 O23 S / O23 C24 S / C24 O25 D /  &
      C24 C26 S / C26 C27 S / C27 C28 S / C28 C29 S /  &
      C29 C30 S / C30 C31 S / C31 C32 S / C32 C33 S /  &
      C33 C34 D / C34 C35 S / C35 C36 S / C36 C37 S /  &
      C37 C38 S / C38 C39 S / C39 C40 S / C40 C41 S /  &
      C41 C42 S / C22 C43 S / C43 O44 S / O44 C45 S /  &
      C45 O46 D / C45 C47 S / C47 C48 S / C48 C49 S /  &
      C49 C50 S / C50 C51 S / C51 C52 S / C52 C53 S /  &
      C53 C54 S / C54 C55 S / C55 C56 S / C56 C57 S /  &
      C57 C58 S / C58 C59 S / C59 C60 S / C60 C61 S /  &
      C61 C62 S / C62 C63 S

ESTIMATE ALL
   ZC SOS DEFINITI
   ZC POS DEFINITI
   ZC POP DEFINITI
   VL POP LEBAS TLOWER=0. TUPPER=1000.
   VL POS LEBAS TLOWER=0. TUPPER=1000.
   VL SOS LEBAS TLOWER=0. TUPPER=1000.
   NRTL POP WATER UNIFAC
   NRTL POS WATER UNIFAC
   NRTL SOS WATER UNIFAC
   NRTL POP PROPANE UNIFAC
   NRTL POS PROPANE UNIFAC
   NRTL SOS PROPANE UNIFAC
   NRTL PROPANE WATER UNIFAC
   NRTL TAG-POS2 WATER UNIFAC
   NRTL TAG-POP2 WATER UNIFAC
   NRTL TAG-SOS2 WATER UNIFAC
   NRTL POP BUTANE UNIFAC
   NRTL POS BUTANE UNIFAC
   NRTL SOS BUTANE UNIFAC
   NRTL BUTANE WATER UNIFAC

PROP-DATA PCES-1
   IN-UNITS MET PRESSURE=bar TEMPERATURE=C DELTA-T=C PDROP=bar  &
      INVERSE-PRES='1/bar'
```

```
   PROP-LIST VB / VLSTD
   PVAL POS 1246.600000 / 673.1506610
   PVAL SOS 1298.400000 / 699.1022110
   PVAL POP 1202.200000 / 651.7593830
   PVAL TAG-PLIS 660.3451080 / 311.6667970
   PVAL TAG-PLIP 635.6195440 / 301.2137180
   PVAL TAG-PPS 637.9978740 / 303.6761370
   PVAL TAG-PSS 662.8517900 / 314.1849610
   PVAL TAG-POS2 661.5363710 / 312.4879070
   PVAL TAG-POP2 636.8003180 / 302.0326180
   PVAL TAG-SOS2 682.7863210 / 320.7959360
   PROP-LIST VLSTD / DHVLB
   PVAL POWDER 0.0 / 1.82873667E+5
   PROP-LIST VLSTD
   PVAL POTAS-01 298.9063450

PROP-DATA REVIEW-1
   IN-UNITS MET PRESSURE=bar TEMPERATURE=C DELTA-T=C PDROP=bar  &
      INVERSE-PRES='1/bar'
   PROP-LIST DGFORM / RKTZRA / ZC
   PVAL POS -1.3212955E+5 / .1556661540 / .1369844490
   PVAL SOS -1.0133515E+5 / .1554476570 / .1359747040
   PVAL POP -1.3615171E+5 / .1565208420 / .1381455880
   PROP-LIST RKTZRA
   PVAL POTAS-01 .2918596200
   PROP-LIST RKTZRA / ZC
   PVAL TAG-PLIS .1037800070 / .1363626340
   PVAL TAG-PLIP .1042286230 / .1374945390
   PVAL TAG-PPS .1050448290 / .1394666880
   PVAL TAG-PSS .1045672400 / .1382323210
   PVAL TAG-POS2 .1039441350 / .1369844490
   PVAL TAG-POP2 .1043993550 / .1381455880
   PVAL TAG-SOS2 .1031860170 / .1359747040
   PROP-LIST TC
   PVAL POWDER 3808.986400

PROP-DATA TDE-1
   IN-UNITS MET PRESSURE='N/sqm' TEMPERATURE=K DELTA-T=C  &
      MOLE-ENTHALP='J/kmol' MOLE-VOLUME='cum/kmol'  &
      DIPOLEMOMENT='(J*cum)**.5' PDROP=bar INVERSE-PRES='1/bar'
   PROP-LIST OMEGA / ZC / VC / PC / TC / MUP / DGFORM /  &
      DHFORM / MW / TB / FREEZEPT / SG / VLSTD
   PVAL PROPANE 0.15232 / 0.27656 / 0.19986 / 4256007.6 /  &
      369.922 / 0 / -24071479.5 / -104514034.8 / 44.097 /  &
      231.063 / 85.51 / 0.507404 / 0.086997

PROP-DATA USRDEF
   IN-UNITS MET PRESSURE=bar TEMPERATURE=C DELTA-T=C PDROP=bar  &
```

```
    INVERSE-PRES='1/bar'
  PROP-LIST SG / DHFORM / DGFORM
  PVAL POS .855 / -510968 / -132130
  PROP-LIST SG
  PVAL SOS 0.855
  PVAL POP 0.855

;TDE Aly-Lee ideal gas Cp
;  "Heat capacity (Ideal gas )"


PROP-DATA CPIALE-1
  IN-UNITS MET MOLE-HEAT-CA='J/kmol-K' PRESSURE=bar  &
    TEMPERATURE=K DELTA-T=C PDROP=bar INVERSE-PRES='1/bar'
  PROP-LIST CPIALEE
  PVAL PROPANE 34416.46 185574.7 968.5094 60044.63 320.9865  &
    0 8.31447 50 1500

;TDE equation for liquid Cp
;  "Heat capacity (Liquid vs. Gas )"


PROP-DATA CPLTDE-1
  IN-UNITS MET MOLE-HEAT-CA='J/kmol-K' PRESSURE=bar  &
    TEMPERATURE=K DELTA-T=C PDROP=bar INVERSE-PRES='1/bar'
  PROP-LIST CPLTDECS
  PVAL PROPANE 79345.31 39.69736 -0.1860955 0.001270954  &
    1763.136 369.9221 4 81.226 362.5237

;ThermoML polynomials for solid Cp
;  "Heat capacity (Crystal 1 vs. Gas )"


PROP-DATA CPSTML-1
  IN-UNITS MET MOLE-HEAT-CA='J/kmol-K' PRESSURE=bar  &
    TEMPERATURE=K DELTA-T=C PDROP=bar INVERSE-PRES='1/bar'
  PROP-LIST CPSTMLPO
  PVAL PROPANE -17141.72 1318.497 -7.537733 0.02007234 0 5  &
    20 85.4

;TDE Watson equation for heat of vaporization
;  "Enthalpy of vaporization or sublimation (Liquid vs. Gas )"


PROP-DATA DHVLTD-1
  IN-UNITS MET PRESSURE=bar TEMPERATURE=K DELTA-T=C  &
    MOLE-ENTHALP='J/kmol' PDROP=bar INVERSE-PRES='1/bar'
```

```
   PROP-LIST DHVLTDEW
   PVAL PROPANE 17.19878 0.8109019 -0.8060312 0.3963184  &
      369.9221 4 81.226 369.9221

PROP-DATA DHVLWT-1
   IN-UNITS MET PRESSURE=bar TEMPERATURE=C DELTA-T=C PDROP=bar  &
      INVERSE-PRES='1/bar'
   PROP-LIST DHVLWT
   PVAL POWDER 1.82873667E+5 2599.850000 .3800000000 0.0  &
      2599.850000

;TDE expansion for liquid molar density
;  "Density (Liquid vs. Gas )"


PROP-DATA DNLEXS-1
   IN-UNITS MET PRESSURE=bar TEMPERATURE=K DELTA-T=C  &
      MOLE-DENSITY='kmol/cum' PDROP=bar INVERSE-PRES='1/bar'
   PROP-LIST DNLEXSAT
   PVAL PROPANE 5.003515 9.978195 2.82091 -0.1586089  &
      0.9601595 0 0 369.9221 6 81.226 369.9221

PROP-DATA KLDIP-1
   IN-UNITS MET PRESSURE=bar TEMPERATURE=C DELTA-T=C PDROP=bar  &
      INVERSE-PRES='1/bar'
   PROP-LIST KLDIP
   PVAL POS -3.917742515 .0278008098 -7.2976298E-5  &
      8.49559300E-8 -3.716939E-11 534.1885140 655.0009430
   PVAL SOS -3.954762758 .0277353126 -7.1975769E-5  &
      8.28421805E-8 -3.583321E-11 540.5892920 661.9410630
   PVAL POP -3.900779259 .0280167558 -7.4416988E-5  &
      8.76583747E-8 -3.880642E-11 527.6972860 647.7813660
   PVAL POWDER -1.689294218 2.45223901E-3 -1.2410738E-6  &
      2.7549006E-10 -2.301472E-14 2599.850000 3768.165040
   PVAL TAG-PLIS -3.936878875 .0279370930 -7.3338798E-5  &
      8.53842247E-8 -3.735940E-11 534.1885140 654.8610670
   PVAL TAG-PLIP -3.909101280 .0280809914 -7.4600288E-5  &
      8.78896324E-8 -3.891569E-11 527.6972860 647.6357410
   PVAL TAG-PPS -3.831512574 .0275146423 -7.3055004E-5  &
      8.60171357E-8 -3.806405E-11 527.6972860 648.4773570
   PVAL TAG-PSS -3.859238478 .0273784985 -7.1836171E-5  &
      8.35889029E-8 -3.655425E-11 534.1885140 655.6695200
   PVAL TAG-POS2 -3.917742515 .0278008098 -7.2976298E-5  &
      8.49559300E-8 -3.716939E-11 534.1885140 655.0009430
   PVAL TAG-POP2 -3.900779259 .0280167558 -7.4416988E-5  &
      8.76583747E-8 -3.880642E-11 527.6972860 647.7813660
   PVAL TAG-SOS2 -3.954762758 .0277353126 -7.1975769E-5  &
      8.28421805E-8 -3.583321E-11 540.5892920 661.9410630
```

```
;ThermoML polynomials for liquid thermal conductivity
;  "Thermal conductivity (Liquid vs. Gas )"


PROP-DATA KLTMLP-1
   IN-UNITS MET PRESSURE=bar TEMPERATURE=K  &
      THERMAL-COND='Watt/m-K' DELTA-T=C PDROP=bar  &
      INVERSE-PRES='1/bar'
   PROP-LIST KLTMLPO
   PVAL PROPANE 0.2112341 0.0003791233 -0.0000049826  &
      0.0000000078865 4 93.158 348.1805

;ThermoML polynomials for vapor thermal conductivity
;  "Thermal conductivity (Gas )"


PROP-DATA KVTMLP-1
   IN-UNITS MET PRESSURE=bar TEMPERATURE=K  &
      THERMAL-COND='Watt/m-K' DELTA-T=C PDROP=bar  &
      INVERSE-PRES='1/bar'
   PROP-LIST KVTMLPO
   PVAL PROPANE 0.003479318 -0.00002229721 0.0000002664949  &
      -9.226184E-11 4 170.524 810.1497

PROP-DATA MULAND-1
   IN-UNITS MET PRESSURE=bar TEMPERATURE=C DELTA-T=C PDROP=bar  &
      INVERSE-PRES='1/bar'
   PROP-LIST MULAND
   PVAL POTAS-01 81.17750888 -12127.32210 -10.25255770  &
      1126.850000 1706.850000

;PPDS9 equation for liquid viscosity
;  "Viscosity (Liquid vs. Gas )"


PROP-DATA MULPPD-1
   IN-UNITS MET PRESSURE=bar TEMPERATURE=K VISCOSITY='N-sec/sqm'  &
      DELTA-T=C PDROP=bar INVERSE-PRES='1/bar'
   PROP-LIST MULPPDS9
   PVAL PROPANE 0.0000105115 2.950715 0.01638895 401.5804  &
      56.94282 83.5 369.9221

PROP-DATA MUVDIP-1
   IN-UNITS MET PRESSURE=bar TEMPERATURE=C DELTA-T=C PDROP=bar  &
      INVERSE-PRES='1/bar'
   PROP-LIST MUVDIP
   PVAL POS 8.67415723E-6 .9831844010 0.0 0.0 0.0  &
```

```
      6.850000000 826.8500000
    PVAL SOS 8.52443691E-6 .9836995870 0.0 0.0 0.0  &
      6.850000000 826.8500000
    PVAL POP 8.86181224E-6 .9826356120 0.0 0.0 0.0  &
      6.850000000 826.8500000

;ThermoML polynomials for vapor viscosity
;  "Viscosity (Gas )"


PROP-DATA MUVTML-1
    IN-UNITS MET PRESSURE=bar TEMPERATURE=K VISCOSITY='N-sec/sqm'  &
      DELTA-T=C PDROP=bar INVERSE-PRES='1/bar'
    PROP-LIST MUVTMLPO
    PVAL PROPANE 0.00000100184 0.0000000149211 4.638362E-11  &
      -5.472325E-14 4 240 548.7791

PROP-DATA SIGDIP-1
    IN-UNITS MET PRESSURE=bar TEMPERATURE=C DELTA-T=C PDROP=bar  &
      INVERSE-PRES='1/bar'
    PROP-LIST SIGDIP
    PVAL POS 16.02907920 1.222222220 1.98528163E-8  &
      -2.1849025E-8 8.13483157E-9 534.1885140 645.6256810
    PVAL SOS 15.21267550 1.222222220 -7.3253955E-9  &
      8.06112577E-9 -3.0009643E-9 540.5892920 652.4956980
    PVAL POP 16.94811190 1.222222210 4.52918561E-8  &
      -4.9850805E-8 1.85629697E-8 527.6972860 638.4790290
    PVAL TAG-PLIS 16.03646570 1.222222200 5.91071476E-8  &
      -6.5049440E-8 2.42183902E-8 534.1885140 645.4872180
    PVAL TAG-PLIP 16.95634330 1.222222210 2.87937828E-8  &
      -3.1691854E-8 1.18011031E-8 527.6972860 638.3348750
    PVAL TAG-PPS 17.03143550 1.222222230 -2.2198724E-8  &
      2.44392755E-8 -9.1041961E-9 527.6972860 639.1679900
    PVAL TAG-PSS 16.10597110 1.222222220 1.94303038E-8  &
      -2.1388649E-8 7.96601941E-9 534.1885140 646.2875040
    PVAL TAG-POS2 16.02907920 1.222222220 1.98528163E-8  &
      -2.1849025E-8 8.13483157E-9 534.1885140 645.6256810
    PVAL TAG-POP2 16.94811190 1.222222210 4.52918561E-8  &
      -4.9850805E-8 1.85629697E-8 527.6972860 638.4790290
    PVAL TAG-SOS2 15.21267550 1.222222220 -7.3253955E-9  &
      8.06112577E-9 -3.0009643E-9 540.5892920 652.4956980

;TDE Watson equation for liquid-gas surface tension
;  "Surface tension (Liquid vs. Gas )"


PROP-DATA SIGTDE-1
    IN-UNITS MET PRESSURE=bar SURFACE-TENS='N/m' TEMPERATURE=K  &
```

```
      DELTA-T=C PDROP=bar INVERSE-PRES='1/bar'
    PROP-LIST SIGTDEW
    PVAL PROPANE -3.073397 0.9198636 0.5972451 -0.7755341  &
      369.9221 4 81.226 369.9221

;TDE Wagner 25 liquid vapor pressure
;  "Vapor pressure (Liquid vs. Gas )"


PROP-DATA WAGN25-1
    IN-UNITS MET PRESSURE='N/sqm' TEMPERATURE=K DELTA-T=C  &
      PDROP=bar INVERSE-PRES='1/bar'
    PROP-LIST WAGNER25
    PVAL PROPANE -6.791833 1.628582 -1.67124 -2.052027  &
      15.26384 369.9221 81.226 369.9221

PROP-DATA NRTL-1
    IN-UNITS MET PRESSURE=bar TEMPERATURE=C DELTA-T=C PDROP=bar  &
      INVERSE-PRES='1/bar'
    PROP-LIST NRTL
    BPVAL POS PROPANE 0.0 30000.00000 .3000000000 0.0 0.0 0.0  &
      25.00000000 25.00000000
    BPVAL PROPANE POS 0.0 -2959.132310 .3000000000 0.0 0.0  &
      0.0 25.00000000 25.00000000
    BPVAL POS WATER 0.0 715.6057000 .3000000000 0.0 0.0 0.0  &
      25.00000000 25.00000000
    BPVAL WATER POS 0.0 15835.11090 .3000000000 0.0 0.0 0.0  &
      25.00000000 25.00000000
    BPVAL SOS PROPANE 0.0 30000.00000 .3000000000 0.0 0.0 0.0  &
      25.00000000 25.00000000
    BPVAL PROPANE SOS 0.0 -3107.795450 .3000000000 0.0 0.0  &
      0.0 25.00000000 25.00000000
    BPVAL SOS WATER 0.0 720.0897280 .3000000000 0.0 0.0 0.0  &
      25.00000000 25.00000000
    BPVAL WATER SOS 0.0 16457.14100 .3000000000 0.0 0.0 0.0  &
      25.00000000 25.00000000
    BPVAL POP PROPANE 0.0 30000.00000 .3000000000 0.0 0.0 0.0  &
      25.00000000 25.00000000
    BPVAL PROPANE POP 0.0 -2810.251010 .3000000000 0.0 0.0  &
      0.0 25.00000000 25.00000000
    BPVAL POP WATER 0.0 710.8481750 .3000000000 0.0 0.0 0.0  &
      25.00000000 25.00000000
    BPVAL WATER POP 0.0 15213.34970 .3000000000 0.0 0.0 0.0  &
      25.00000000 25.00000000
    BPVAL PROPANE WATER 0.0 1899.070780 .3000000000 0.0 0.0  &
      0.0 25.00000000 25.00000000
    BPVAL WATER PROPANE 0.0 1384.028300 .3000000000 0.0 0.0  &
      0.0 25.00000000 25.00000000
```

```
    BPVAL WATER TAG-POS2 0.0 15835.11090 .3000000000 0.0 0.0  &
      0.0 25.00000000 25.00000000
    BPVAL TAG-POS2 WATER 0.0 715.6056630 .3000000000 0.0 0.0  &
      0.0 25.00000000 25.00000000
    BPVAL WATER TAG-POP2 0.0 15213.34970 .3000000000 0.0 0.0  &
      0.0 25.00000000 25.00000000
    BPVAL TAG-POP2 WATER 0.0 710.8481100 .3000000000 0.0 0.0  &
      0.0 25.00000000 25.00000000
    BPVAL WATER TAG-SOS2 0.0 16457.14100 .3000000000 0.0 0.0  &
      0.0 25.00000000 25.00000000
    BPVAL TAG-SOS2 WATER 0.0 720.0897060 .3000000000 0.0 0.0  &
      0.0 25.00000000 25.00000000
    BPVAL POS BUTANE 0.0 18411.94060 .3000000000 0.0 0.0 0.0  &
      25.00000000 25.00000000
    BPVAL BUTANE POS 0.0 -2155.138420 .3000000000 0.0 0.0 0.0  &
      25.00000000 25.00000000
    BPVAL SOS BUTANE 0.0 21952.32180 .3000000000 0.0 0.0 0.0  &
      25.00000000 25.00000000
    BPVAL BUTANE SOS 0.0 -2273.541080 .3000000000 0.0 0.0 0.0  &
      25.00000000 25.00000000
    BPVAL POP BUTANE 0.0 15382.04740 .3000000000 0.0 0.0 0.0  &
      25.00000000 25.00000000
    BPVAL BUTANE POP 0.0 -2036.520180 .3000000000 0.0 0.0 0.0  &
      25.00000000 25.00000000
    BPVAL WATER BUTANE 0.0 1763.960710 .3000000000 0.0 0.0  &
      0.0 25.00000000 25.00000000
    BPVAL BUTANE WATER 0.0 1916.981850 .3000000000 0.0 0.0  &
      0.0 25.00000000 25.00000000

PROP-DATA PRKBV-1
    IN-UNITS MET PRESSURE=bar TEMPERATURE=C DELTA-T=C PDROP=bar  &
      INVERSE-PRES='1/bar'
    PROP-LIST PRKBV
    BPVAL PROPANE BUTANE 3.30000000E-3 0.0 0.0 -273.1500000  &
      726.8500000
    BPVAL BUTANE PROPANE 3.30000000E-3 0.0 0.0 -273.1500000  &
      726.8500000

PROP-SET PS-5 TEMP KVL GAMMA BETA MASSFRAC SUBSTREAM=MIXED  &
      COMPS=POS WATER PHASE=V L1 L2

PROP-SET PS-6 PL UNITS='psia' SUBSTREAM=MIXED COMPS=POS  &
      TAG-POS2 TAG-POP2 POP PHASE=L

PROP-SET PS-7 RHO UNITS='gm/ml' SUBSTREAM=MIXED COMPS=POS  &
      TAG-POS2 POP TAG-POP2 SOS TAG-SOS2 PHASE=L

PROP-SET PS-8 CP UNITS='Btu/lb-R' SUBSTREAM=MIXED COMPS=POS  &
```

```
    TAG-POS2 POP TAG-POP2 SOS TAG-SOS2 PHASE=L

PROP-SET PS-9 PL UNITS='bar' SUBSTREAM=MIXED COMPS=PROPANE  &
    PHASE=L

STREAM LIQUOR
  SUBSTREAM MIXED TEMP=95. PRES=1.013250000 MASS-FLOW=8600.
  MASS-FRAC POS 0.2366 / SOS 0.1237 / POP 0.1775 / WATER  &
    0.0024 / POWDER 0.43 / POTAS-01 0.0298
  SUBSTREAM CISOLID TEMP=30.00000000 PRES=1.013250000  &
    MOLE-FLOW=36758.22998
  MASS-FRAC POWDER 0.533333

STREAM S10
  SUBSTREAM MIXED TEMP=50. VFRAC=0.

STREAM S13
  SUBSTREAM MIXED TEMP=50. VFRAC=0. MASS-FLOW=21500.
  MASS-FLOW BUTANE 1.

STREAM S14
  SUBSTREAM MIXED TEMP=50. VFRAC=0. MASS-FLOW=490.
  MASS-FRAC BUTANE 1.

STREAM S24
  SUBSTREAM MIXED TEMP=50. VFRAC=0. MASS-FLOW=5804.
  MASS-FRAC BUTANE 1.

BLOCK B8 FSPLIT
  FRAC LOWFAT 0.2

BLOCK B15 SEP
  PARAM
  FRAC STREAM=NOFAT SUBSTREAM=MIXED COMPS=POS SOS POP  &
    WATER POWDER BUTANE POTAS-01 FRACS=0.133 0.133 0.133  &
    0.133 1. 0.133 1.

BLOCK B25 SEP
  PARAM
  FRAC STREAM=S38 SUBSTREAM=MIXED COMPS=POS SOS POP WATER  &
    POWDER BUTANE POTAS-01 FRACS=0.31 0.31 0.31 0.31 1.  &
    0.31 1.

BLOCK CFUGE SEP
  PARAM PRES=0. NPHASE=1 PHASE=L MAXIT=100
  FRAC STREAM=S7 SUBSTREAM=MIXED COMPS=POS SOS POP WATER  &
    POWDER BUTANE POTAS-01 FRACS=0.1 0.1 0.1 0.1 1. 0.1  &
    1.
```

```
    FLASH-SPECS S7 KODE=NOFLASH
    BLOCK-OPTION FREE-WATER=NO

BLOCK B2 FLASH2
    PARAM TEMP=50. PRES=2.

BLOCK B4 FLASH2
    PARAM TEMP=50. VFRAC=0.

BLOCK B6 FLASH2
    PARAM TEMP=50. PRES=6.

BLOCK B23 FLASH2
    PARAM TEMP=50. PRES=6.

BLOCK B1 PUMP
    PARAM PRES=2.

BLOCK B3 PUMP
    PARAM PRES=2.

BLOCK B5 PUMP
    PARAM PRES=6. EFF=0.75

BLOCK B9 PUMP
    PARAM PRES=6. EFF=0.75

BLOCK B20 PUMP
    PARAM PRES=6.

BLOCK B22 PUMP
    PARAM PRES=6. EFF=0.75

EO-CONV-OPTI

CALCULATOR C-1
    DEFINE TEMPPUMP STREAM-VAR STREAM=S1 SUBSTREAM=MIXED  &
        VARIABLE=TEMP UOM="C"
F     TEMPPUMP=95
F
    WRITE-VARS TEMPPUMP

STREAM-REPOR MOLEFLOW MASSFLOW MASSFRAC

PROPERTY-REP PCES PARAM-PLUS

PROP-TABLE BINRY-1 FLASHCURVE
```

```
  PROPERTIES NRTL FREE-WATER=STEAM-TA SOLU-WATER=3  &
     TRUE-COMPS=YES
  MASS-FLOW POS 1 /  WATER  1
  STATE VFRAC=0.0
  VARY PRES
  RANGE LIST=1.013250000
  VARY MASSFRAC COMP=POS
  RANGE LOWER=0.0 UPPER=1.0 INCR=0.005
  PARAM NPHASE=3
  TABULATE PROPERTIES=PS-5

PROP-TABLE PURE-1 PROPS
  IN-UNITS MET PRESSURE=bar TEMPERATURE=C DELTA-T=C PDROP=bar  &
     INVERSE-PRES='1/bar'
  MOLE-FLOW POS 1 / TAG-POS2 1 / TAG-POP2 1 / POP 1
  PROPERTIES NRTL-RK FREE-WATER=STEAM-TA SOLU-WATER=3  &
     TRUE-COMPS=YES
  VARY TEMP
  RANGE LOWER=0 UPPER=200. INCR=5.
  VARY PRES
  RANGE LIST=1.013250000
  PARAM
  TABULATE PROPERTIES=PS-6

PROP-TABLE PURE-2 PROPS
  IN-UNITS MET PRESSURE=bar TEMPERATURE=C DELTA-T=C PDROP=bar  &
     INVERSE-PRES='1/bar'
  MOLE-FLOW POS 1 / TAG-POS2 1 / POP 1 / TAG-POP2 1 /  &
     SOS 1 / TAG-SOS2 1
  PROPERTIES UNIFAC FREE-WATER=STEAM-TA SOLU-WATER=3  &
     TRUE-COMPS=YES
  VARY TEMP
  RANGE LOWER=0 UPPER=250. INCR=5.
  VARY PRES
  RANGE LIST=1.013250000
  PARAM
  TABULATE PROPERTIES=PS-7

PROP-TABLE PURE-3 PROPS
  IN-UNITS MET PRESSURE=bar TEMPERATURE=C DELTA-T=C PDROP=bar  &
     INVERSE-PRES='1/bar'
  MOLE-FLOW POS 1 / TAG-POS2 1 / POP 1 / TAG-POP2 1 /  &
     SOS 1 / TAG-SOS2 1
  PROPERTIES UNIFAC FREE-WATER=STEAM-TA SOLU-WATER=3  &
     TRUE-COMPS=YES
  VARY TEMP
  RANGE LOWER=0 UPPER=150. INCR=5.
  VARY PRES
```

```
   RANGE LIST=1.013250000
   PARAM
   TABULATE PROPERTIES=PS-8

PROP-TABLE PURE-4 PROPS
   IN-UNITS MET PRESSURE=bar TEMPERATURE=C DELTA-T=C PDROP=bar  &
      INVERSE-PRES='1/bar'
   MOLE-FLOW PROPANE 1
   PROPERTIES NRTL-RK FREE-WATER=STEAM-TA SOLU-WATER=3  &
      TRUE-COMPS=YES
   VARY TEMP
   RANGE LOWER=0 UPPER=100.0000000 NPOINT= 50
   VARY PRES
   RANGE LIST=1.013250000
   PARAM
   TABULATE PROPERTIES=PS-9
```

Solvent Extraction Block Report

```
 BLOCK:  B1       MODEL: PUMP
 ----------------------------
   INLET STREAM:          LIQUOR
   OUTLET STREAM:         S1
   PROPERTY OPTION SET:   NRTL-RK   RENON (NRTL) / REDLICH-KWONG

                 ***  MASS AND ENERGY BALANCE  ***
                              IN              OUT         RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(KMOL/HR )            36797.8          36797.8          0.00000
       MASS(KG/HR   )          0.437217E+07    0.437217E+07     0.00000
       ENTHALPY(CAL/SEC )       -638664.        -638554.       -0.171520E-03

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

                     ***  INPUT DATA  ***
    OUTLET PRESSURE  BAR                              2.00000
    DRIVER EFFICIENCY                                 1.00000

    FLASH SPECIFICATIONS:
    3 PHASE FLASH
    MAXIMUM NUMBER OF ITERATIONS                         30
    TOLERANCE                                    0.000100000
```

```
                    ***  RESULTS  ***
 VOLUMETRIC FLOW RATE  L/MIN                        91.4395
 PRESSURE CHANGE  BAR                           0.98675
 NPSH AVAILABLE   M-KGF/KG                        9.25127
 FLUID POWER  KW                            0.15038
 BRAKE POWER  KW                             0.45987
 ELECTRICITY  KW                           0.45987
 PUMP EFFICIENCY USED                          0.32700
 NET WORK REQUIRED  KW                           0.45987
 HEAD DEVELOPED M-KGF/KG                           6.41908

BLOCK:  B2       MODEL: FLASH2
------------------------------
 INLET STREAM:          S1
 OUTLET VAPOR STREAM:   S0
 OUTLET LIQUID STREAM:  S3
 PROPERTY OPTION SET:   NRTL-RK   RENON (NRTL) / REDLICH-KWONG

                ***  MASS AND ENERGY BALANCE  ***
                          IN            OUT       RELATIVE DIFF.
 TOTAL BALANCE
   MOLE(KMOL/HR )          36797.8        36797.8        0.00000
   MASS(KG/HR   )        0.437217E+07   0.437217E+07    0.00000
   ENTHALPY(CAL/SEC )      -638554.        690985.        -1.92412

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

                   ***  INPUT DATA  ***
 THREE  PHASE  TP  FLASH
 SPECIFIED TEMPERATURE C                          50.0000
 SPECIFIED PRESSURE    BAR                        2.00000
 MAXIMUM NO. ITERATIONS                           30
 CONVERGENCE TOLERANCE                              0.000100000

                    ***  RESULTS  ***
 OUTLET TEMPERATURE    C                          50.000
 OUTLET PRESSURE       BAR                        2.0000
 HEAD DUTY             CAL/SEC                 0.13295E+07
 VAPOR FRACTION                               0.0000
 1ST LIQUID/TOTAL LIQUID                          1.0000

 V-L1-L2 PHASE EQUILIBRIUM :
```

COMP	F(I)	X1(I)	X2(I)	Y(I)	K1(I)	K2(I)
POS	0.361	0.361	0.361	0.648E-15	0.600E-16	0.600E-16
SOS	0.183	0.183	0.183	0.156E-15	0.285E-16	0.285E-16
POP	0.280	0.280	0.280	0.106E-14	0.126E-15	0.126E-15
WATER	0.175	0.175	0.175	1.00	0.191	0.191

BLOCK: B3 MODEL: PUMP

INLET STREAM: S3

OUTLET STREAM: S4

PROPERTY OPTION SET: NRTL-RK RENON (NRTL) / REDLICH-KWONG

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(KMOL/HR)	36797.8	36797.8	0.00000
MASS(KG/HR)	0.437217E+07	0.437217E+07	0.00000
ENTHALPY(CAL/SEC)	690985.	691254.	-0.389094E-03

*** CO2 EQUIVALENT SUMMARY ***

FEED STREAMS CO2E 0.00000 KG/HR

PRODUCT STREAMS CO2E 0.00000 KG/HR

NET STREAMS CO2E PRODUCTION 0.00000 KG/HR

UTILITIES CO2E PRODUCTION 0.00000 KG/HR

TOTAL CO2E PRODUCTION 0.00000 KG/HR

*** INPUT DATA ***

OUTLET PRESSURE BAR 4.42000

DRIVER EFFICIENCY 1.00000

FLASH SPECIFICATIONS:

3 PHASE FLASH

MAXIMUM NUMBER OF ITERATIONS 30

TOLERANCE 0.000100000

*** RESULTS ***

VOLUMETRIC FLOW RATE L/MIN 91.4395

PRESSURE CHANGE BAR 2.42000

NPSH AVAILABLE M-KGF/KG 18.8838

FLUID POWER KW 0.36881

BRAKE POWER KW 1.12784

ELECTRICITY KW 1.12784

PUMP EFFICIENCY USED 0.32700

NET WORK REQUIRED KW 1.12784

HEAD DEVELOPED M-KGF/KG 15.7428

BLOCK: B4 MODEL: FLASH2

INLET STREAMS: S4 S13
OUTLET VAPOR STREAM: S00
OUTLET LIQUID STREAM: S5
PROPERTY OPTION SET: NRTL-RK RENON (NRTL) / REDLICH-KWONG

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(KMOL/HR)	37167.7	37167.7	0.195760E-15
MASS(KG/HR)	0.439367E+07	0.439367E+07	0.00000
ENTHALPY(CAL/SEC)	-0.282906E+07	-0.283553E+07	0.228183E-02

*** CO2 EQUIVALENT SUMMARY ***

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

*** INPUT DATA ***

THREE PHASE TV FLASH
SPECIFIED TEMPERATURE C 50.0000
VAPOR FRACTION 0.0
MAXIMUM NO. ITERATIONS 30
CONVERGENCE TOLERANCE 0.000100000

*** RESULTS ***

OUTLET TEMPERATURE C 50.000
OUTLET PRESSURE BAR 5.0233
HEAT DUTY CAL/SEC -6470.2
VAPOR FRACTION 0.0000
1ST LIQUID/TOTAL LIQUID 0.99810

V-L1-L2 PHASE EQUILIBRIUM :

COMP	F(I)	X1(I)	X2(I)	Y(I)	K1(I)	K2(I)
POS	0.627E-02	0.629E-02	0.716E-03	0.660E-21	0.105E-18	0.922E-18
SOS	0.318E-02	0.318E-02	0.371E-03	0.114E-21	0.357E-19	0.307E-18
POP	0.487E-02	0.487E-02	0.543E-03	0.151E-20	0.309E-18	0.277E-17
WATER	0.304E-02	0.116E-02	0.996	0.256E-01	22.1	0.257E-01
BUTANE	0.983	0.985	0.247E-02	0.974	0.990	394.

BLOCK: B5 MODEL: PUMP

INLET STREAM: S5
OUTLET STREAM: S6
PROPERTY OPTION SET: NRTL-RK RENON (NRTL) / REDLICH-KWONG

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(KMOL/HR)	37167.7	37167.7	0.00000
MASS(KG/HR)	0.439367E+07	0.439367E+07	0.00000
ENTHALPY(CAL/SEC)	-0.283553E+07	-0.282740E+07	-0.286536E-02

*** CO2 EQUIVALENT SUMMARY ***

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

*** INPUT DATA ***

OUTLET PRESSURE BAR 20.0000
DRIVER EFFICIENCY 1.00000

FLASH SPECIFICATIONS:
3 PHASE FLASH
MAXIMUM NUMBER OF ITERATIONS 30
TOLERANCE 0.000100000

*** RESULTS ***

VOLUMETRIC FLOW RATE L/MIN 866.334
PRESSURE CHANGE BAR 14.9767
NPSH AVAILABLE M-KGF/KG 0.0
FLUID POWER KW 21.6247
BRAKE POWER KW 34.0748
ELECTRICITY KW 34.0748
PUMP EFFICIENCY USED 0.63463
NET WORK REQUIRED KW 34.0748
HEAD DEVELOPED M-KGF/KG 263.734

BLOCK: B6 MODEL: FLASH2

INLET STREAMS: S14 S34
OUTLET VAPOR STREAM: S2
OUTLET LIQUID STREAM: S12
PROPERTY OPTION SET: NRTL-RK RENON (NRTL) / REDLICH-KWONG

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(KMOL/HR)	23.8486	23.8486	-0.148969E-15
MASS(KG/HR)	1810.02	1810.02	0.00000
ENTHALPY(CAL/SEC)	-198613.	-198802.	0.951830E-03

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

*** INPUT DATA ***
THREE PHASE TV FLASH
SPECIFIED TEMPERATURE C 50.0000
VAPOR FRACTION 0.0
MAXIMUM NO. ITERATIONS 30
CONVERGENCE TOLERANCE 0.000100000

*** RESULTS ***
OUTLET TEMPERATURE C 50.000
OUTLET PRESSURE BAR 5.0954
HEAT DUTY CAL/SEC -189.23
VAPOR FRACTION 0.0000
1ST LIQUID/TOTAL LIQUID 0.98768

V-L1-L2 PHASE EQUILIBRIUM :

COMP	F(I)	X1(I)	X2(I)	Y(I)	K1(I)	K2(I)
POS	0.822E-03	0.830E-03	0.178E-03	0.864E-22	0.104E-18	0.484E-18
SOS	0.416E-03	0.420E-03	0.911E-04	0.149E-22	0.355E-19	0.164E-18
POP	0.637E-03	0.643E-03	0.137E-03	0.197E-21	0.306E-18	0.144E-17
WATER	0.133E-01	0.100E-02	0.998	0.253E-01	25.2	0.253E-01
BUTANE	0.985	0.997	0.180E-02	0.975	0.978	540.

BLOCK: B7 MODEL: PUMP

INLET STREAM: S27
OUTLET STREAM: S8
PROPERTY OPTION SET: NRTL-RK RENON (NRTL) / REDLICH-KWONG

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(KMOL/HR)	172.111	172.111	0.00000
MASS(KG/HR)	12424.8	12424.8	0.00000
ENTHALPY(CAL/SEC)	-0.155045E+07	-0.154748E+07	-0.191849E-02

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

TOTAL CO2E PRODUCTION 0.00000 KG/HR

*** INPUT DATA ***

OUTLET PRESSURE BAR 18.2000
DRIVER EFFICIENCY 1.00000

FLASH SPECIFICATIONS:
3 PHASE FLASH
MAXIMUM NUMBER OF ITERATIONS 30
TOLERANCE 0.000100000

*** RESULTS ***

VOLUMETRIC FLOW RATE L/MIN 282.840
PRESSURE CHANGE BAR 13.1162
NPSH AVAILABLE M-KGF/KG 0.0
FLUID POWER KW 6.18296
BRAKE POWER KW 12.4496
ELECTRICITY KW 12.4496
PUMP EFFICIENCY USED 0.49664
NET WORK REQUIRED KW 12.4496
HEAD DEVELOPED M-KGF/KG 182.679

BLOCK: B8 MODEL: FSPLIT

INLET STREAM: S38
OUTLET STREAMS: LOWFAT S34
PROPERTY OPTION SET: NRTL-RK RENON (NRTL) / REDLICH-KWONG

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(KMOL/HR)	75.5395	75.5395	0.00000
MASS(KG/HR)	6509.88	6509.88	0.139710E-15
ENTHALPY(CAL/SEC)	-577144.	-577144.	0.00000

*** CO2 EQUIVALENT SUMMARY ***

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

*** INPUT DATA ***

FRACTION OF FLOW STRM=LOWFAT FRAC= 0.80000

*** RESULTS ***

STREAM= LOWFAT SPLIT= 0.80000 KEY= 0 STREAM-ORDER= 1
S34 0.20000 0 2

BLOCK: B9 MODEL: PUMP

INLET STREAM: S9
OUTLET STREAM: S10
PROPERTY OPTION SET: NRTL-RK RENON (NRTL) / REDLICH-KWONG

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(KMOL/HR)	96.5719	96.5719	0.00000
MASS(KG/HR)	5914.91	5914.91	0.00000
ENTHALPY(CAL/SEC)	-970424.	-970435.	0.114287E-04

*** CO2 EQUIVALENT SUMMARY ***

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

*** INPUT DATA ***

OUTLET PRESSURE BAR 18.0000
PUMP EFFICIENCY 0.75000
DRIVER EFFICIENCY 1.00000

FLASH SPECIFICATIONS:
3 PHASE FLASH
MAXIMUM NUMBER OF ITERATIONS 30
TOLERANCE 0.000100000

*** RESULTS ***

VOLUMETRIC FLOW RATE L/MIN 186.389
PRESSURE CHANGE BAR -0.20000
NPSH AVAILABLE M-KGF/KG 251.253
FLUID POWER KW -0.062130
BRAKE POWER KW -0.046597
ELECTRICITY KW -0.046597
PUMP EFFICIENCY USED 0.75000
NET WORK REQUIRED KW -0.046597
HEAD DEVELOPED M-KGF/KG -3.85596

BLOCK: B15 MODEL: SEP

INLET STREAM: S12
OUTLET STREAMS: NOFAT S36

PROPERTY OPTION SET: NRTL-RK RENON (NRTL) / REDLICH-KWONG

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(KMOL/HR)	23.8486	23.8486	0.297939E-15
MASS(KG/HR)	1810.02	1810.02	0.00000
ENTHALPY(CAL/SEC)	-198802.	-198756.	-0.229979E-03

*** CO2 EQUIVALENT SUMMARY ***

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

*** INPUT DATA ***

FLASH SPECS FOR STREAM NOFAT
THREE PHASE TP FLASH

PRESSURE DROP	BAR	0.0
MAXIMUM NO. ITERATIONS		30
CONVERGENCE TOLERANCE		0.000100000

FLASH SPECS FOR STREAM S36
THREE PHASE TP FLASH

PRESSURE DROP	BAR	0.0
MAXIMUM NO. ITERATIONS		30
CONVERGENCE TOLERANCE		0.000100000

FRACTION OF FEED
SUBSTREAM= MIXED
STREAM= NOFAT CPT= POS FRACTION= 0.14110

SOS	0.14110
POP	0.14110
WATER	1.00000
POWDER	1.00000
BUTANE	0.14110
POTAS-01	1.00000

*** RESULTS ***

HEAD DUTY CAL/SEC 45.720

COMPONENT = POS
STREAM SUBSTREAM SPLIT FRACTION

NOFAT MIXED 0.14110
S36 MIXED 0.85890

COMPONENT = SOS
STREAM SUBSTREAM SPLIT FRACTION
NOFAT MIXED 0.14110
S36 MIXED 0.85890

COMPONENT = POP
STREAM SUBSTREAM SPLIT FRACTION
NOFAT MIXED 0.14110
S36 MIXED 0.85890

COMPONENT = WATER
STREAM SUBSTREAM SPLIT FRACTION
NOFAT MIXED 1.00000

COMPONENT = POWDER
STREAM SUBSTREAM SPLIT FRACTION
NOFAT MIXED 1.00000

COMPONENT = BUTANE
STREAM SUBSTREAM SPLIT FRACTION
NOFAT MIXED 0.14110
S36 MIXED 0.85890

COMPONENT = POTAS-01
STREAM SUBSTREAM SPLIT FRACTION
NOFAT MIXED 1.00000

BLOCK: B20 MODEL: PUMP

INLET STREAM: S36
OUTLET STREAM: S37
PROPERTY OPTION SET: NRTL-RK RENON (NRTL) / REDLICH-KWONG

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(KMOL/HR)	14.6170	14.6170	0.00000
MASS(KG/HR)	871.812	871.812	0.00000
ENTHALPY(CAL/SEC)	-143035.	-143002.	-0.230646E-03

*** CO2 EQUIVALENT SUMMARY ***

FEED STREAMS CO2E 0.00000 KG/HR
PRODUCT STREAMS CO2E 0.00000 KG/HR
NET STREAMS CO2E PRODUCTION 0.00000 KG/HR
UTILITIES CO2E PRODUCTION 0.00000 KG/HR

TOTAL CO2E PRODUCTION 0.00000 KG/HR

*** INPUT DATA ***
OUTLET PRESSURE BAR 6.00000
DRIVER EFFICIENCY 1.00000

FLASH SPECIFICATIONS:
3 PHASE FLASH
MAXIMUM NUMBER OF ITERATIONS 30
TOLERANCE 0.000100000

*** RESULTS ***
VOLUMETRIC FLOW RATE L/MIN 27.0861
PRESSURE CHANGE BAR 0.90462
NPSH AVAILABLE M-KGF/KG 2.69474
FLUID POWER KW 0.040838
BRAKE POWER KW 0.13812
ELECTRICITY KW 0.13812
PUMP EFFICIENCY USED 0.29566
NET WORK REQUIRED KW 0.13812
HEAD DEVELOPED M-KGF/KG 17.1957

BLOCK: B22 MODEL: PUMP

INLET STREAM: S11
OUTLET STREAM: TOFLASH
PROPERTY OPTION SET: NRTL-RK RENON (NRTL) / REDLICH-KWONG

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(KMOL/HR)	37096.0	37096.0	0.00000
MASS(KG/HR)	0.438708E+07	0.438708E+07	0.00000
ENTHALPY(CAL/SEC)	-0.223372E+07	-0.223410E+07	0.168985E-03

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

*** INPUT DATA ***
OUTLET PRESSURE BAR 18.0000
DRIVER EFFICIENCY 1.00000

FLASH SPECIFICATIONS:
3 PHASE FLASH

MAXIMUM NUMBER OF ITERATIONS 30
TOLERANCE 0.000100000

*** RESULTS ***

VOLUMETRIC FLOW RATE L/MIN	764.046
PRESSURE CHANGE BAR	-2.00000
NPSH AVAILABLE M-KGF/KG	300.340
FLUID POWER KW	-2.54682
BRAKE POWER KW	-1.58064
ELECTRICITY KW	-1.58064
PUMP EFFICIENCY USED	0.62064
NET WORK REQUIRED KW	-1.58064
HEAD DEVELOPED M-KGF/KG	-39.7630

BLOCK: B23 MODEL: FLASH2

INLET STREAMS: S7 S24
OUTLET VAPOR STREAM: S28
OUTLET LIQUID STREAM: S27
PROPERTY OPTION SET: NRTL-RK RENON (NRTL) / REDLICH-KWONG

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(KMOL/HR)	172.111	172.111	0.00000
MASS(KG/HR)	12424.8	12424.8	0.00000
ENTHALPY(CAL/SEC)	-955784.	-0.155045E+07	0.383545

*** CO2 EQUIVALENT SUMMARY ***

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

*** INPUT DATA ***

THREE PHASE TV FLASH

SPECIFIED TEMPERATURE C	50.0000
VAPOR FRACTION	0.0
MAXIMUM NO. ITERATIONS	30
CONVERGENCE TOLERANCE	0.000100000

*** RESULTS ***

OUTLET TEMPERATURE	C	50.000
OUTLET PRESSURE	BAR	5.0838
HEAT DUTY	CAL/SEC	0.0000
VAPOR FRACTION		0.0000
1ST LIQUID/TOTAL LIQUID		0.99276

V-L1-L2 PHASE EQUILIBRIUM :

COMP	F(I)	X1(I)	X2(I)	Y(I)	K1(I)	K2(I)
POS	0.170E-02	0.171E-02	0.300E-03	0.178E-21	0.104E-18	0.595E-18
SOS	0.860E-03	0.865E-03	0.154E-03	0.307E-22	0.355E-19	0.200E-18
POP	0.132E-02	0.132E-02	0.229E-03	0.406E-21	0.306E-18	0.177E-17
WATER	0.824E-02	0.103E-02	0.997	0.253E-01	24.7	0.254E-01
BUTANE	0.988	0.995	0.193E-02	0.975	0.980	506.

BLOCK: B25 MODEL: SEP

INLET STREAM: S8

OUTLET STREAMS: S9 S38

PROPERTY OPTION SET: NRTL-RK RENON (NRTL) / REDLICH-KWONG

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(KMOL/HR)	172.111	172.111	0.00000
MASS(KG/HR)	12424.8	12424.8	0.00000
ENTHALPY(CAL/SEC)	-0.154748E+07	-0.154757E+07	0.595264E-04

*** CO2 EQUIVALENT SUMMARY ***

FEED STREAMS CO2E 0.00000 KG/HR

PRODUCT STREAMS CO2E 0.00000 KG/HR

NET STREAMS CO2E PRODUCTION 0.00000 KG/HR

UTILITIES CO2E PRODUCTION 0.00000 KG/HR

TOTAL CO2E PRODUCTION 0.00000 KG/HR

*** INPUT DATA ***

FLASH SPECS FOR STREAM S9

THREE PHASE TP FLASH

PRESSURE DROP BAR 0.0

MAXIMUM NO. ITERATIONS 30

CONVERGENCE TOLERANCE 0.000100000

FLASH SPECS FOR STREAM S38

THREE PHASE TP FLASH

PRESSURE DROP BAR 0.0

MAXIMUM NO. ITERATIONS 30

CONVERGENCE TOLERANCE 0.000100000

FRACTION OF FEED

SUBSTREAM= MIXED

STREAM= S38 CPT= POS FRACTION= 0.30000

SOS	0.30000
POP	0.30000
WATER	1.00000
POWDER	1.00000
BUTANE	0.30000
POTAS-01	1.00000

*** RESULTS ***

HEAT DUTY CAL/SEC -92.121

COMPONENT = POS

STREAM	SUBSTREAM	SPLIT FRACTION
S9	MIXED	0.70000
S38	MIXED	0.30000

COMPONENT = SOS

STREAM	SUBSTREAM	SPLIT FRACTION
S9	MIXED	0.70000
S38	MIXED	0.30000

COMPONENT = POP

STREAM	SUBSTREAM	SPLIT FRACTION
S9	MIXED	0.70000
S38	MIXED	0.30000

COMPONENT = WATER

STREAM	SUBSTREAM	SPLIT FRACTION
S38	MIXED	1.00000

COMPONENT = POWDER

STREAM	SUBSTREAM	SPLIT FRACTION
S38	MIXED	1.00000

COMPONENT = BUTANE

STREAM	SUBSTREAM	SPLIT FRACTION
S9	MIXED	0.70000
S38	MIXED	0.30000

COMPONENT = POTAS-01

STREAM	SUBSTREAM	SPLIT FRACTION
S38	MIXED	1.00000

BLOCK: CFUGE MODEL: SEP

INLET STREAM: S6

OUTLET STREAMS: S7 S11

PROPERTY OPTION SET: NRTL-RK RENON (NRTL) / REDLICH-KWONG

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(KMOL/HR)	37167.7	37167.7	0.00000
MASS(KG/HR)	0.439367E+07	0.439367E+07	0.00000
ENTHALPY(CAL/SEC)	-0.282740E+07	-0.223372E+07	-0.209974

*** CO2 EQUIVALENT SUMMARY ***

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

*** INPUT DATA ***

INLET PRESSURE DROP BAR 0.0

FLASH SPECS FOR STREAM S11
THREE PHASE TP FLASH
PRESSURE DROP BAR 0.0
MAXIMUM NO. ITERATIONS 30
CONVERGENCE TOLERANCE 0.000100000

FRACTION OF FEED
SUBSTREAM= MIXED
STREAM= S7 CPT= POS FRACTION= 0.100000

SOS	0.100000
POP	0.100000
WATER	1.00000
POWDER	1.00000
BUTANE	0.100000
POTAS-01	1.00000

*** RESULTS ***

HEAT DUTY CAL/SEC 0.18298E+36

COMPONENT = POS

STREAM	SUBSTREAM	SPLIT FRACTION
S7	MIXED	0.100000
S11	MIXED	0.90000

COMPONENT = SOS

STREAM	SUBSTREAM	SPLIT FRACTION
S7	MIXED	0.100000
S11	MIXED	0.90000

COMPONENT = POP

STREAM	SUBSTREAM	SPLIT FRACTION
S7	MIXED	0.100000
S11	MIXED	0.90000

COMPONENT = WATER

STREAM	SUBSTREAM	SPLIT FRACTION
S7	MIXED	1.00000

COMPONENT = POWDER

STREAM	SUBSTREAM	SPLIT FRACTION
S7	MIXED	1.00000
S11	CISOLID	1.00000

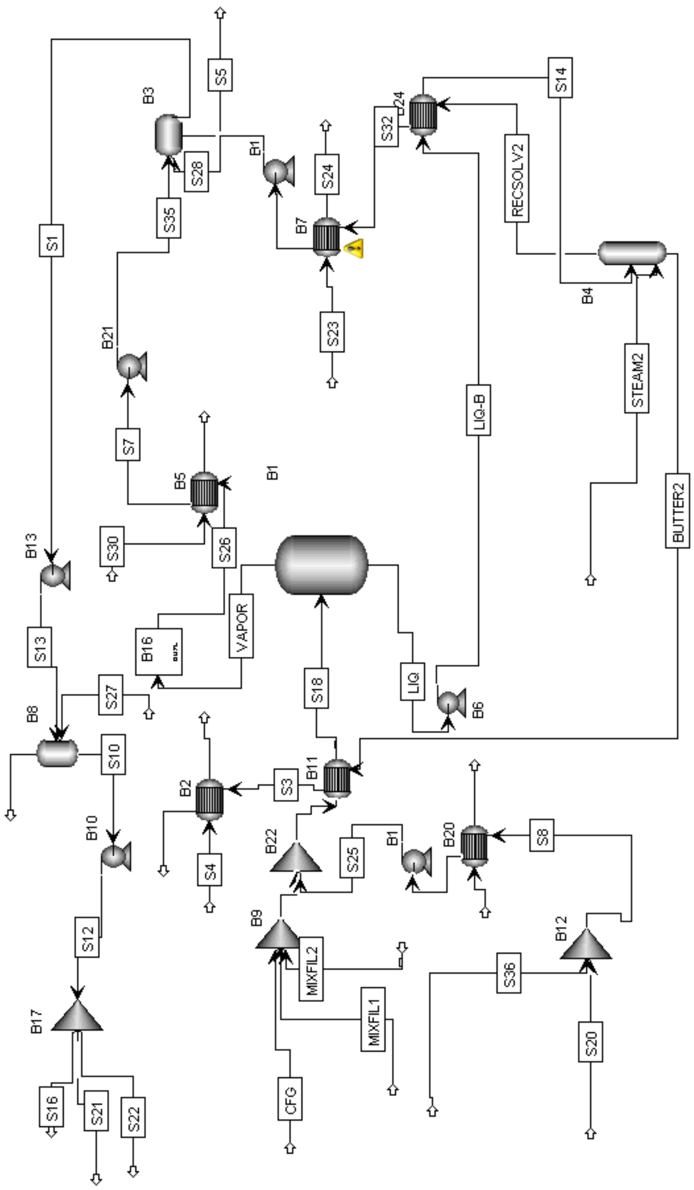
COMPONENT = BUTANE

STREAM	SUBSTREAM	SPLIT FRACTION
S7	MIXED	0.100000
S11	MIXED	0.90000

COMPONENT = POTAS-01

STREAM	SUBSTREAM	SPLIT FRACTION
S7	MIXED	1.00000

Butter Recovery Flowsheet



Butter Recovery Input Summary

```
;Input Summary created by Aspen Plus Rel. 34.0 at 03:21:13 Tue Apr 12, 2016
;Directory \\base\root\homedir  Filename C:\Users\jmorales\AppData\Local\Temp\~apb6d.txt

IN-UNITS MET VOLUME-FLOW='cum/hr' ENTHALPY-FLO='Gcal/hr'  &
        HEAT-TRANS-C='kcal/hr-sqm-K' PRESSURE=bar TEMPERATURE=C  &
        VOLUME=cum DELTA-T=C HEAD=meter MASS-DENSITY='kg/cum'  &
        MOLE-ENTHALP='kcal/mol' MASS-ENTHALP='kcal/kg'  &
        MOLE-VOLUME='cum/kmol' HEAT=Gcal MOLE-CONC='mol/l'  &
          PDROP=bar

DEF-STREAMS MIXCISLD ALL

MODEL-OPTION

DESCRIPTION "
        Chemical Simulation with Metric Units :
        C, bar, kg/hr, kmol/hr, Gcal/hr, cum/hr.

        Property Method: NRTL

        Flow basis for input: Mole

        Stream report composition: Mole flow
        "

DATABANKS 'APV88 PURE32' / 'APV88 AQUEOUS' / 'APV88 SOLIDS' /  &
        'APV88 INORGANIC' / 'APEOSV88 AP-EOS' / 'APV88 BIODIESEL' &
        / NOASPENPCD

PROP-SOURCES 'APV88 PURE32' / 'APV88 AQUEOUS' / 'APV88 SOLIDS' &
        / 'APV88 INORGANIC' / 'APEOSV88 AP-EOS' /  &
        'APV88 BIODIESEL'

COMPONENTS
        POS C55H104O6-3 /
        SOS C57H108O6-3 /
        POP C53H100O6-5 /
        PROPANE C3H8 /
        N-BUTANE C4H10-1 /
        POWDER1 NI /
        WATER H2O /
        GLYCOL C2H6O2 /
        NITROGEN N2

CISOLID-COMPS PROPANE POWDER1
```

```
FORMULA SOS C57H108O6-3 / POP C53H100O6-5

SOLVE
        RUN-MODE MODE=SIM

FLOWSHEET
        BLOCK B1 IN=S18 OUT=VAPOR LIQ
        BLOCK B4 IN=STEAM2 S14 OUT=RECSOLV2 BUTTER2
        BLOCK B6 IN=LIQ OUT=LIQ-B
        BLOCK B9 IN=MIXFIL2 MIXFIL1 CFG OUT=S17
        BLOCK B12 IN=S20 S36 OUT=S8
        BLOCK B15 IN=S40 OUT=S25
        BLOCK B16 IN=VAPOR OUT=S26
        BLOCK B3 IN=S28 S35 OUT=S1 S5
        BLOCK B8 IN=S13 S27 OUT=S6 S10
        BLOCK B10 IN=S10 OUT=S12
        BLOCK B13 IN=S1 OUT=S13
        BLOCK B17 IN=S12 OUT=S16 S21 S22
        BLOCK B19 IN=S29 OUT=S28
        BLOCK B21 IN=S7 OUT=S35
        BLOCK B22 IN=S17 S25 OUT=S37
        BLOCK B11 IN=BUTTER2 S37 OUT=S3 S18
        BLOCK B2 IN=S3 S4 OUT=S2 S9
        BLOCK B24 IN=RECSOLV2 LIQ-B OUT=S32 S14
        BLOCK B7 IN=S32 S23 OUT=S29 S24
        BLOCK B5 IN=S26 S30 OUT=S7 S31
        BLOCK B20 IN=S8 S38 OUT=S40 S39

PROPERTIES NRTL-RK
        PROPERTIES NRTL

ESTIMATE ALL
        NRTL POS WATER UNIF-LL
        NRTL SOS WATER UNIF-LL
        NRTL POP WATER UNIF-LL
        NRTL PROPANE WATER UNIF-LL
        NRTL N-BUTANE WATER UNIF-LL

PROP-DATA PCES-1
        IN-UNITS MET VOLUME-FLOW='cum/hr' ENTHALPY-FLO='Gcal/hr'  &
        HEAT-TRANS-C='kcal/hr-sqm-K' PRESSURE=bar TEMPERATURE=C  &
        VOLUME=cum DELTA-T=C HEAD=meter MASS-DENSITY='kg/cum'  &
        MOLE-ENTHALP='kcal/mol' MASS-ENTHALP='kcal/kg'  &
        MOLE-VOLUME='cum/kmol' HEAT=Gcal MOLE-CONC='mol/l'  &
           PDROP=bar
        PROP-LIST ZC / VB / RKTZRA / VLSTD
        PVAL POS .1369844490 / .6615363710 / .1039441350 /  &
        .3124879070
```

```
    PVAL SOS .1359747040 / .6827863210 / .1031860170 /  &
    .3207959360
    PVAL POP .1381455880 / .6368003180 / .1043993550 /  &
    .3020326180
    PROP-LIST RKTZRA / VLSTD
    PVAL POWDER1 .2918596200 / .2989063450

PROP-DATA KLDIP-1
    IN-UNITS MET VOLUME-FLOW='cum/hr' ENTHALPY-FLO='Gcal/hr'  &
    HEAT-TRANS-C='kcal/hr-sqm-K' PRESSURE=bar TEMPERATURE=C  &
    VOLUME=cum DELTA-T=C HEAD=meter MASS-DENSITY='kg/cum'  &
    MOLE-ENTHALP='kcal/mol' MASS-ENTHALP='kcal/kg'  &
    MOLE-VOLUME='cum/kmol' HEAT=Gcal MOLE-CONC='mol/l'  &
    PDROP=bar
    PROP-LIST KLDIP
    PVAL POS -3.917742515 .0278008098 -7.2976298E-5  &
    8.49559300E-8 -3.716939E-11 534.1885140 655.0009430
    PVAL SOS -3.954762758 .0277353126 -7.1975769E-5  &
    8.28421805E-8 -3.583321E-11 540.5892920 661.9410630
    PVAL POP -3.900779259 .0280167558 -7.4416988E-5  &
    8.76583747E-8 -3.880642E-11 527.6972860 647.7813660
    PVAL POWDER1 -5.683295086 .0195545231 -2.2517884E-5  &
    1.13047419E-8 -2.137818E-12 1126.850000 1706.850000

PROP-DATA MULAND-1
    IN-UNITS MET VOLUME-FLOW='cum/hr' ENTHALPY-FLO='Gcal/hr'  &
    HEAT-TRANS-C='kcal/hr-sqm-K' PRESSURE=bar TEMPERATURE=C  &
    VOLUME=cum DELTA-T=C HEAD=meter MASS-DENSITY='kg/cum'  &
    MOLE-ENTHALP='kcal/mol' MASS-ENTHALP='kcal/kg'  &
  MOLE-VOLUME='cum/kmol' HEAT=Gcal MOLE-CONC='mol/l'  &
    PDROP=bar
    PROP-LIST MULAND
    PVAL POWDER1 80.74935608 -12127.32210 -10.25255770  &
    1126.850000 1706.850000

PROP-DATA SIGDIP-1
    IN-UNITS MET VOLUME-FLOW='cum/hr' ENTHALPY-FLO='Gcal/hr'  &
    HEAT-TRANS-C='kcal/hr-sqm-K' PRESSURE=bar TEMPERATURE=C  &
    VOLUME=cum DELTA-T=C HEAD=meter MASS-DENSITY='kg/cum'  &
    MOLE-ENTHALP='kcal/mol' MASS-ENTHALP='kcal/kg'  &
    MOLE-VOLUME='cum/kmol' HEAT=Gcal MOLE-CONC='mol/l'  &
    PDROP=bar
    PROP-LIST SIGDIP
    PVAL POS 16.02907920 1.222222220 1.98528163E-8  &
    -2.1849025E-8 8.13483157E-9 534.1885140 645.6256810
    PVAL SOS 15.21267550 1.222222220 -7.3253955E-9  &
    8.06112577E-9 -3.0009643E-9 540.5892920 652.4956980
    PVAL POP 16.94811190 1.222222210 4.52918561E-8  &
```

```
    -4.9850805E-8 1.85629697E-8 527.6972860 638.4790290
    PVAL POWDER1 157.4081400 1.222222220 -4.410621E-10  &
    4.9467696E-10 -1.969408E-10 1126.850000 1686.850000

PROP-DATA NRTL-1
    IN-UNITS MET VOLUME-FLOW='cum/hr' ENTHALPY-FLO='Gcal/hr'  &
    HEAT-TRANS-C='kcal/hr-sqm-K' PRESSURE=bar TEMPERATURE=C  &
    VOLUME=cum DELTA-T=C HEAD=meter MASS-DENSITY='kg/cum'  &
    MOLE-ENTHALP='kcal/mol' MASS-ENTHALP='kcal/kg'  &
    MOLE-VOLUME='cum/kmol' HEAT=Gcal MOLE-CONC='mol/l'  &
    PDROP=bar
    PROP-LIST NRTL
    BPVAL POS WATER 0.0 929.7625090 .3000000000 0.0 0.0 0.0  &
    25.00000000 25.00000000
    BPVAL WATER POS 0.0 18222.13870 .3000000000 0.0 0.0 0.0  &
    25.00000000 25.00000000
    BPVAL SOS WATER 0.0 930.3916600 .3000000000 0.0 0.0 0.0  &
    25.00000000 25.00000000
    BPVAL WATER SOS 0.0 18878.26580 .3000000000 0.0 0.0 0.0  &
    25.00000000 25.00000000
    BPVAL POP WATER 0.0 929.0213710 .3000000000 0.0 0.0 0.0  &
    25.00000000 25.00000000
    BPVAL WATER POP 0.0 17566.00890 .3000000000 0.0 0.0 0.0  &
    25.00000000 25.00000000
    BPVAL PROPANE WATER 0.0 1903.992330 .3000000000 0.0 0.0  &
    0.0 25.00000000 25.00000000
    BPVAL WATER PROPANE 0.0 1478.999130 .3000000000 0.0 0.0  &
    0.0 25.00000000 25.00000000
    BPVAL N-BUTANE WATER 0.0 1927.796300 .3000000000 0.0 0.0  &
    0.0 25.00000000 25.00000000
    BPVAL WATER N-BUTANE 0.0 1882.505070 .3000000000 0.0 0.0  &
    0.0 25.00000000 25.00000000
    BPVAL WATER GLYCOL .3479000000 34.82340000 .3000000000 0.0  &
    0.0 0.0 30.40000000 196.7000000
    BPVAL GLYCOL WATER -.0567000000 -147.1373000 .3000000000  &
    0.0 0.0 0.0 30.40000000 196.7000000

PROP-SET THERMAL HMX CPMX KMX UNITS='kcal/kg' 'cal/gm-K'  &
    SUBSTREAM=MIXED PHASE=V L
;  "Enthalpy, heat capacity, and thermal conductivity"


PROP-SET TXPORT RHOMX MUMX SIGMAMX UNITS='gm/cc'  &
    SUBSTREAM=MIXED PHASE=V L
;  "Density, viscosity, and surface tension"


STREAM CFG
```

```
        SUBSTREAM MIXED TEMP=50.00000000 PRES=6.000000000  &
        MASS-FLOW=36587.99999
        MASS-FLOW POS 2734.160000 / SOS 1429.220000 / POP  &
        2050.620000 / PROPANE 0.0 / N-BUTANE 30073.00000 /  &
        WATER 301.0000000

STREAM MIXFIL1
        SUBSTREAM MIXED TEMP=50.00000000 PRES=6.000000000  &
        MASS-FLOW=9006.000000
        MASS-FLOW POS 209.4399994 / SOS 109.4800000 / POP  &
        157.0799999 / N-BUTANE 8507.000000 / WATER 23.00000000

STREAM MIXFIL2
        SUBSTREAM MIXED TEMP=50.00000000 PRES=6.000000000  &
        MASS-FLOW=1361.000000
        MASS-FLOW POS 16.28000000 / SOS 8.510000000 / POP  &
        12.21000000 / N-BUTANE 1322.000000 / WATER 2.000000000

STREAM S4
        SUBSTREAM MIXED TEMP=32.22000000 PRES=4.000000000  &
        MASS-FLOW=7905.000000
        MASS-FRAC WATER 1.

STREAM S20
        SUBSTREAM MIXED TEMP=53.00000000 PRES=1.200000000  &
        MASS-FLOW=203.0000000
        MASS-FLOW N-BUTANE 203.0000000 / WATER 0.0

STREAM S23
        SUBSTREAM MIXED TEMP=7.220000000 PRES=1.000000000  &
        MASS-FLOW=500.0000000
        MASS-FRAC WATER 1.

STREAM S27
        SUBSTREAM MIXED TEMP=50.00000000 PRES=6.000000000  &
        MASS-FLOW=1.000000000
        MASS-FRAC N-BUTANE 1.

STREAM S30
        SUBSTREAM MIXED TEMP=-12.22222222 PRES=4.481592241  &
        MASS-FLOW=4.00000000E+5
        MASS-FRAC WATER 0.7 / GLYCOL 0.3

STREAM S36
        SUBSTREAM MIXED TEMP=53.00000000 PRES=1.200000000  &
        MASS-FLOW=3059.000000
        MASS-FLOW N-BUTANE 30599.00000
```

```
STREAM S38
        SUBSTREAM MIXED TEMP=-12.22222222 PRES=4.481592241  &
        MASS-FLOW=35750.00000
        MASS-FRAC WATER 0.7 / GLYCOL 0.3

STREAM STEAM2
        SUBSTREAM MIXED TEMP=148.8888889 PRES=4.460628651  &
        MASS-FLOW=150.0000000
        MASS-FRAC WATER 1.

BLOCK B9 MIXER
        PARAM NPHASE=2
        BLOCK-OPTION FREE-WATER=NO

BLOCK B12 MIXER
        PARAM

BLOCK B22 MIXER
        PARAM NPHASE=2
        BLOCK-OPTION FREE-WATER=NO

BLOCK B17 FSPLIT
        FRAC S16 0.7735 / S21 0.2088

BLOCK B1 FLASH2
        PARAM TEMP=56.90000000 PRES=1.564830580

BLOCK B8 FLASH2
        PARAM TEMP=50.00000000 PRES=0.0

BLOCK B3 DECANTER
        PARAM TEMP=50.00000000 PRES=0.0 L2-COMPS=WATER
        SOLID-FRAC CISOLID

BLOCK B2 HEATX
        PARAM T-HOT=50. MIN-TAPP=5.560000000 CALC-METHOD=SHORTCUT
        FEEDS HOT=S3 COLD=S4
        OUTLETS-HOT S2
        OUTLETS-COLD S9
        HOT-SIDE DPPARMOPT=NO
        COLD-SIDE DPPARMOPT=NO
        TQ-PARAM CURVE=YES

BLOCK B5 HEATX
        PARAM VFRAC-HOT=0. PRES-HOT=0.0 CALC-METHOD=SHORTCUT
        FEEDS HOT=S26 COLD=S30
        OUTLETS-HOT S7
        OUTLETS-COLD S31
```

```
    PROPERTIES NRTL-RK FREE-WATER=STEAM-TA SOLU-WATER=3  &
    TRUE-COMPS=YES / NRTL-RK FREE-WATER=STEAM-TA  &
    SOLU-WATER=3 TRUE-COMPS=YES
    FLASH-SPECS S7 NPHASE=2 FREE-WATER=NO MAXIT=30 TOL=0.0001
    HOT-SIDE DPPARMOPT=NO
    COLD-SIDE DPPARMOPT=NO
    TQ-PARAM CURVE=YES
    EO-OPTIONS CHECK-FREE-W=YES NEG-COMP-CHK=-1E-008  &
    NEG-FLOW-CHK=-1E-015 ALWAYS-INST=NO FLASH-FORM=PML  &
    PRES-TOL=1.00000000E-5 MIN-PRES=YES COMP-TOL=1E-015  &
    CHEM-METHOD=YES AUTO-COMPS-T=0. AUTO-PHASE=YES  &
    AUTO-PHASE-T=0.1 TEMP-TOL=1.00000000E-3
    BLOCK-OPTION SIM-LEVEL=4 PROP-LEVEL=4 STREAM-LEVEL=4  &
    TERM-LEVEL=4 RESTART=YES ENERGY-BAL=YES
    REPORT REPORT NONEWPAGE TOTBAL INPUT NOCOMPBAL RESULTS

BLOCK B7 HEATX
    PARAM VFRAC-HOT=0. MIN-TAPP=5.560000000 CALC-METHOD=SHORTCUT
    FEEDS HOT=S32 COLD=S23
    OUTLETS-HOT S29
    OUTLETS-COLD S24
    HOT-SIDE DPPARMOPT=NO
    COLD-SIDE DPPARMOPT=NO
    TQ-PARAM CURVE=YES

BLOCK B11 HEATX
    PARAM T-HOT=80. PRES-COLD=0.0 MIN-TAPP=5.560000000  &
    CALC-METHOD=SHORTCUT
    FEEDS HOT=BUTTER2 COLD=S37
    OUTLETS-HOT S3
    OUTLETS-COLD S18
    PROPERTIES NRTL-RK FREE-WATER=STEAM-TA SOLU-WATER=3  &
    TRUE-COMPS=YES / NRTL-RK FREE-WATER=STEAM-TA  &
    SOLU-WATER=3 TRUE-COMPS=YES
    FLASH-SPECS S18 NPHASE=2 FREE-WATER=NO MAXIT=30 TOL=0.0001
    HOT-SIDE DPPARMOPT=NO
    COLD-SIDE DPPARMOPT=NO
    TQ-PARAM CURVE=YES
    EO-OPTIONS CHECK-FREE-W=YES NEG-COMP-CHK=-1E-008  &
    NEG-FLOW-CHK=-1E-015 ALWAYS-INST=NO FLASH-FORM=PML  &
    PRES-TOL=1.00000000E-5 MIN-PRES=YES COMP-TOL=1E-015  &
    CHEM-METHOD=YES AUTO-COMPS-T=0. AUTO-PHASE=YES  &
    AUTO-PHASE-T=0.1 TEMP-TOL=1.00000000E-3
    BLOCK-OPTION SIM-LEVEL=4 PROP-LEVEL=4 STREAM-LEVEL=4  &
    TERM-LEVEL=4 RESTART=YES ENERGY-BAL=YES
    REPORT REPORT NONEWPAGE TOTBAL INPUT NOCOMPBAL RESULTS

BLOCK B20 HEATX
```

```
    PARAM VFRAC-HOT=0. MIN-TAPP=5.560000000 CALC-METHOD=SHORTCUT
    FEEDS HOT=S8 COLD=S38
    OUTLETS-HOT S40
    OUTLETS-COLD S39
    HOT-SIDE DPPARMOPT=NO
    COLD-SIDE DPPARMOPT=NO
    TQ-PARAM CURVE=YES

BLOCK B24 HEATX
    PARAM DUTY=27271.3 <kJ/hr> PRES-HOT=0.0  &
    MIN-TAPP=5.560000000 CALC-METHOD=SHORTCUT
    FEEDS HOT=RECSOLV2 COLD=LIQ-B
    OUTLETS-HOT S32
    OUTLETS-COLD S14
    PROPERTIES NRTL-RK FREE-WATER=STEAM-TA SOLU-WATER=3  &
    TRUE-COMPS=YES / NRTL-RK FREE-WATER=STEAM-TA  &
    SOLU-WATER=3 TRUE-COMPS=YES
    FLASH-SPECS S32 NPHASE=2 FREE-WATER=NO MAXIT=30 TOL=0.0001
    HOT-SIDE DPPARMOPT=NO
    COLD-SIDE DPPARMOPT=NO
    TQ-PARAM CURVE=YES
    EO-OPTIONS CHECK-FREE-W=YES NEG-COMP-CHK=-1E-008  &
    NEG-FLOW-CHK=-1E-015 ALWAYS-INST=NO FLASH-FORM=PML  &
    PRES-TOL=1.00000000E-5 MIN-PRES=YES COMP-TOL=1E-015  &
    CHEM-METHOD=YES AUTO-COMPS-T=0. AUTO-PHASE=YES  &
    AUTO-PHASE-T=0.1 TEMP-TOL=1.00000000E-3
    BLOCK-OPTION SIM-LEVEL=4 PROP-LEVEL=4 STREAM-LEVEL=4  &
    TERM-LEVEL=4 RESTART=YES ENERGY-BAL=YES
    REPORT REPORT NONEWPAGE TOTBAL INPUT NOCOMPBAL RESULTS

BLOCK B4 RADFRAC
    PARAM NSTAGE=3 ALGORITHM=STANDARD MAXOL=25 DAMPING=NONE
    COL-CONFIG CONDENSER=NONE REBOILER=NONE
    FEEDS STEAM2 3 ON-STAGE / S14 1
    PRODUCTS RECSOLV2 1 V / BUTTER2 3 L
    P-SPEC 1 3.700000000
    COL-SPECS DP-STAGE=.1000000000

BLOCK B6 PUMP
    PARAM PRES=6.000000000 EFF=0.75

BLOCK B10 PUMP
    PARAM PRES=6.000000000 EFF=0.75

BLOCK B13 PUMP
    PARAM PRES=6.000000000 EFF=0.75

BLOCK B15 PUMP
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            PARAM PRES=6.000000000 EFF=0.75

BLOCK B19 PUMP
            PARAM PRES=4.000000000 EFF=0.75

BLOCK B21 PUMP
            PARAM PRES=4.000000000 EFF=0.75

BLOCK B16 DUPL

DESIGN-SPEC SSTRIP2
            DEFINE LIQUIDIN STREAM-VAR STREAM=LIQ SUBSTREAM=MIXED  &
            VARIABLE=MASS-FLOW UOM="kg/hr"
            DEFINE BUTTER STREAM-VAR STREAM=BUTTER2 SUBSTREAM=MIXED  &
            VARIABLE=MASS-FLOW UOM="kg/hr"
            DEFINE SLVFRAC LOCAL-PARAM
            DEFINE SOLVENT MASS-FLOW STREAM=BUTTER2 SUBSTREAM=MIXED  &
            COMPONENT=N-BUTANE UOM="kg/hr"
F           SLVFRAC = SOLVENT/BUTTER*1000000
            SPEC "SOLVENT/BUTTER*1000000" TO "0.500"
            TOL-SPEC "0.001"
            VARY STREAM-VAR STREAM=STEAM2 SUBSTREAM=MIXED  &
            VARIABLE=MASS-FLOW UOM="kg/hr"
            LIMITS "25" "1000"

EO-CONV-OPTI

STREAM-REPOR NOZEROFLOW NOMOLEFLOW MASSFLOW STDVOLFLOW MASSFRAC  &
            NOVOLFRAC PROPERTIES=THERMAL TXPORT

PROPERTY-REP PARAMS PCES
```

Butter Recovery Block Report

***** BLOCK: B1 MODEL: FLASH2

INLET STREAM: S18
OUTLET VAPOR STREAM: VAPOR
OUTLET LIQUID STREAM: LIQ
PROPERTY OPTION SET: NRTL-RK RENON (NRTL) / REDLICH-KWONG

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(KMOL/HR)	768.562	768.562	0.147922E-15
MASS(KG/HR)	50217.0	50217.0	0.156090E-11
ENTHALPY(GCAL/HR)	-30.6520	-27.0309	-0.118135

*** CO2 EQUIVALENT SUMMARY ***

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

*** INPUT DATA ***

TWO PHASE TP FLASH

SPECIFIED TEMPERATURE C		56.9000
SPECIFIED PRESSURE	BAR	1.56483
MAXIMUM NO. ITERATIONS		30
CONVERGENCE TOLERANCE		0.000100000

*** RESULTS ***

OUTLET TEMPERATURE	C	56.900
OUTLET PRESSURE	BAR	1.5648
HEAT DUTY	GCAL/HR	3.6211
VAPOR FRACTION		0.98566

V-L PHASE EQUILIBRIUM :

COMP	F(I)	X(I)	Y(I)	K(I)
POS	0.44707E-02	0.31175	0.80867E-16	0.25940E-15
SOS	0.22633E-02	0.15782	0.19820E-16	0.12559E-15
POP	0.34659E-02	0.24168	0.12943E-15	0.53552E-15
N-BUTANE	0.96626	0.28163	0.97622	3.4664
WATER	0.23545E-01	0.71270E-02	0.23784E-01	3.3372

BLOCK: B2   MODEL: HEATX

HOT SIDE:

INLET STREAM: S3
OUTLET STREAM: S2
PROPERTY OPTION SET: NRTL-RK   RENON (NRTL) / REDLICH-KWONG
COLD SIDE:

INLET STREAM: S4
OUTLET STREAM: S9
PROPERTY OPTION SET: NRTL-RK   RENON (NRTL) / REDLICH-KWONG

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(KMOL/HR)	484.120	484.120	0.00000
MASS(KG/HR)	15307.3	15307.3	0.00000
ENTHALPY(GCAL/HR)	-36.5401	-36.5401	-0.168505E-07

*** CO2 EQUIVALENT SUMMARY ***

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

*** INPUT DATA ***

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   50.0000
LMTD CORRECTION FACTOR   1.00000

PRESSURE SPECIFICATION:
HOT SIDE PRESSURE DROP   BAR   0.0000

```
        COLD SIDE PRESSURE DROP    BAR                 0.0000

HEAT TRANSFER COEFFICIENT SPECIFICATION:
        HOT LIQUID     COLD LIQUID    KCAL/HR-SQM-K         730.8684
        HOT 2-PHASE    COLD LIQUID    KCAL/HR-SQM-K         730.8684
        HOT VAPOR      COLD LIQUID    KCAL/HR-SQM-K         730.8684
        HOT LIQUID     COLD 2-PHASE   KCAL/HR-SQM-K         730.8684
        HOT 2-PHASE    COLD 2-PHASE   KCAL/HR-SQM-K         730.8684
        HOT VAPOR      COLD 2-PHASE   KCAL/HR-SQM-K         730.8684
        HOT LIQUID     COLD VAPOR     KCAL/HR-SQM-K         730.8684
        HOT 2-PHASE    COLD VAPOR     KCAL/HR-SQM-K         730.8684
        HOT VAPOR      COLD VAPOR     KCAL/HR-SQM-K         730.8684

                  ***  OVERALL RESULTS  ***

STREAMS:
                 --------------------------------------
                 |                                    |
S3       ----->|          HOT                         |-----> S2
T=  8.0000D+01  |                                     |        T=  5.0000D+01
P=  3.9000D+00  |                                     |        P=  3.9000D+00
V=  0.0000D+00  |                                     |        V=  0.0000D+00
                 |                                    |
S9       <-----|          COLD                        |<----- S4
T=  4.7931D+01  |                                     |        T=  3.2220D+01
P=  4.0000D+00  |                                     |        P=  4.0000D+00
V=  0.0000D+00  |                                     |        V=  0.0000D+00
                 --------------------------------------

DUTY AND AREA:
        CALCULATED HEAT DUTY         GCAL/HR              0.1235
        CALCULATED (REQUIRED) AREA   SQM                  6.9773
        ACTUAL EXCHANGER AREA        SQM                  6.9773
        PER CENT OVER-DESIGN                              0.0000

HEAT TRANSFER COEFFICIENT:
        AVERAGE COEFFICIENT (DIRTY)   KCAL/HR-SQM-K       730.8684
        UA (DIRTY)                    CAL/SEC-K           1416.5346

LOG-MEAN TEMPERATURE DIFFERENCE:
        LMTD CORRECTION FACTOR                            1.0000
        LMTD (CORRECTED)              C                   24.2263
        NUMBER OF SHELLS IN SERIES                        1

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

```
                    ***  ZONE RESULTS  ***

 TEMPERATURE LEAVING EACH ZONE:

                                   HOT
    ------------------------------------------------------------
        |                                             |
HOT IN  |                     LIQ                            | HOT OUT
------> |                                         |------>
 80.0  |                                            |  50.0
        |                                             |
COLDOUT |                          LIQ                        | COLDIN
<------ |                                           |<------
 47.9  |                                            |  32.2
        |                                             |
        ------------------------------------------------------------
                                   COLD

 ZONE HEAT TRANSFER AND AREA:

 ZONE      HEAT DUTY           AREA    LMTD   AVERAGE U     UA
        GCAL/HR          SQM      C          KCAL/HR-SQM-K   CAL/SEC-K
        1          0.124       6.9773    24.2263   730.8684          1416.5346

HEATX COLD-TQCU B2           TQCURV INLET
------------------------------------
 PRESSURE PROFILE:  CONSTANT2
 PRESSURE DROP:       0.0         BAR
 PROPERTY OPTION SET:   NRTL-RK   RENON (NRTL) / REDLICH-KWONG

----------------------------------------------------
!  DUTY            !  PRES      !  TEMP      !  VFRAC  !
!          !          !          !          !
!          !          !          !          !
!          !          !          !          !
!  GCAL/HR   !  BAR       !  C        !          !
!          !          !          !          !
!============!============!============!============!
!    0.0  !           4.0000 !    47.9306 !          0.0         !
!  5.8830-03 !      4.0000 ! 47.1877 !           0.0    !
!  1.1766-02 !      4.0000 ! 46.4442 !           0.0    !
!  1.7649-02 !      4.0000 ! 45.7003 !           0.0    !
!  2.3532-02 !      4.0000 ! 44.9557 !           0.0    !
!------------+------------+------------+------------!
!  2.9415-02 !      4.0000 ! 44.2107 !           0.0    !
!  3.5298-02 !      4.0000 ! 43.4651 !           0.0    !
!  4.1181-02 !      4.0000 ! 42.7190 !           0.0    !
!  4.7064-02 !      4.0000 ! 41.9724 !           0.0    !
```

```
!  5.2947-02 !      4.0000 ! 41.2253 !            0.0    !
!------------+------------+------------+------------!
!  5.8830-02 !      4.0000 ! 40.4776 !            0.0    !
!  6.4713-02 !      4.0000 ! 39.7294 !            0.0    !
!  7.0596-02 !      4.0000 ! 38.9808 !            0.0    !
!  7.6479-02 !      4.0000 ! 38.2316 !            0.0    !
!  8.2362-02 !      4.0000 ! 37.4819 !            0.0    !
!------------+------------+------------+------------!
!  8.8245-02 !      4.0000 ! 36.7317 !            0.0    !
!  9.4128-02 !      4.0000 ! 35.9810 !            0.0    !
!     0.1000 !      4.0000 ! 35.2298 !            0.0    !
!     0.1059 !     4.0000 !    34.4781 !            0.0         !
!     0.1118 !      4.0000 ! 33.7259 !            0.0    !
!------------+------------+------------+------------!
!     0.1177 !      4.0000 ! 32.9732 !            0.0    !
!     0.1235 !      4.0000 ! 32.2201 !            0.0    !
-----------------------------------------------------

HEATX HOT-TQCUR B2            TQCURV INLET
-------------------------------------
  PRESSURE PROFILE:  CONSTANT2
  PRESSURE DROP:        0.0         BAR
  PROPERTY OPTION SET:   NRTL-RK   RENON (NRTL) / REDLICH-KWONG

-----------------------------------------------------
!  DUTY            !  PRES      !  TEMP          !  VFRAC           !
!          !          !          !          !
!          !          !                  !                 !
!          !          !          !          !
!  GCAL/HR   !  BAR       !  C        !          !
!          !          !          !          !
!============!============!============!============!
!     0.0  !            3.9000 !    80.0000 !          0.0         !
!  5.8830-03 !      3.9000 ! 78.5931 !            0.0    !
!  1.1766-02 !      3.9000 ! 77.1841 !            0.0    !
!  1.7649-02 !      3.9000 ! 75.7730 !            0.0    !
!  2.3532-02 !      3.9000 ! 74.3597 !            0.0    !
!------------+------------+------------+------------!
!  2.9415-02 !      3.9000 ! 72.9443 !            0.0    !
!  3.5298-02 !      3.9000 ! 71.5267 !            0.0    !
!  4.1181-02 !      3.9000 ! 70.1069 !            0.0    !
!  4.7064-02 !     3.9000 !    68.6850 !            0.0         !
!  5.2947-02 !      3.9000 ! 67.2609 !            0.0    !
!------------+------------+------------+------------!
!  5.8830-02 !      3.9000 ! 65.8347 !            0.0    !
!  6.4713-02 !      3.9000 ! 64.4062 !            0.0    !
!  7.0596-02 !      3.9000 ! 62.9756 !            0.0    !
!  7.6479-02 !      3.9000 ! 61.5428 !            0.0    !
```

```
!  8.2362-02 !      3.9000 ! 60.1077 !            0.0    !
!------------+------------+------------+------------!
!  8.8245-02 !      3.9000 ! 58.6704 !            0.0    !
!  9.4128-02 !      3.9000 ! 57.2310 !            0.0    !
!     0.1000 !      3.9000 ! 55.7893 !            0.0    !
!     0.1059 !      3.9000 ! 54.3453 !            0.0    !
!     0.1118 !      3.9000 ! 52.8991 !            0.0    !
!------------+------------+------------+------------!
!     0.1177 !      3.9000 ! 51.4507 !            0.0    !
!     0.1235 !      3.9000 ! 50.0000 !            0.0    !
-----------------------------------------------------

BLOCK:  B3      MODEL: DECANTER
--------------------------------
  INLET STREAMS:        S28        S35
  FIRST LIQUID OUTLET:   S1
  SECOND LIQUID OUTLET:  S5
  PROPERTY OPTION SET:   NRTL-RK   RENON (NRTL) / REDLICH-KWONG

                    ***  MASS AND ENERGY BALANCE  ***
                              IN          OUT      RELATIVE DIFF.
        TOTAL BALANCE
        MOLE(KMOL/HR )         761.488              761.488              0.895774E-15
        MASS(KG/HR   )          43503.8              43503.8              0.123104E-07
        ENTHALPY(GCAL/HR )              -27.7535              -26.7198              -0.372458E-01

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

                    ***  INPUT DATA  ***

  LIQUID-LIQUID SPLIT, TP SPECIFICATION
  SPECIFIED TEMPERATURE                    C                    50.0000
  SPECIFIED PRESSURE DROP              BAR                  0.0
  CONVERGENCE TOLERANCE ON EQUILIBRIUM                    0.10000E-03
  MAXIMUM NO ITERATIONS ON EQUILIBRIUM                    30
  EQUILIBRIUM METHOD                        EQUATION-SOLVING
  KLL COEFFICIENTS FROM                   OPTION SET OR EOS
  KLL BASIS                                        MOLE
  KEY COMPONENT(S):               WATER
  SOLID SPLIT FRACTIONS:
  CISOLID SUBSTREAM
        1ST LIQUID:      0.0000     2ND LIQUID:    1.0000
```

*** RESULTS ***

OUTLET TEMPERATURE C 50.000
OUTLET PRESSURE BAR 4.0000
CALCULATED HEAT DUTY GCAL/HR 1.0337
MOLAR RATIO 1ST LIQUID / TOTAL LIQUID 0.97618

L1-L2 PHASE EQUILIBRIUM :

COMP	F	X1	X2	K
N-BUTANE	0.97523	0.99900	0.0011775	0.0011787
WATER	0.024769	0.00099732	0.99882	1,001.51

BLOCK: B4 MODEL: RADFRAC

INLETS - STEAM2 STAGE 3
S14 STAGE 1
OUTLETS - RECSOLV2 STAGE 1
BUTTER2 STAGE 3
PROPERTY OPTION SET: NRTL-RK RENON (NRTL) / REDLICH-KWONG

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(KMOL/HR)	49.2742	49.2742	0.00000
MASS(KG/HR)	7597.96	7597.96	-0.119703E-15
ENTHALPY(GCAL/HR)	-6.47939	-6.47939	0.326717E-07

*** CO2 EQUIVALENT SUMMARY ***

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

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

**** INPUT PARAMETERS ****

NUMBER OF STAGES 3
ALGORITHM OPTION STANDARD
ABSORBER OPTION NO
INITIALIZATION OPTION STANDARD
HYDRAULIC PARAMETER CALCULATIONS NO
INSIDE LOOP CONVERGENCE METHOD BROYDEN

DESIGN SPECIFICATION METHOD NESTED
MAXIMUM NO. OF OUTSIDE LOOP ITERATIONS 25
MAXIMUM NO. OF INSIDE LOOP ITERATIONS 10
MAXIMUM NUMBER OF FLASH ITERATIONS 30
FLASH TOLERANCE 0.000100000
OUTSIDE LOOP CONVERGENCE TOLERANCE 0.000100000

**** COL-SPECS ****

MOLAR VAPOR DIST / TOTAL DIST 1.00000
CONDENSER DUTY (W/O SUBCOOL) GCAL/HR 0.0
REBOILER DUTY GCAL/HR 0.0

**** PROFILES ****

P-SPEC STAGE 1 PRES, BAR 3.70000

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

*** COMPONENT SPLIT FRACTIONS ***

OUTLET STREAMS

	RECSOLV2	BUTTER2
COMPONENT:		
POS	.55895E-13	1.0000
SOS	.30277E-13	1.0000
POP	.10310E-12	1.0000
N-BUTANE	.99998	.20532E-04
WATER	.22018E-01	.97798

*** SUMMARY OF KEY RESULTS ***

TOP STAGE TEMPERATURE C 100.618
BOTTOM STAGE TEMPERATURE C 149.085
TOP STAGE LIQUID FLOW KMOL/HR 24.5013
BOTTOM STAGE LIQUID FLOW KMOL/HR 45.3262
TOP STAGE VAPOR FLOW KMOL/HR 3.94793
BOILUP VAPOR FLOW KMOL/HR 37.1465
CONDENSER DUTY (W/O SUBCOOL) GCAL/HR 0.0
REBOILER DUTY GCAL/HR 0.0

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

DEW POINT 0.17927E-09 STAGE= 1
BUBBLE POINT 0.54538E-09 STAGE= 1
COMPONENT MASS BALANCE 0.23093E-08 STAGE= 1 COMP=POS
ENERGY BALANCE 0.34556E-07 STAGE= 1

**** PROFILES ****

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

STAGE	TEMPERATURE C	PRESSURE BAR	ENTHALPY KCAL/MOL LIQUID	ENTHALPY KCAL/MOL VAPOR	HEAT DUTY GCAL/HR
1	100.62	3.7000	-209.86	-34.398	
2	146.89	3.8000	-142.02	-55.725	
3	149.09	3.9000	-139.95	-56.788	

STAGE	FLOW RATE KMOL/HR LIQUID	FLOW RATE KMOL/HR VAPOR	FEED RATE KMOL/HR LIQUID	FEED RATE KMOL/HR VAPOR	FEED RATE KMOL/HR MIXED	PRODUCT RATE KMOL/HR LIQUID	PRODUCT RATE KMOL/HR VAPOR
1	24.50	3.948	11.0218			3.9479	
2	44.22	17.43					
3	45.33	37.15		38.2523	45.3262		

**** MASS FLOW PROFILES ****

STAGE	FLOW RATE KG/HR LIQUID	FLOW RATE KG/HR VAPOR	FEED RATE KG/HR LIQUID	FEED RATE KG/HR VAPOR	FEED RATE KG/HR MIXED	PRODUCT RATE KG/HR LIQUID	PRODUCT RATE KG/HR VAPOR
1	7053.	195.6	6908.8320			195.6173	
2	7383.	339.3					
3	7402.	669.6		689.1267	7402.3414		

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

STAGE	POS	SOS	POP	N-BUTANE	WATER
1	0.14024	0.70994E-01	0.10872	0.25796E-01	0.65425
2	0.77702E-01	0.39336E-01	0.60238E-01	0.20998E-03	0.82251
3	0.75806E-01	0.38376E-01	0.58769E-01	0.14061E-05	0.82705

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

STAGE	POS	SOS	POP	N-BUTANE	WATER
1	0.48648E-13	0.13340E-13	0.69564E-13	0.78623	0.21377
2	0.84845E-11	0.25158E-11	0.11224E-10	0.36264E-01	0.96374
3	0.10341E-10	0.30771E-11	0.13632E-10	0.24826E-03	0.99975

**** K-VALUES ****

STAGE	POS	SOS	POP	N-BUTANE	WATER
1	0.34689E-12	0.18790E-12	0.63985E-12	30.478	0.32674
2	0.10919E-09	0.63957E-10	0.18633E-09	172.70	1.1717
3	0.13641E-09	0.80182E-10	0.23197E-09	176.56	1.2088

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

STAGE	POS	SOS	POP	N-BUTANE	WATER
1	0.41969	0.21938	0.31477	0.52090E-02	0.40948E-01
2	0.40092	0.20957	0.30069	0.73104E-04	0.88754E-01
3	0.39986	0.20902	0.29989	0.50042E-06	0.91233E-01

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

STAGE	POS	SOS	POP	N-BUTANE	WATER
1	0.84575E-12	0.23947E-12	0.11700E-11	0.92228	0.77724E-01
2	0.37539E-09	0.11494E-09	0.48042E-09	0.10826	0.89174
3	0.49420E-09	0.15184E-09	0.63027E-09	0.80052E-03	0.99920

BLOCK: B5 MODEL: HEATX

HOT SIDE:

INLET STREAM: S26
OUTLET STREAM: S7
PROPERTY OPTION SET: NRTL-RK RENON (NRTL) / REDLICH-KWONG
COLD SIDE:

INLET STREAM: S30
OUTLET STREAM: S31
PROPERTY OPTION SET: NRTL-RK RENON (NRTL) / REDLICH-KWONG

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(KMOL/HR)	18233.3	18233.3	0.00000
MASS(KG/HR)	443308.	443308.	0.393909E-15
ENTHALPY(GCAL/HR)	-1308.45	-1308.45	-0.386334E-11

*** CO2 EQUIVALENT SUMMARY ***

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

*** INPUT DATA ***

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 VAPOR FRACTION
SPECIFIED VALUE 0.0000
LMTD CORRECTION FACTOR 1.00000

PRESSURE SPECIFICATION:
HOT SIDE PRESSURE DROP BAR 0.0000
COLD SIDE PRESSURE DROP BAR 0.0000

HEAT TRANSFER COEFFICIENT SPECIFICATION:

HOT LIQUID	COLD LIQUID	KCAL/HR-SQM-K	730.8684
HOT 2-PHASE	COLD LIQUID	KCAL/HR-SQM-K	730.8684
HOT VAPOR	COLD LIQUID	KCAL/HR-SQM-K	730.8684
HOT LIQUID	COLD 2-PHASE	KCAL/HR-SQM-K	730.8684
HOT 2-PHASE	COLD 2-PHASE	KCAL/HR-SQM-K	730.8684
HOT VAPOR	COLD 2-PHASE	KCAL/HR-SQM-K	730.8684
HOT LIQUID	COLD VAPOR	KCAL/HR-SQM-K	730.8684
HOT 2-PHASE	COLD VAPOR	KCAL/HR-SQM-K	730.8684
HOT VAPOR	COLD VAPOR	KCAL/HR-SQM-K	730.8684

*** OVERALL RESULTS ***

STREAMS:

```
          --------------------------------------
          |                                    |
S26  ----->|           HOT                     |-----> S7
T=  5.6900D+01  |                              |       T=  9.7401D+00
P=  1.5648D+00  |                              |       P=  1.5648D+00
V=  1.0000D+00  |                              |       V=  0.0000D+00
          |                                    |
S31  <-----|           COLD                    |<----- S30
T=  2.3286D+00  |                              |       T= -1.2222D+01
P=  4.4816D+00  |                              |       P=  4.4816D+00
V=  0.0000D+00  |                              |       V=  0.0000D+00
          --------------------------------------
```

DUTY AND AREA:

CALCULATED HEAT DUTY GCAL/HR 4.8756
CALCULATED (REQUIRED) AREA SQM 263.2219
ACTUAL EXCHANGER AREA SQM 263.2219
PER CENT OVER-DESIGN 0.0000

HEAT TRANSFER COEFFICIENT:
AVERAGE COEFFICIENT (DIRTY) KCAL/HR-SQM-K 730.8684
UA (DIRTY) CAL/SEC-K 53439.0426

LOG-MEAN TEMPERATURE DIFFERENCE:
LMTD CORRECTION FACTOR 1.0000
LMTD (CORRECTED) C 25.3434
NUMBER OF SHELLS IN SERIES 1

PRESSURE DROP:
HOTSIDE, TOTAL BAR 0.0000
COLDSIDE, TOTAL BAR 0.0000

*** ZONE RESULTS ***

TEMPERATURE LEAVING EACH ZONE:

```
                         HOT
    -------------------------------------------------------------
        |                |                         |
HOT IN  |      VAP            |        COND            | HOT OUT
------> |                |               |------>
 56.9  |              27.4|                  |       9.7
        |                |               |
COLDOUT |                LIQ             |      LIQ           | COLDIN
<------ |                |               |<------
        2.3  |                     0.7|                        |  -12.2
        |                |               |
    -------------------------------------------------------------
                         COLD
```

ZONE HEAT TRANSFER AND AREA:

ZONE	HEAT DUTY	AREA	LMTD	AVERAGE U	UA
	GCAL/HR	SQM	C	KCAL/HR-SQM-K	CAL/SEC-K
1	0.545	19.1115	39.0154	730.8684	3879.9909
2	4.331	244.1104	24.2730	730.8684	49559.0517

HEATX COLD-TQCU B5 TQCURV INLET

PRESSURE PROFILE: CONSTANT2
PRESSURE DROP: 0.0 BAR
PROPERTY OPTION SET: NRTL-RK RENON (NRTL) / REDLICH-KWONG

```
-----------------------------------------------------
! DUTY        ! PRES    ! TEMP      ! VFRAC       !
!       !       !       !       !
!          !    !       !       !
!       !       !       !       !
! GCAL/HR  ! BAR     ! C     !       !
!       !       !       !       !
!============!============!============!============!
!   0.0  !        4.4816 ! 2.3286 ! 0.0   !
!   0.2322 !      4.4816 ! 1.6372 ! 0.0   !
!   0.4643 !      4.4816 ! 0.9454 ! 0.0   !
!   0.6965 !      4.4816 ! 0.2533 ! 0.0   !
!   0.5450 !      4.4816 ! 0.7051 ! 0.0   !
!------------+------------+------------+------------!
!   0.9287 !      4.4816 ! -0.4390 !         0.0   !
!   1.1609 !      4.4816 ! -1.1315 !         0.0   !
!   1.3930 !      4.4816 ! -1.8240 !         0.0   !
!       1.6252 ! 4.4816 ! -2.5166 !          0.0   !
!   1.8574 !      4.4816 ! -3.2093 !         0.0   !
!------------+------------+------------+------------!
!   2.0895 !      4.4816 ! -3.9021 !         0.0   !
!   2.3217 !      4.4816 ! -4.5950 !    0.0   !
!   2.5539 !      4.4816 ! -5.2879 !         0.0   !
!   2.7860 !      4.4816 ! -5.9810 !         0.0   !
!   3.0182 !      4.4816 ! -6.6741 !         0.0   !
!------------+------------+------------+------------!
!   3.2504 !      4.4816 ! -7.3674 !         0.0   !
!   3.4826 !      4.4816 ! -8.0607 !         0.0   !
!   3.7147 !      4.4816 ! -8.7541 !         0.0   !
!   3.9469 !      4.4816 ! -9.4475 !         0.0   !
!   4.1791 !      4.4816 !   -10.1411 !      0.0   !
!------------+------------+------------+------------!
!   4.4112 !      4.4816 !   -10.8347 !      0.0   !
!   4.6434 !      4.4816 !   -11.5284 !      0.0   !
!   4.8756 !      4.4816 !   -12.2222 !      0.0   !
-----------------------------------------------------

HEATX HOT-TQCUR B5          TQCURV INLET
------------------------------------
  PRESSURE PROFILE:  CONSTANT2
  PRESSURE DROP:       0.0        BAR
  PROPERTY OPTION SET:   NRTL-RK   RENON (NRTL) / REDLICH-KWONG

-----------------------------------------------------
! DUTY        ! PRES    ! TEMP      ! VFRAC       !
!       !       !       !       !       !
!       !       !       !       !        !
```

```
!            !            !            !            !
!  GCAL/HR   !  BAR       !  C         !            !
!            !            !            !            !
!============!============!============!============!
!     0.0    !     1.5648 !    56.9000 !     1.0000 !
!     0.2322 !     1.5648 !    44.5843 !     1.0000 !
!     0.4643 !     1.5648 !    31.9246 !     1.0000 !
!     0.6965 !     1.5648 !    18.9094 !     1.0000 !
!     0.5450 !     1.5648 !    27.4454 ! DEW>1.0000 !
!------------+------------+------------+------------!
!     0.9287 !     1.5648 !    10.7653 !     0.9772 !
!     1.1609 !     1.5648 !    10.7233 !     0.9185 !
!     1.3930 !     1.5648 !    10.6760 !     0.8599 !
!     1.6252 !     1.5648 !    10.6227 !     0.8014 !
!     1.8574 !     1.5648 !    10.5620 !     0.7429 !
!------------+------------+------------+------------!
!     2.0895 !     1.5648 !    10.4924 !     0.6845 !
!     2.3217 !     1.5648 !    10.4121 !     0.6262 !
!     2.5539 !     1.5648 !    10.3188 !     0.5680 !
!     2.7860 !     1.5648 !    10.2096 !     0.5100 !
!     3.0182 !     1.5648 !    10.0817 !     0.4521 !
!------------+------------+------------+------------!
!     3.2504 !     1.5648 !     9.9333 !     0.3945 !
!     3.4826 !     1.5648 !     9.7676 !     0.3373 !
!     3.7147 !     1.5648 !     9.6054 !     0.2805 !
!     3.9469 !     1.5648 !     9.5068 !     0.2242 !
!     4.1791 !     1.5648 !     9.5304 !     0.1682 !
!------------+------------+------------+------------!
!     4.4112 !     1.5648 !     9.6134 !     0.1123 !
!     4.6434 !     1.5648 !     9.6868 ! 5.6217-02  !
!     4.8756 !     1.5648 !     9.7401 !     0.0    !
-----------------------------------------------------

BLOCK:  B6       MODEL: PUMP
----------------------------
  INLET STREAM:          LIQ
  OUTLET STREAM:         LIQ-B
  PROPERTY OPTION SET:   NRTL-RK   RENON (NRTL) / REDLICH-KWONG

                  ***  MASS AND ENERGY BALANCE  ***
                            IN          OUT      RELATIVE DIFF.
        TOTAL BALANCE
        MOLE(KMOL/HR )        11.0218         11.0218         0.00000
        MASS(KG/HR   )        6908.83         6908.83        -0.263285E-15
        ENTHALPY(GCAL/HR )   -4.31378        -4.31302        -0.174802E-03

                  ***  CO2 EQUIVALENT SUMMARY ***
        FEED STREAMS CO2E          0.00000         KG/HR
```

PRODUCT STREAMS CO2E 0.00000 KG/HR
NET STREAMS CO2E PRODUCTION 0.00000 KG/HR
UTILITIES CO2E PRODUCTION 0.00000 KG/HR
TOTAL CO2E PRODUCTION 0.00000 KG/HR

*** INPUT DATA ***

OUTLET PRESSURE BAR 6.00000
PUMP EFFICIENCY 0.75000
DRIVER EFFICIENCY 1.00000

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

*** RESULTS ***

VOLUMETRIC FLOW RATE CUM/HR 5.33874
PRESSURE CHANGE BAR 4.43517
NPSH AVAILABLE METER 0.0
FLUID POWER KW 0.65773
BRAKE POWER KW 0.87697
ELECTRICITY KW 0.87697
PUMP EFFICIENCY USED 0.75000
NET WORK REQUIRED KW 0.87697
HEAD DEVELOPED METER 34.9481

BLOCK: B7 MODEL: HEATX

HOT SIDE:

INLET STREAM: S32
OUTLET STREAM: S29
PROPERTY OPTION SET: NRTL-RK RENON (NRTL) / REDLICH-KWONG
COLD SIDE:

INLET STREAM: S23
OUTLET STREAM: S24
PROPERTY OPTION SET: NRTL-RK RENON (NRTL) / REDLICH-KWONG

****
* *
* TEMPERATURE CROSS DETECTED IN TQ-CURVE *
* *
****

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(KMOL/HR)	31.7021	31.7021	0.00000
MASS(KG/HR)	695.617	695.617	0.00000
ENTHALPY(GCAL/HR)	-2.04556	-2.04556	-0.326447E-08

*** CO2 EQUIVALENT SUMMARY ***

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

*** INPUT DATA ***

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 VAPOR FRACTION
SPECIFIED VALUE 0.0000
LMTD CORRECTION FACTOR 1.00000

PRESSURE SPECIFICATION:
HOT SIDE PRESSURE DROP BAR 0.0000
COLD SIDE PRESSURE DROP BAR 0.0000

HEAT TRANSFER COEFFICIENT SPECIFICATION:

HOT LIQUID	COLD LIQUID	KCAL/HR-SQM-K	730.8684
HOT 2-PHASE	COLD LIQUID	KCAL/HR-SQM-K	730.8684
HOT VAPOR	COLD LIQUID	KCAL/HR-SQM-K	730.8684
HOT LIQUID	COLD 2-PHASE	KCAL/HR-SQM-K	730.8684
HOT 2-PHASE	COLD 2-PHASE	KCAL/HR-SQM-K	730.8684
HOT VAPOR	COLD 2-PHASE	KCAL/HR-SQM-K	730.8684
HOT LIQUID	COLD VAPOR	KCAL/HR-SQM-K	730.8684
HOT 2-PHASE	COLD VAPOR	KCAL/HR-SQM-K	730.8684
HOT VAPOR	COLD VAPOR	KCAL/HR-SQM-K	730.8684

*** OVERALL RESULTS ***

```
STREAMS:
               --------------------------------------
                        |                              |
S32       ----->|              HOT                 |-----> S29
T=  7.7114D+01  |                                  |          T=  3.2250D+01
P=  3.7000D+00  |                                  |          P=  3.7000D+00
V=  8.8985D-01  |                                  |          V=  0.0000D+00
                        |                              |
S24       <-----|              COLD                |<----- S23
T=  5.6089D+01  |                                  |          T=  7.2200D+00
P=  1.0000D+00  |                                  |          P=  1.0000D+00
V=  0.0000D+00  |                                  |          V=  0.0000D+00
               --------------------------------------

DUTY AND AREA:
          CALCULATED HEAT DUTY        GCAL/HR                  0.0241
          CALCULATED (REQUIRED) AREA        SQM                1.4385
          ACTUAL EXCHANGER AREA             SQM                1.4385
          PER CENT OVER-DESIGN                           0.0000

HEAT TRANSFER COEFFICIENT:
          AVERAGE COEFFICIENT (DIRTY)          KCAL/HR-SQM-K          730.8684
          UA (DIRTY)                 CAL/SEC-K                292.0369

LOG-MEAN TEMPERATURE DIFFERENCE:
          LMTD CORRECTION FACTOR                         1.0000
          LMTD (CORRECTED)                C                      22.9692
          NUMBER OF SHELLS IN SERIES                     1

PRESSURE DROP:
          HOTSIDE, TOTAL                  BAR                0.0000
          COLDSIDE, TOTAL                 BAR                0.0000

                    ***  ZONE RESULTS  ***

TEMPERATURE LEAVING EACH ZONE:


                                HOT
          ------------------------------------------------------------
            |                                                |
HOT IN  |                     COND                         | HOT OUT
------> |                                              |------>
  77.1  |                                              |   32.2
            |                                                |
COLDOUT |                          LIQ                              | COLDIN
<------ |                                              |<------
  56.1  |                                                  |        7.2
```

| |

COLD

ZONE HEAT TRANSFER AND AREA:

ZONE	HEAT DUTY	AREA	LMTD	AVERAGE U	UA
	GCAL/HR	SQM	C	KCAL/HR-SQM-K	CAL/SEC-K
1	0.024	1.4385	22.9692	730.8684	292.0369

HEATX COLD-TQCU B7 TQCURV INLET

PRESSURE PROFILE: CONSTANT2
PRESSURE DROP: 0.0 BAR
PROPERTY OPTION SET: NRTL-RK RENON (NRTL) / REDLICH-KWONG

DUTY	PRES	TEMP	VFRAC
GCAL/HR	BAR	C	
0.0	1.0000	56.0885	0.0
1.1499-03	1.0000	53.8098	0.0
2.2998-03	1.0000	51.5257	0.0
3.4498-03	1.0000	49.2365	0.0
4.5997-03	1.0000	46.9420	0.0
5.7496-03	1.0000	44.6425	0.0
6.8995-03	1.0000	42.3379	0.0
8.0494-03	1.0000	40.0284	0.0
9.1994-03	1.0000	37.7139	0.0
1.0349-02	1.0000	35.3947	0.0
1.1499-02	1.0000	33.0707	0.0
1.2649-02	1.0000	30.7420	0.0
1.3799-02	1.0000	28.4088	0.0
1.4949-02	1.0000	26.0711	0.0
1.6099-02	1.0000	23.7290	0.0
1.7249-02	1.0000	21.3826	0.0
1.8399-02	1.0000	19.0320	0.0
1.9549-02	1.0000	16.6774	0.0
2.0699-02	1.0000	14.3187	0.0
2.1848-02	1.0000	11.9562	0.0

```
! 2.2998-02 !     1.0000 ! 9.5899 ! 0.0    !
! 2.4148-02 !     1.0000 ! 7.2200 ! 0.0    !
-----------------------------------------------------

HEATX HOT-TQCUR B7          TQCURV INLET
-------------------------------------
 PRESSURE PROFILE:  CONSTANT2
 PRESSURE DROP:       0.0         BAR
 PROPERTY OPTION SET:   NRTL-RK   RENON (NRTL) / REDLICH-KWONG

-----------------------------------------------------
! DUTY          ! PRES     ! TEMP        ! VFRAC          !
!          !          !          !          !
!          !          !          !          !
!          !          !          !          !
! GCAL/HR  ! BAR       ! C       !          !
!          !          !          !          !
!============!============!============!============!
!    0.0  !         3.7000 !    77.1137 !         0.8899 !
! 1.1499-03 !     3.7000 ! 72.8190 !           0.8711 !
! 2.2998-03 !     3.7000 ! 67.9596 !           0.8537 !
! 3.4498-03 !     3.7000 ! 62.4328 !           0.8380 !
! 4.5997-03 !     3.7000 ! 56.1202 !           0.8242 !
!------------+------------+------------+------------!
! 5.7496-03 !     3.7000 ! 48.8936 !           0.8126 !
! 6.8995-03 !     3.7000 ! 40.6320 !           0.8032 !
! 8.0494-03 !     3.7000 ! 31.2532 !           0.7962 !
! 9.1994-03 !     3.7000 ! 20.7562 !           0.7914 !
! 1.0349-02 !     3.7000 ! 9.2521 ! 0.7885 !
!------------+------------+------------+------------!
! 1.1499-02 !     3.7000 ! -3.0468 !           0.7869 !
! 1.2649-02 !     3.7000 !   -15.8716 !        0.7861 !
! 1.3799-02 !     3.7000 !   -28.9407 !        0.7855 !
! 1.4949-02 !     3.7000 ! 31.7343 !           0.4722 !
! 1.6099-02 !    3.7000 !    31.4823 !         0.4165 !
!------------+------------+------------+------------!
! 1.7249-02 !     3.7000 ! 31.3848 !           0.3594 !
! 1.8399-02 !     3.7000 ! 31.4011 !           0.3011 !
! 1.9549-02 !     3.7000 ! 31.4976 !           0.2419 !
! 2.0699-02 !     3.7000 ! 31.6481 !           0.1820 !
! 2.1848-02 !     3.7000 ! 31.8327 !           0.1216 !
!------------+------------+------------+------------!
! 2.2998-02 !     3.7000 ! 32.0367 !  6.0911-02 !
! 2.4148-02 !     3.7000 ! 32.2496 !           0.0    !
-----------------------------------------------------

BLOCK:  B8      MODEL: FLASH2
------------------------------
```

INLET STREAMS: S13 S27
OUTLET VAPOR STREAM: S6
OUTLET LIQUID STREAM: S10
PROPERTY OPTION SET: NRTL-RK RENON (NRTL) / REDLICH-KWONG

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(KMOL/HR)	743.364	743.364	0.00000
MASS(KG/HR)	43177.1	43177.1	0.168514E-15
ENTHALPY(GCAL/HR)	-25.4859	-25.4902	0.166887E-03

** CO2 EQUIVALENT SUMMARY ***

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

*** INPUT DATA ***

TWO PHASE TP FLASH
SPECIFIED TEMPERATURE C 50.0000
PRESSURE DROP BAR 0.0
MAXIMUM NO. ITERATIONS 30
CONVERGENCE TOLERANCE 0.000100000

*** RESULTS ***

OUTLET TEMPERATURE C 50.000
OUTLET PRESSURE BAR 6.0000
HEAT DUTY GCAL/HR -0.42540E-02
VAPOR FRACTION 0.0000

V-L PHASE EQUILIBRIUM :

COMP	F(I)	X(I)	Y(I)	K(I)
N-BUTANE	0.99900	0.99900	0.97512	0.84947
WATER	0.99730E-03	0.99730E-03	0.24878E-01	21.709

BLOCK: B9 MODEL: MIXER

INLET STREAMS: MIXFIL2 MIXFIL1 CFG
OUTLET STREAM: S17
PROPERTY OPTION SET: NRTL-RK RENON (NRTL) / REDLICH-KWONG

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			

MOLE(KMOL/HR) 712.440 712.440 0.00000
MASS(KG/HR) 46955.0 46955.0 0.154956E-15
ENTHALPY(GCAL/HR) 0.00000 -28.9395 1.00000

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

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

BLOCK: B10 MODEL: PUMP

INLET STREAM: S10
OUTLET STREAM: S12
PROPERTY OPTION SET: NRTL-RK RENON (NRTL) / REDLICH-KWONG

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(KMOL/HR)	743.364	743.364	0.00000
MASS(KG/HR)	43177.1	43177.1	0.00000
ENTHALPY(GCAL/HR)	-25.4902	-25.4902	0.378440E-07

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

*** INPUT DATA ***
OUTLET PRESSURE BAR 6.00000
PUMP EFFICIENCY 0.75000
DRIVER EFFICIENCY 1.00000

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

*** RESULTS ***

VOLUMETRIC FLOW RATE CUM/HR 79.5748
PRESSURE CHANGE BAR 0.0
NPSH AVAILABLE METER 16.7963
FLUID POWER KW 0.0
BRAKE POWER KW 0.0
ELECTRICITY KW 0.0
PUMP EFFICIENCY USED 0.75000
NET WORK REQUIRED KW 0.0
HEAD DEVELOPED METER 0.0

BLOCK: B11 MODEL: HEATX

HOT SIDE:

INLET STREAM: BUTTER2
OUTLET STREAM: S3
PROPERTY OPTION SET: NRTL-RK RENON (NRTL) / REDLICH-KWONG
COLD SIDE:

INLET STREAM: S37
OUTLET STREAM: S18
PROPERTY OPTION SET: NRTL-RK RENON (NRTL) / REDLICH-KWONG

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(KMOL/HR)	813.888	813.888	0.00000
MASS(KG/HR)	57619.3	57619.3	0.00000
ENTHALPY(GCAL/HR)	-37.2957	-37.2957	0.198867E-06

*** CO2 EQUIVALENT SUMMARY ***

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

*** INPUT DATA ***

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 80.0000
LMTD CORRECTION FACTOR 1.00000

PRESSURE SPECIFICATION:

HOT SIDE PRESSURE DROP BAR 0.0000
COLD SIDE PRESSURE DROP BAR 0.0000

HEAT TRANSFER COEFFICIENT SPECIFICATION:

HOT LIQUID	COLD LIQUID	KCAL/HR-SQM-K	730.8684
HOT 2-PHASE	COLD LIQUID	KCAL/HR-SQM-K	730.8684
HOT VAPOR	COLD LIQUID	KCAL/HR-SQM-K	730.8684
HOT LIQUID	COLD 2-PHASE	KCAL/HR-SQM-K	730.8684
HOT 2-PHASE	COLD 2-PHASE	KCAL/HR-SQM-K	730.8684
HOT VAPOR	COLD 2-PHASE	KCAL/HR-SQM-K	730.8684
HOT LIQUID	COLD VAPOR	KCAL/HR-SQM-K	730.8684
HOT 2-PHASE	COLD VAPOR	KCAL/HR-SQM-K	730.8684
HOT VAPOR	COLD VAPOR	KCAL/HR-SQM-K	730.8684

*** OVERALL RESULTS ***

STREAMS:

```
            --------------------------------------
                 |                              |
BUTTER2   ----->|            HOT                |-----> S3
T=  1.4909D+02  |                               |  T=  8.0000D+01
P=  3.9000D+00  |                               |  P=  3.9000D+00
V=  0.0000D+00  |                               |  V=  0.0000D+00
                 |                              |
S18       <-----|            COLD               |<----- S37
T=  5.1547D+01  |                               |  T=  4.6999D+01
P=  6.0000D+00  |                               |  P=  6.0000D+00
V=  3.9907D-02  |                               |  V=  0.0000D+00
            --------------------------------------
```

DUTY AND AREA:

CALCULATED HEAT DUTY GCAL/HR 0.3001
CALCULATED (REQUIRED) AREA SQM 6.9950
ACTUAL EXCHANGER AREA SQM 6.9950
PER CENT OVER-DESIGN 0.0000

HEAT TRANSFER COEFFICIENT:

AVERAGE COEFFICIENT (DIRTY) KCAL/HR-SQM-K 730.8685
UA (DIRTY) CAL/SEC-K 1420.1278

LOG-MEAN TEMPERATURE DIFFERENCE:

LMTD CORRECTION FACTOR		1.0000
LMTD (CORRECTED)	C	58.6902
NUMBER OF SHELLS IN SERIES		1

PRESSURE DROP:

HOTSIDE, TOTAL	BAR	0.0000
COLDSIDE, TOTAL	BAR	0.0000

*** ZONE RESULTS ***

TEMPERATURE LEAVING EACH ZONE:

```
                          HOT
    -----------------------------------------------------------
        |                 |                 |
HOT IN  |      LIQ        |      LIQ        | HOT OUT
------> |                 |------>
 149.1  |            113.6|                 |  80.0
        |                 |                 |
COLDOUT |        BOIL     |      LIQ        | COLDIN
<------ |                 |<------
  51.5  |             51.6|                 |  47.0
        |                 |                 |
    -----------------------------------------------------------
                          COLD
```

ZONE HEAT TRANSFER AND AREA:

ZONE	HEAT DUTY	AREA	LMTD	AVERAGE U	UA
	GCAL/HR	SQM	C	KCAL/HR-SQM-K	CAL/SEC-K
1	0.157	2.7337	78.4610	730.8684	554.9839
2	0.143	4.2614	46.0073	730.8684	865.1438

```
HEATX COLD-TQCU B11          TQCURV INLET
-------------------------------------
  PRESSURE PROFILE:  CONSTANT2
  PRESSURE DROP:       0.0        BAR
  PROPERTY OPTION SET:   NRTL-RK   RENON (NRTL) / REDLICH-KWONG

----------------------------------------------------
!  DUTY        !  PRES     !  TEMP       !  VFRAC        !
!         !         !         !         !
!         !         !         !         !
!         !         !         !         !
!  GCAL/HR  !  BAR     !  C      !         !
!         !         !         !         !
```

```
!============!============!============!============!
!    0.0  !         6.0000 !    51.5467 !  3.9907-02 !
!  1.4288-02 !      6.0000 ! 51.5422 !  3.6314-02 !
!  2.8576-02 !      6.0000 ! 51.5396 !  3.2711-02 !
!  4.2864-02 !      6.0000 ! 51.5388 !  2.9098-02 !
!  5.7153-02 !      6.0000 ! 51.5395 !  2.5475-02 !
!------------+------------+------------+------------!
!  7.1441-02 !      6.0000 ! 51.5417 !  2.1843-02 !
!  8.5729-02 !      6.0000 ! 51.5452 !  1.8203-02 !
!    0.1000 !       6.0000 ! 51.5500 !  1.4555-02 !
!    0.1143 !    6.0000 !    51.5558 !  1.0900-02 !
!    0.1286 !       6.0000 ! 51.5627 !  7.2374-03 !
!------------+------------+------------+------------!
!    0.1429 !       6.0000 ! 51.5705 !  3.5690-03 !
!    0.1568 !       6.0000 ! 51.5788 ! BUB>0.0          !
!    0.1572 !       6.0000 ! 51.5658 !           0.0    !
!    0.1715 !       6.0000 ! 51.1115 !           0.0    !
!    0.1857 !       6.0000 ! 50.6566 !           0.0    !
!------------+------------+------------+------------!
!    0.2000 !       6.0000 ! 50.2012 !           0.0    !
!    0.2143 !       6.0000 ! 49.7453 !           0.0    !
!    0.2286 !       6.0000 ! 49.2888 !           0.0    !
!    0.2429 !       6.0000 ! 48.8318 !           0.0    !
!    0.2572 !       6.0000 ! 48.3742 !           0.0    !
!------------+------------+------------+------------!
!    0.2715 !       6.0000 ! 47.9161 !           0.0    !
!    0.2858 !       6.0000 ! 47.4575 !           0.0    !
!    0.3001 !       6.0000 ! 46.9984 !           0.0    !
-----------------------------------------------------

HEATX HOT-TQCUR B11          TQCURV INLET
-------------------------------------
  PRESSURE PROFILE:  CONSTANT2
  PRESSURE DROP:       0.0        BAR
  PROPERTY OPTION SET:   NRTL-RK   RENON (NRTL) / REDLICH-KWONG

-----------------------------------------------------
!  DUTY           !  PRES      !  TEMP         !  VFRAC           !
!           !           !           !           !
!           !           !                !                 !
!           !           !           !           !
!  GCAL/HR   !  BAR       !  C        !           !
!           !           !           !           !
!============!============!============!============!
!    0.0  !         3.9000 !   149.0854 !        0.0         !
!  1.4288-02 !      3.9000 !   145.9086 !        0.0    !
!  2.8576-02 !      3.9000 !   142.7210 !        0.0    !
!  4.2864-02 !      3.9000 !   139.5225 !        0.0    !
```

```
!  5.7153-02 !      3.9000 !   136.3130 !         0.0    !
!------------+------------+------------+------------!
!  7.1441-02 !      3.9000 !   133.0925 !         0.0    !
!  8.5729-02 !      3.9000 !   129.8610 !         0.0    !
!     0.1000 !      3.9000 !   126.6183 !         0.0    !
!     0.1143 !      3.9000 !   123.3643 !         0.0    !
!     0.1286 !      3.9000 !   120.0990 !         0.0    !
!------------+------------+------------+------------!
!     0.1429 !      3.9000 !   116.8223 !         0.0    !
!     0.1568 !      3.9000 !   113.6284 !         0.0    !
!     0.1572 !      3.9000 !   113.5340 !         0.0    !
!     0.1715 !      3.9000 !   110.2342 !         0.0    !
!     0.1857 !      3.9000 !   106.9228 !         0.0    !
!------------+------------+------------+------------!
!     0.2000 !      3.9000 !   103.5995 !         0.0    !
!     0.2143 !      3.9000 !   100.2645 !         0.0    !
!     0.2286 !      3.9000 ! 96.9174 !            0.0    !
!     0.2429 !      3.9000 ! 93.5584 !            0.0    !
!     0.2572 !      3.9000 ! 90.1872 !            0.0    !
!------------+------------+------------+------------!
!     0.2715 !      3.9000 ! 86.8038 !            0.0    !
!     0.2858 !      3.9000 ! 83.4081 !            0.0    !
!     0.3001 !      3.9000 ! 80.0000 !            0.0    !
----------------------------------------------------

BLOCK:  B12     MODEL: MIXER
----------------------------
 INLET STREAMS:        S20        S36
 OUTLET STREAM:        S8
 PROPERTY OPTION SET:   NRTL-RK   RENON (NRTL) / REDLICH-KWONG

              ***  MASS AND ENERGY BALANCE  ***
                               IN          OUT      RELATIVE DIFF.
         TOTAL BALANCE
         MOLE(KMOL/HR )          56.1220              56.1220              0.00000
         MASS(KG/HR   )          3262.00         3262.00          0.00000
         ENTHALPY(GCAL/HR )              0.00000              -1.65021              1.00000

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

                    ***  INPUT DATA  ***
 TWO    PHASE              FLASH
 MAXIMUM NO. ITERATIONS                                 30
```

CONVERGENCE TOLERANCE 0.000100000
OUTLET PRESSURE: MINIMUM OF INLET STREAM PRESSURES

BLOCK: B13 MODEL: PUMP

INLET STREAM: S1
OUTLET STREAM: S13
PROPERTY OPTION SET: NRTL-RK RENON (NRTL) / REDLICH-KWONG

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(KMOL/HR)	743.347	743.347	0.00000
MASS(KG/HR)	43176.1	43176.1	0.00000
ENTHALPY(GCAL/HR)	-25.4904	-25.4853	-0.198827E-03

*** CO2 EQUIVALENT SUMMARY ***

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

*** INPUT DATA ***

OUTLET PRESSURE BAR 6.00000
PUMP EFFICIENCY 0.75000
DRIVER EFFICIENCY 1.00000

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

*** RESULTS ***

VOLUMETRIC FLOW RATE CUM/HR 79.5729
PRESSURE CHANGE BAR 2.00000
NPSH AVAILABLE METER -20.7902
FLUID POWER KW 4.42072
BRAKE POWER KW 5.89429
ELECTRICITY KW 5.89429
PUMP EFFICIENCY USED 0.75000
NET WORK REQUIRED KW 5.89429
HEAD DEVELOPED METER 37.5864
NEGATIVE NPSH MAY BE DUE TO VAPOR IN THE FEED OR UNACCOUNTED SUCTION HEAD.

BLOCK: B15 MODEL: PUMP

INLET STREAM: S40
OUTLET STREAM: S25
PROPERTY OPTION SET: NRTL-RK RENON (NRTL) / REDLICH-KWONG

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(KMOL/HR)	56.1220	56.1220	0.00000
MASS(KG/HR)	3262.00	3262.00	0.00000
ENTHALPY(GCAL/HR)	-2.01341	-2.01257	-0.414395E-03

*** CO2 EQUIVALENT SUMMARY ***

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

*** INPUT DATA ***

OUTLET PRESSURE BAR 6.00000
PUMP EFFICIENCY 0.75000
DRIVER EFFICIENCY 1.00000

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

*** RESULTS ***

VOLUMETRIC FLOW RATE CUM/HR 5.45791
PRESSURE CHANGE BAR 4.80000
NPSH AVAILABLE METER 0.0
FLUID POWER KW 0.72772
BRAKE POWER KW 0.97029
ELECTRICITY KW 0.97029
PUMP EFFICIENCY USED 0.75000
NET WORK REQUIRED KW 0.97029
HEAD DEVELOPED METER 81.8960

BLOCK: B16 MODEL: DUPL

INLET STREAM: VAPOR
OUTLET STREAM: S26

BLOCK: B17 MODEL: FSPLIT

INLET STREAM: S12

OUTLET STREAMS: S16 S21 S22
PROPERTY OPTION SET: NRTL-RK RENON (NRTL) / REDLICH-KWONG

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(KMOL/HR)	743.364	743.364	0.00000
MASS(KG/HR)	43177.1	43177.1	-0.168514E-15
ENTHALPY(GCAL/HR)	-25.4902	-25.4902	-0.519969E-11

*** CO2 EQUIVALENT SUMMARY ***

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

*** INPUT DATA ***

FRACTION OF FLOW STRM=S16 FRAC= 0.77350
STRM=S21 FRAC= 0.20880

*** RESULTS ***

STREAM=	SPLIT=	KEY=	STREAM-ORDER=
S16	0.77350	0	1
S21	0.20880	0	2
S22	0.017700	0	3

BLOCK: B19 MODEL: PUMP

INLET STREAM: S29
OUTLET STREAM: S28
PROPERTY OPTION SET: NRTL-RK RENON (NRTL) / REDLICH-KWONG

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(KMOL/HR)	3.94793	3.94793	0.00000
MASS(KG/HR)	195.617	195.617	0.00000
ENTHALPY(GCAL/HR)	-0.166462	-0.166459	-0.187166E-04

*** CO2 EQUIVALENT SUMMARY ***

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

*** INPUT DATA ***

OUTLET PRESSURE BAR	4.00000
PUMP EFFICIENCY	0.75000
DRIVER EFFICIENCY	1.00000

FLASH SPECIFICATIONS:
LIQUID PHASE CALCULATION
NO FLASH PERFORMED

MAXIMUM NUMBER OF ITERATIONS	30
TOLERANCE	0.000100000

*** RESULTS ***

VOLUMETRIC FLOW RATE CUM/HR	0.32559
PRESSURE CHANGE BAR	0.30000
NPSH AVAILABLE METER	0.0
FLUID POWER KW	0.0027132
BRAKE POWER KW	0.0036176
ELECTRICITY KW	0.0036176
PUMP EFFICIENCY USED	0.75000
NET WORK REQUIRED KW	0.0036176
HEAD DEVELOPED METER	5.09168

BLOCK: B20 MODEL: HEATX

HOT SIDE:

INLET STREAM: S8
OUTLET STREAM: S40
PROPERTY OPTION SET: NRTL-RK RENON (NRTL) / REDLICH-KWONG
COLD SIDE:

INLET STREAM: S38
OUTLET STREAM: S39
PROPERTY OPTION SET: NRTL-RK RENON (NRTL) / REDLICH-KWONG

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(KMOL/HR)	1618.01	1618.01	0.00000
MASS(KG/HR)	39012.0	39012.0	0.00000
ENTHALPY(GCAL/HR)	-116.562	-116.562	-0.122839E-10

*** CO2 EQUIVALENT SUMMARY ***

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

```
                    ***  INPUT DATA  ***

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 VAPOR FRACTION
         SPECIFIED VALUE                        0.0000
 LMTD CORRECTION FACTOR                             1.00000

PRESSURE SPECIFICATION:
         HOT  SIDE PRESSURE DROP     BAR                0.0000
         COLD SIDE PRESSURE DROP     BAR                0.0000

HEAT TRANSFER COEFFICIENT SPECIFICATION:
         HOT LIQUID     COLD LIQUID   KCAL/HR-SQM-K          730.8684
         HOT 2-PHASE    COLD LIQUID   KCAL/HR-SQM-K          730.8684
         HOT VAPOR      COLD LIQUID   KCAL/HR-SQM-K          730.8684
         HOT LIQUID     COLD 2-PHASE    KCAL/HR-SQM-K        730.8684
         HOT 2-PHASE    COLD 2-PHASE  KCAL/HR-SQM-K          730.8684
         HOT VAPOR      COLD 2-PHASE            KCAL/HR-SQM-K          730.8684
         HOT LIQUID     COLD VAPOR    KCAL/HR-SQM-K          730.8684
         HOT 2-PHASE    COLD VAPOR    KCAL/HR-SQM-K          730.8684
         HOT VAPOR      COLD VAPOR    KCAL/HR-SQM-K          730.8684

                    ***  OVERALL RESULTS  ***

STREAMS:
             --------------------------------------
                    |                               |
S8        ----->|             HOT                |-----> S40
T=  5.3000D+01  |                               |           T=  4.0012D+00
P=  1.2000D+00  |                              |            P=  1.2000D+00
V=  1.0000D+00  |                               |           V=  0.0000D+00
                    |                               |
S39       <-----|             COLD               |<----- S38
T= -9.0640D-02  |                               |           T= -1.2222D+01
P=  4.4816D+00  |                               |           P=  4.4816D+00
V=  0.0000D+00  |                               |           V=  0.0000D+00
```

DUTY AND AREA:

CALCULATED HEAT DUTY	GCAL/HR	0.3632
CALCULATED (REQUIRED) AREA	SQM	42.8818
ACTUAL EXCHANGER AREA	SQM	42.8818
PER CENT OVER-DESIGN		0.0000

HEAT TRANSFER COEFFICIENT:

AVERAGE COEFFICIENT (DIRTY)	KCAL/HR-SQM-K	730.8684
UA (DIRTY)	CAL/SEC-K	8705.8140

LOG-MEAN TEMPERATURE DIFFERENCE:

LMTD CORRECTION FACTOR		1.0000
LMTD (CORRECTED)	C	11.5885
NUMBER OF SHELLS IN SERIES		1

PRESSURE DROP:

HOTSIDE, TOTAL	BAR	0.0000
COLDSIDE, TOTAL	BAR	0.0000

*** ZONE RESULTS ***

TEMPERATURE LEAVING EACH ZONE:

```
                         HOT
      ------------------------------------------------------------
         |                  |                  |
HOT IN  |       VAP         |       COND       | HOT OUT
------> |                   |                  |------>
  53.0  |               4.0|                   |       4.0
         |                  |                  |
COLDOUT |              LIQ  |          LIQ     | COLDIN
<------ |                   |                  |<------
  -0.1  |              -2.3|                   |  -12.2
         |                  |                  |
           ------------------------------------------------------------
                         COLD
```

ZONE HEAT TRANSFER AND AREA:

ZONE	HEAT DUTY	AREA	LMTD	AVERAGE U	UA
	GCAL/HR	SQM	C	KCAL/HR-SQM-K	CAL/SEC-K
1	0.066	4.1175	21.9479	730.8684	835.9231
2	0.297	38.7643	10.4882	730.8684	7869.8909

HEATX COLD-TQCU B20 TQCURV INLET

```
 PRESSURE PROFILE:  CONSTANT2
 PRESSURE DROP:       0.0         BAR
 PROPERTY OPTION SET:   NRTL-RK   RENON (NRTL) / REDLICH-KWONG

-----------------------------------------------------
!  DUTY          !  PRES     !  TEMP        !  VFRAC          !
!          !          !          !          !
!          !          !          !          !
!          !          !          !             !
!  GCAL/HR   !  BAR       !  C       !          !
!          !          !          !          !
!============!============!============!============!
!     0.0  !           4.4816 ! -9.0640-02 !        0.0    !
!  1.7295-02 !     4.4816 !    -0.6677 !     0.0 !
!  3.4590-02 !     4.4816 ! -1.2449 !            0.0    !
!  5.1885-02 !     4.4816 ! -1.8221 !            0.0    !
!  6.6048-02 !     4.4816 ! -2.2948 !            0.0    !
!------------+------------+------------+------------!
!  6.9180-02 !     4.4816 ! -2.3994 !            0.0    !
!  8.6475-02 !     4.4816 ! -2.9767 !            0.0    !
!     0.1038 !       4.4816 ! -3.5541 !            0.0    !
!     0.1211 !       4.4816 ! -4.1316 !            0.0    !
!     0.1384 !       4.4816 ! -4.7091 !            0.0    !
!------------+------------+------------+------------!
!     0.1557 !       4.4816 ! -5.2867 !            0.0    !
!     0.1729 !       4.4816 ! -5.8643 !            0.0    !
!     0.1902 !       4.4816 ! -6.4420 !            0.0    !
!     0.2075 !       4.4816 ! -7.0198 !            0.0    !
!     0.2248 !       4.4816 ! -7.5976 !            0.0    !
!------------+------------+------------+------------!
!     0.2421 !       4.4816 ! -8.1755 !            0.0    !
!     0.2594 !    4.4816 !    -8.7534 !            0.0         !
!     0.2767 !       4.4816 ! -9.3314 !            0.0    !
!     0.2940 !       4.4816 ! -9.9095 !            0.0    !
!     0.3113 !       4.4816 !   -10.4876 !         0.0    !
!------------+------------+------------+------------!
!     0.3286 !       4.4816 !   -11.0657 !         0.0    !
!     0.3459 !       4.4816 !   -11.6439 !         0.0    !
!     0.3632 !       4.4816 !   -12.2222 !         0.0    !
-----------------------------------------------------

HEATX HOT-TQCUR B20          TQCURV INLET
------------------------------------
 PRESSURE PROFILE:  CONSTANT2
 PRESSURE DROP:       0.0         BAR
 PROPERTY OPTION SET:   NRTL-RK   RENON (NRTL) / REDLICH-KWONG

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

```
!  DUTY          !  PRES     !  TEMP        !  VFRAC        !
!          !          !          !          !
!          !          !          !          !
!          !          !          !          !
!  GCAL/HR   !  BAR      !  C       !          !
!          !          !          !          !
!============!============!============!============!
!    0.0  !           1.2000 !    53.0000 !          1.0000 !
!  1.7295-02 !      1.2000 ! 40.6738 !            1.0000 !
!  3.4590-02 !      1.2000 ! 27.9963 !            1.0000 !
!  5.1885-02 !      1.2000 ! 14.9556 !            1.0000 !
!  6.6048-02 !      1.2000 ! 4.0012 ! DEW>1.0000 !
!------------+------------+------------+------------!
!  6.9180-02 !     1.2000 !     4.0012 !            0.9895 !
!  8.6475-02 !      1.2000 ! 4.0012 ! 0.9313 !
!    0.1038 !        1.2000 ! 4.0012 ! 0.8731 !
!    0.1211 !        1.2000 ! 4.0012 ! 0.8149 !
!    0.1384 !        1.2000 ! 4.0012 ! 0.7566 !
!------------+------------+------------+------------!
!    0.1557 !        1.2000 ! 4.0012 ! 0.6984 !
!    0.1729 !        1.2000 ! 4.0012 ! 0.6402 !
!    0.1902 !        1.2000 ! 4.0012 ! 0.5820 !
!    0.2075 !        1.2000 ! 4.0012 ! 0.5238 !
!    0.2248 !        1.2000 ! 4.0012 ! 0.4656 !
!------------+------------+------------+------------!
!    0.2421 !        1.2000 ! 4.0012 ! 0.4074 !
!    0.2594 !        1.2000 ! 4.0012 ! 0.3492 !
!    0.2767 !        1.2000 ! 4.0012 ! 0.2910 !
!    0.2940 !        1.2000 ! 4.0012 ! 0.2328 !
!    0.3113 !        1.2000 ! 4.0012 ! 0.1746 !
!------------+------------+------------+------------!
!    0.3286 !        1.2000 ! 4.0012 ! 0.1164 !
!    0.3459 !        1.2000 ! 4.0012 !  5.8204-02 !
!    0.3632 !        1.2000 ! 4.0012 ! 0.0     !
-----------------------------------------------------

BLOCK:  B21     MODEL: PUMP
----------------------------
  INLET STREAM:          S7
  OUTLET STREAM:       S35
  PROPERTY OPTION SET:   NRTL-RK   RENON (NRTL) / REDLICH-KWONG

                         ***  MASS AND ENERGY BALANCE  ***
                                    IN             OUT      RELATIVE DIFF.
            TOTAL BALANCE
            MOLE(KMOL/HR )         757.540              757.540              0.00000
            MASS(KG/HR   )          43308.2                43308.2              0.00000
            ENTHALPY(GCAL/HR )             -27.5927              -27.5871              -0.204560E-03
```

*** CO2 EQUIVALENT SUMMARY ***

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

*** INPUT DATA ***

OUTLET PRESSURE BAR 4.00000
PUMP EFFICIENCY 0.75000
DRIVER EFFICIENCY 1.00000

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

*** RESULTS ***

VOLUMETRIC FLOW RATE CUM/HR 72.7842
PRESSURE CHANGE BAR 2.43517
NPSH AVAILABLE METER 0.0
FLUID POWER KW 4.92338
BRAKE POWER KW 6.56451
ELECTRICITY KW 6.56451
PUMP EFFICIENCY USED 0.75000
NET WORK REQUIRED KW 6.56451
HEAD DEVELOPED METER 41.7326

BLOCK: B22 MODEL: MIXER

INLET STREAMS: S17 S25
OUTLET STREAM: S37
PROPERTY OPTION SET: NRTL-RK RENON (NRTL) / REDLICH-KWONG

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(KMOL/HR)	768.562	768.562	0.00000
MASS(KG/HR)	50217.0	50217.0	0.00000
ENTHALPY(GCAL/HR)	-30.9521	-30.9521	0.794885E-07

*** CO2 EQUIVALENT SUMMARY ***

FEED STREAMS CO2E 0.00000 KG/HR
PRODUCT STREAMS CO2E 0.00000 KG/HR
NET STREAMS CO2E PRODUCTION 0.00000 KG/HR
UTILITIES CO2E PRODUCTION 0.00000 KG/HR

TOTAL CO2E PRODUCTION 0.00000 KG/HR

*** INPUT DATA ***

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

BLOCK: B24 MODEL: HEATX

HOT SIDE:

INLET STREAM: RECSOLV2
OUTLET STREAM: S32
PROPERTY OPTION SET: NRTL-RK RENON (NRTL) / REDLICH-KWONG
COLD SIDE:

INLET STREAM: LIQ-B
OUTLET STREAM: S14
PROPERTY OPTION SET: NRTL-RK RENON (NRTL) / REDLICH-KWONG

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(KMOL/HR)	14.9697	14.9697	0.00000
MASS(KG/HR)	7104.45	7104.45	0.583760E-13
ENTHALPY(GCAL/HR)	-4.44882	-4.44882	-0.128774E-08

*** CO2 EQUIVALENT SUMMARY ***

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

*** INPUT DATA ***

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 EXCHANGER DUTY
        SPECIFIED VALUE              GCAL/HR                0.0065
        LMTD CORRECTION FACTOR                      1.00000

PRESSURE SPECIFICATION:
        HOT  SIDE PRESSURE DROP      BAR            0.0000
        COLD SIDE PRESSURE DROP      BAR            0.0000

HEAT TRANSFER COEFFICIENT SPECIFICATION:
        HOT LIQUID     COLD LIQUID   KCAL/HR-SQM-K          730.8684
        HOT 2-PHASE    COLD LIQUID   KCAL/HR-SQM-K          730.8684
        HOT VAPOR      COLD LIQUID   KCAL/HR-SQM-K          730.8684
        HOT LIQUID     COLD 2-PHASE          KCAL/HR-SQM-K          730.8684
        HOT 2-PHASE    COLD 2-PHASE  KCAL/HR-SQM-K          730.8684
        HOT VAPOR      COLD 2-PHASE          KCAL/HR-SQM-K          730.8684
        HOT LIQUID     COLD VAPOR    KCAL/HR-SQM-K          730.8684
        HOT 2-PHASE    COLD VAPOR    KCAL/HR-SQM-K          730.8684
        HOT VAPOR      COLD VAPOR    KCAL/HR-SQM-K          730.8684

                *** OVERALL RESULTS ***

STREAMS:
             --------------------------------------
              |                          |
RECSOLV2  ----->|               HOT                |-----> S32
T=  1.0062D+02  |                          |          T=  7.7114D+01
P=  3.7000D+00  |                          |      P=  3.7000D+00
V=  1.0000D+00  |                          |          V=  8.8985D-01
                |                          |
S14       <-----|           COLD           |<----- LIQ-B
T=  5.8919D+01  |                          |          T=  5.7061D+01
P=  6.0000D+00  |                          |          P=  6.0000D+00
V=  0.0000D+00  |                          |          V=  0.0000D+00
                --------------------------------------

DUTY AND AREA:
        CALCULATED HEAT DUTY         GCAL/HR                0.0065
        CALCULATED (REQUIRED) AREA          SQM             0.3258
        ACTUAL EXCHANGER AREA               SQM             0.3258
        PER CENT OVER-DESIGN                        0.0000

HEAT TRANSFER COEFFICIENT:
        AVERAGE COEFFICIENT (DIRTY)         KCAL/HR-SQM-K          730.8684
        UA (DIRTY)               CAL/SEC-K          66.1387

LOG-MEAN TEMPERATURE DIFFERENCE:
        LMTD CORRECTION FACTOR                      1.0000
```

```
        LMTD (CORRECTED)              C                  27.3568
        NUMBER OF SHELLS IN SERIES                       1

  PRESSURE DROP:
        HOTSIDE, TOTAL                BAR                0.0000
        COLDSIDE, TOTAL               BAR                0.0000

                *** ZONE RESULTS ***

  TEMPERATURE LEAVING EACH ZONE:

                        HOT
      ------------------------------------------------------------
        |                |                |
HOT IN  |      VAP       |      COND      | HOT OUT
------> |                |                |------>
 100.6  |            92.7|                |  77.1
        |                |                |
COLDOUT |       LIQ      |       LIQ      | COLDIN
<------ |                |                |<------
  58.9  |            58.7|                |  57.1
        |                |                |
        ------------------------------------------------------------
                        COLD

  ZONE HEAT TRANSFER AND AREA:

  ZONE    HEAT DUTY        AREA    LMTD    AVERAGE U       UA
          GCAL/HR          SQM     C       KCAL/HR-SQM-K   CAL/SEC-K
        1     0.001       0.0273  37.7116  730.8684        5.5412
        2     0.006       0.2985  26.4099  730.8684        60.5975

HEATX COLD-TQCU B24        TQCURV INLET
-------------------------------------
  PRESSURE PROFILE:  CONSTANT2
  PRESSURE DROP:       0.0       BAR
  PROPERTY OPTION SET:   NRTL-RK   RENON (NRTL) / REDLICH-KWONG

-----------------------------------------------------
! DUTY       ! PRES       ! TEMP       ! VFRAC      !
!            !            !            !            !
!            !            !            !            !
!            !            !            !            !
! GCAL/HR    ! BAR        ! C          !            !
!            !            !            !            !
!============!============!============!============!
!    0.0     !    6.0000  !   58.9192  !    0.0     !
! 3.1017-04  !    6.0000  !   58.8308  !    0.0     !
```

```
!  6.2035-04 !      6.0000 ! 58.7424 !            0.0    !
!  7.5228-04 !      6.0000 ! 58.7048 !            0.0    !
!  9.3052-04 !      6.0000 ! 58.6540 !            0.0    !
!------------+------------+------------+------------!
!  1.2407-03 !     6.0000 !    58.5655 !           0.0         !
!  1.5509-03 !      6.0000 ! 58.4771 !            0.0    !
!  1.8610-03 !      6.0000 ! 58.3887 !            0.0    !
!  2.1712-03 !      6.0000 ! 58.3002 !            0.0    !
!  2.4814-03 !      6.0000 ! 58.2118 !            0.0    !
!------------+------------+------------+------------!
!  2.7916-03 !      6.0000 ! 58.1233 !            0.0    !
!  3.1017-03 !      6.0000 ! 58.0348 !            0.0    !
!  3.4119-03 !      6.0000 ! 57.9463 !            0.0    !
!  3.7221-03 !      6.0000 ! 57.8578 !            0.0    !
!  4.0323-03 !      6.0000 ! 57.7693 !            0.0    !
!------------+------------+------------+------------!
!  4.3424-03 !      6.0000 ! 57.6808 !            0.0    !
!  4.6526-03 !      6.0000 ! 57.5923 !            0.0    !
!  4.9628-03 !      6.0000 ! 57.5038 !            0.0    !
!  5.2729-03 !      6.0000 ! 57.4152 !            0.0    !
!  5.5831-03 !      6.0000 ! 57.3267 !            0.0    !
!------------+------------+------------+------------!
!  5.8933-03 !      6.0000 ! 57.2381 !            0.0    !
!  6.2035-03 !      6.0000 ! 57.1496 !            0.0    !
!  6.5136-03 !      6.0000 ! 57.0610 !            0.0    !
-----------------------------------------------------

HEATX HOT-TQCUR B24           TQCURV INLET
-------------------------------------
  PRESSURE PROFILE:  CONSTANT2
  PRESSURE DROP:        0.0          BAR
  PROPERTY OPTION SET:   NRTL-RK   RENON (NRTL) / REDLICH-KWONG


-----------------------------------------------------
!  DUTY            !  PRES      !  TEMP          !  VFRAC            !
!           !            !            !            !
!           !            !            !            !
!           !            !            !            !
!  GCAL/HR   !  BAR       !  C         !            !
!           !            !            !            !
!============!============!============!============!
!     0.0  !            3.7000 !   100.6183 !          1.0000 !
!  3.1017-04 !      3.7000 ! 97.3646 !            1.0000 !
!  6.2035-04 !      3.7000 ! 94.0905 !            1.0000 !
!  7.5228-04 !      3.7000 ! 92.6915 ! DEW>1.0000 !
!  9.3052-04 !      3.7000 ! 92.3194 !            0.9963 !
!------------+------------+------------+------------!
!  1.2407-03 !      3.7000 ! 91.6585 !            0.9899 !
```

1.5509-03	3.7000	90.9803	0.9835
1.8610-03	3.7000	90.2841	0.9772
2.1712-03	3.7000	89.5693	0.9709
2.4814-03	3.7000	88.8351	0.9647
2.7916-03	3.7000	88.0807	0.9585
3.1017-03	3.7000	87.3053	0.9524
3.4119-03	3.7000	86.5081	0.9464
3.7221-03	3.7000	85.6882	0.9404
4.0323-03	3.7000	84.8446	0.9345
4.3424-03	3.7000	83.9764	0.9286
4.6526-03	3.7000	83.0825	0.9229
4.9628-03	3.7000	82.1618	0.9172
5.2729-03	3.7000	81.2131	0.9115
5.5831-03	3.7000	80.2353	0.9060
5.8933-03	3.7000	79.2270	0.9005
6.2035-03	3.7000	78.1870	0.8951
6.5136-03	3.7000	77.1137	0.8899

Appendix C - Material Safety Data Sheets

This appendix includes the material safety data sheets for all major materials involved in the process. The MSDS forms are presented in the following order:

Butane
Water
Ethylene Glycol
Potassium Carbonate
Bunker C Fuel

MATHESON
ask. . .The Gas Professionals™

Safety Data Sheet

rial Name: N-BUTANE SDS ID: MAT

*** Section 1 - IDENTIFICATION ***

acturer Information
ESON TRI-GAS, INC.
len Road, Suite 302
g Ridge, NJ 07920

General Information: 1-800-416-2505
Emergency #: 1-800-424-9300 (CHEMTREC)
Outside the US: 703-527-3887 (Call collect)

luct Identifier: N-BUTANE

Names/Synonyms
MTG MSDS 11; BUTANE; LIQUIFIED PETROLEUM GAS; NORMAL BUTANE; BUTYL HYDRIDE; LPG; U
1011; C4H10

ical Family
hydrocarbons, aliphatic

ct Use
industrial

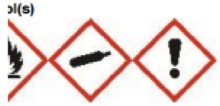
ctions on Use
None known.

*** Section 2 - HAZARDS IDENTIFICATION ***

lassification
Flammable gas, Category 1
Gas under pressure, Liquefied gas
Specific Target Organ Toxicity - Single Exposure, Category 3 (central nervous system)

ABEL ELEMENTS

ol(s)



Word
DANGER

d Statement(s)
Extremely flammable gas
Contains gas under pressure; may explode if heated
May cause drowsiness and dizziness

utionary Statement(s)

ntion
Keep away from heat, sparks, open flame, and hot surfaces - No smoking. Avoid breathing gas. Use only outdoors or in a well-ventilated area.

Safety Data Sheet

ame: N-BUTANE SDS ID:

king gas fire: Do not extinguish, unless leak can be stopped safely. Eliminate all ignition sources if
IF INHALED: Remove victim to fresh air and keep at rest in a position comfortable for breathing. C
SON CENTER or doctor/physician if you feel unwell.

re in a well-ventilated place. Protect from sunlight. Keep container tightly closed. Store locked up.

bose in accordance with all applicable regulations.

rds which do not Result in Classification
/ cause frostbite upon sudden release of liquefied gas. May cause asphyxia.

*** Section 3 - COMPOSITION / INFORMATION ON INGREDIENTS ***

	Component	Percent
	N-BUTANE	100

t Related Regulatory Information
s product may be regulated, have exposure limits or other information identified as the following: Al
rocarbon gases (Alkane [C1-C4]).

*** Section 4 - FIRST AID MEASURES ***

dverse effects occur, remove to uncontaminated area. Give artificial respiration if not breathing. If b
cult, oxygen should be administered by qualified personnel. Get immediate medical attention.

ostbite or freezing occur, immediately flush with plenty of lukewarm water (105-115 F; 41-46 C). D
T WATER. If warm water is not available, gently wrap affected parts in blankets. Get immediate me
ntion.

nediately flush eyes with plenty of water for at least 15 minutes. Then get immediate medical attent

large amount is swallowed, get medical attention.

ysicians
inhalation, consider oxygen.

Immediate
ocation, frostbite, central nervous system effects

Delayed
information on significant adverse effects.

*** Section 5 - FIRE FIGHTING MEASURES ***

Section 9 for Flammability Properties

zards Arising from the Chemical
ere explosion hazard. Severe fire hazard. Vapor/air mixtures are explosive. The vapor is heavier t
ors or gases may ignite at distant ignition sources and flash back.

ing Media
bon dioxide, regular dry chemical
ge fires: water spray or fog

Extinguishing Media
ne known.

Physical State:	Gas	**Appearance:**	colorless, gas
Color:	colorless	**Physical Form:**	gas
Odor:	unpleasant odor	**Odor Threshold:**	6.16 ppm
pH:	Not available	**Melting/Freezing Point:**	-138 °C
Boiling Point:	-1 °C	**Flash Point:**	-60 °C CC
Decomposition:	Not available	**Evaporation Rate:**	Not available
LEL:	1.9 %	**UEL:**	8.5 %
Vapor Pressure:	1557 mmHg @ 20 °C	**Henry's Law Constant:**	0.00079380 atm-m3/mol
Vapor Density (air = 1):	2.1	**Specific Gravity (water=1):**	0.5788 @ 0 °C
Water Solubility:	15 %	**Log KOW:**	2.89
KOC:	900 (estimate)	**Auto Ignition:**	287 °C
Viscosity:	Not available	**Molecular Weight:**	58.12
Molecular Formula:	C-H3-(C-H2)2-C-H3		

Solvent Solubility
Soluble: alcohol, ether, chloroform

* * *Section 10 - STABILITY AND REACTIVITY* * *

Reactivity
No reactivity hazard is expected.
Chemical Stability
Stable at normal temperatures and pressure.
Conditions to Avoid
Avoid heat, flames, sparks and other sources of ignition. Minimize contact with material. Containers may rupture or explode if exposed to heat.
Possibility of Hazardous Reactions
Will not polymerize.
Incompatible Materials
oxidizing materials
Hazardous Decomposition
Combustion: oxides of carbon

* * *Section 11 - TOXICOLOGICAL INFORMATION* * *

Acute and Chronic Toxicity
Component Analysis - LD50/LC50
The components of this material have been reviewed in various sources and the following selected endpoints are published:
N-BUTANE (106-97-8)
Inhalation LC50 Rat 658 g/m3 4 h

RTECS Acute Toxicity (selected)
The components of this material have been reviewed, and RTECS publishes the following endpoints:
N-BUTANE (106-97-8)
Inhalation: 680000 mg/m3/2 hour Inhalation Mouse LC50
658000 mg/m3/4 hour Inhalation Rat LC50
Acute Toxicity Level
N-BUTANE (106-97-8)
Non Toxic: inhalation
Immediate Effects
suffocation, frostbite, central nervous system effects
Delayed Effects
No information on significant adverse effects.
Irritation/Corrosivity Data
No animal testing data available for skin or eyes.
RTECS Irritation
The components of this material have been reviewed and RTECS publishes no data as of the date on this document.
Target Organs
N-BUTANE (106-97-8)
central nervous system
Respiratory Sensitizer
No data available.
Dermal Sensitizer
No data available.
Carcinogenicity
Component Carcinogenicity
None of this product's components are listed by ACGIH, IARC, NTP, OSHA or DFG.
RTECS Mutagenic
The components of this material have been reviewed, and RTECS publishes data for one or more components.
Reproductive Effects Data
No data available.
RTECS Tumorigenic
The components of this material have been reviewed, and RTECS publishes data for one or more components.
Specific Target Organ Toxicity - Single Exposure
central nervous system
Specific Target Organ Toxicity - Repeated Exposure
No data available.
Aspiration Hazard
Not applicable.
Medical Conditions Aggravated by Exposure
None known.
Additional Data
Stimulants such as epinephrine may induce ventricular fibrillation.

* * *Section 12 - ECOLOGICAL INFORMATION* * *

Component Analysis - Aquatic Toxicity
No LOLI ecotoxicity data are available for this product's components.

Persistence and Degradability
No data available.
Bioaccumulative Potential
Bioconcentration potential in aquatic organisms is moderate based on a BCF value of 33.
Mobility in Environmental Media
Expected to have low mobility in soil.

* * *Section 13 - DISPOSAL CONSIDERATIONS* * *

Disposal Methods
Dispose in accordance with all applicable regulations. Subject to disposal regulations: U.S. EPA 40 CFR 262. Hazardous Waste Number(s): D001.
Component Waste Numbers
The U.S. EPA has not published waste numbers for this product's components.

* * *Section 14 - TRANSPORT INFORMATION* * *

US DOT Information
Shipping Name: Butane
UN/NA #: UN1011 **Hazard Class:** 2.1
Required Label(s): 2.1

IMDG Information
Shipping Name: Butane
UN #: UN1011 **Hazard Class:** 2.1
Required Label(s): 2.1

* * *Section 15 - REGULATORY INFORMATION* * *

Component Analysis
U.S. Federal Regulations
None of this products components are listed under SARA Sections 302/304 (40 CFR 355 Appendix A), SARA Section 313 (40 CFR 372.65), CERCLA (40 CFR 302.4), TSCA 12(b), or require an OSHA process safety plan.
SARA 311/312 Hazardous Categories

Acute Health: Yes **Chronic Health:** No **Fire:** Yes **Pressure:** Yes **Reactive:** No
U.S. State Regulations
The following components appear on one or more of the following state hazardous substances lists:

Component	CAS	CA	MA	MN	NJ	PA
N-BUTANE	106-97-8	Yes	Yes	Yes	Yes	Yes

Not regulated under California Proposition 65
Component Analysis - Inventory
Listed on inventory.
Component Analysis - Inventory

Component	CAS	US	CA	EU	AU	PH	JP	KR	CN	NZ
N-BUTANE	106-97-8	Yes	DSL	EIN	Yes	Yes	Yes	Yes	Yes	Yes

* * *Section 16 - OTHER INFORMATION* * *

NFPA Ratings: Health: 1 **Fire:** 4 **Reactivity:** 0
Hazard Scale: 0 = Minimal 1 = Slight 2 = Moderate 3 = Serious 4 = Severe
Key / Legend
ACGIH - American Conference of Governmental Industrial Hygienists; ADR - European Road Transport; AU - Australia; BOD - Biochemical Oxygen Demand; C - Celsius; CA - Canada; CAS - Chemical Abstracts Service; CERCLA - Comprehensive Environmental Response, Compensation, and Liability Act; CN - China; CPR - Controlled Products Regulations; DFG - Deutsche Forschungsgemeinschaft; DOT - Department of Transportation; DSL - Domestic Substances List; EEC - European Economic Community; EINECS - European Inventory of Existing Commercial Chemical Substances; EPA - Environmental Protection Agency; EU - European Union; F - Fahrenheit; IARC - International Agency for Research on Cancer; IATA - International Air Transport Association; ICAO - International Civil Aviation Organization; IDL - Ingredient Disclosure List; IDLH - Immediately Dangerous to Life and Health; IMDG - International Maritime Dangerous Goods; JP - Japan; Kow - Octanol/water partition coefficient; KR - Korea; LEL - Lower Explosive Limit; LOLI - List Of Lists™ - ChemADVISOR's Regulatory Database; MAK - Maximum Concentration Value in the Workplace; MEL - Maximum Exposure Limits; NFPA - National Fire Protection Agency; NIOSH - National Institute for Occupational Safety and Health; NJTSR - New Jersey Trade Secret Registry; NTP - National Toxicology Program; NZ - New Zealand; OSHA - Occupational Safety and Health Administration; PH - Philippines; RCRA - Resource Conservation and Recovery Act; RID - European Rail Transport; RTECS - Registry of Toxic Effects of Chemical Substances®; SARA - Superfund Amendments and Reauthorization Act; STEL - Short-term Exposure Limit; TDG - Transportation of Dangerous Goods; TSCA - Toxic Substances Control Act; TWA - Time Weighted Average; UEL - Upper Explosive Limit; US - United States
Other Information

End of Sheet MAT15370

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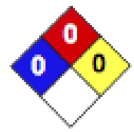

Health	0
Fire	0
Reactivity	0
Personal Protection	A

Material Safety Data Sheet
Water MSDS

Section 1: Chemical Product and Company Identification

Product Name: Water

Catalog Codes: SLW1063

CAS#: 7732-18-5

RTECS: ZC0110000

TSCA: TSCA 8(b) inventory: Water

CI#: Not available.

Synonym: Dihydrogen oxide

Chemical Name: Water

Chemical Formula: H2O

Contact Information:

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

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

Order Online: ScienceLab.com

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

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

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

Section 2: Composition and Information on Ingredients

Composition:

Name	CAS #	% by Weight
Water	7732-18-5	100

Toxicological Data on Ingredients: Not applicable.

Section 3: Hazards Identification

Potential Acute Health Effects:
Non-corrosive for skin. Non-irritant for skin. Non-sensitizer for skin. Non-permeator by skin. Non-irritating to the eyes. Non-hazardous in case of ingestion. Non-hazardous in case of inhalation. Non-irritant for lungs. Non-sensitizer for lungs. Non-corrosive to the eyes. Non-corrosive for lungs.

Potential Chronic Health Effects:
Non-corrosive for skin. Non-irritant for skin. Non-sensitizer for skin. Non-permeator by skin. Non-irritating to the eyes. Non-hazardous in case of ingestion. Non-hazardous in case of inhalation. Non-irritant for lungs. Non-sensitizer for lungs. CARCINOGENIC EFFECTS: Not available. MUTAGENIC EFFECTS: Not available. TERATOGENIC EFFECTS: Not available. DEVELOPMENTAL TOXICITY: Not available.

Section 4: First Aid Measures

Eye Contact: Not applicable.

p. 1

Skin Contact: Not applicable.

Serious Skin Contact: Not available.

Inhalation: Not applicable.

Serious Inhalation: Not available.

Ingestion: Not Applicable

Serious Ingestion: Not available.

Section 5: Fire and Explosion Data

Flammability of the Product: Non-flammable.

Auto-Ignition Temperature: Not applicable.

Flash Points: Not applicable.

Flammable Limits: Not applicable.

Products of Combustion: Not available.

Fire Hazards in Presence of Various Substances: Not applicable.

Explosion Hazards in Presence of Various Substances: Not Applicable

Fire Fighting Media and Instructions: Not applicable.

Special Remarks on Fire Hazards: Not available.

Special Remarks on Explosion Hazards: Not available.

Section 6: Accidental Release Measures

Small Spill: Mop up, or absorb with an inert dry material and place in an appropriate waste disposal container.

Large Spill: Absorb with an inert material and put the spilled material in an appropriate waste disposal.

Section 7: Handling and Storage

Precautions: No specific safety phrase has been found applicable for this product.

Storage: Not applicable.

Section 8: Exposure Controls/Personal Protection

Engineering Controls: Not Applicable

Personal Protection: Safety glasses. Lab coat.

Personal Protection in Case of a Large Spill: Not Applicable

Exposure Limits: Not available.

Section 9: Physical and Chemical Properties

Physical state and appearance: Liquid.

p. 2

Odor: Odorless.

Taste: Not available.

Molecular Weight: 18.02 g/mole

Color: Colorless.

pH (1% soln/water): 7 [Neutral.]

Boiling Point: 100°C (212°F)

Melting Point: Not available.

Critical Temperature: Not available.

Specific Gravity: 1 (Water = 1)

Vapor Pressure: 2.3 kPa (@ 20°C)

Vapor Density: 0.62 (Air = 1)

Volatility: Not available.

Odor Threshold: Not available.

Water/Oil Dist. Coeff.: Not available.

Ionicity (in Water): Not available.

Dispersion Properties: Not applicable

Solubility: Not Applicable

Section 10: Stability and Reactivity Data

Stability: The product is stable.

Instability Temperature: Not available.

Conditions of Instability: Not available.

Incompatibility with various substances: Not available.

Corrosivity: Not available.

Special Remarks on Reactivity: Not available.

Special Remarks on Corrosivity: Not available.

Polymerization: Will not occur.

Section 11: Toxicological Information

Routes of Entry: Absorbed through skin. Eye contact.

Toxicity to Animals:
LD50: [Rat] - Route: oral; Dose: > 90 ml/kg LC50: Not available.

Chronic Effects on Humans: Not available.

Other Toxic Effects on Humans:
Non-corrosive for skin. Non-irritant for skin. Non-sensitizer for skin. Non-permeator by skin. Non-hazardous in case of ingestion. Non-hazardous in case of inhalation. Non-irritant for lungs. Non-sensitizer for lungs. Non-corrosive to the eyes. Non-corrosive for lungs.

Special Remarks on Toxicity to Animals: Not available.

Special Remarks on Chronic Effects on Humans: Not available.

Special Remarks on other Toxic Effects on Humans: Not available.

Section 12: Ecological Information

Ecotoxicity: Not available.

BOD5 and COD: Not available.

Products of Biodegradation:
Possibly hazardous short term degradation products are not likely. However, long term degradation products may arise.

Toxicity of the Products of Biodegradation: The product itself and its products of degradation are not toxic.

Special Remarks on the Products of Biodegradation: Not available.

Section 13: Disposal Considerations

Waste Disposal:
Waste must be disposed of in accordance with federal, state and local environmental control regulations.

Section 14: Transport Information

DOT Classification: Not a DOT controlled material (United States).

Identification: Not applicable.

Special Provisions for Transport: Not applicable.

Section 15: Other Regulatory Information

Federal and State Regulations: TSCA 8(b) inventory: Water

Other Regulations: EINECS: This product is on the European Inventory of Existing Commercial Chemical Substances.

Other Classifications:

WHMIS (Canada): Not controlled under WHMIS (Canada).

DSCL (EEC):
This product is not classified according to the EU regulations. Not applicable.

HMIS (U.S.A.):

- **Health Hazard:** 0
- **Fire Hazard:** 0
- **Reactivity:** 0
- **Personal Protection:** a

National Fire Protection Association (U.S.A.):

- **Health:** 0
- **Flammability:** 0
- **Reactivity:** 0
- **Specific hazard:**

Protective Equipment:
Not applicable. Lab coat. Not applicable. Safety glasses.

Section 16: Other Information

References: Not available.

Other Special Considerations: Not available.

Created: 10/10/2005 08:33 PM

Last Updated: 05/21/2013 12:00 PM

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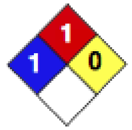

Health	1
Fire	1
Reactivity	0
Personal Protection	C

Material Safety Data Sheet
Ethylene glycol MSDS

Section 1: Chemical Product and Company Identification

Product Name: Ethylene glycol

Catalog Codes: SLE1072

CAS#: 107-21-1

RTECS: KW2975000

TSCA: TSCA 8(b) inventory: Ethylene glycol

CI#: Not available.

Synonym: 1,2-Dihydroxyethane; 1,2-Ethanediol; 1,2-Ethandiol; Ethylene dihydrate; Glycol alcohol; Monoethylene glycol; Tescol

Chemical Name: Ethylene Glycol

Chemical Formula: HOCH2CH2OH

Contact Information:

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

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

Order Online: ScienceLab.com

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

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

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

Section 2: Composition and Information on Ingredients

Composition:

Name	CAS #	% by Weight
Ethylene glycol	107-21-1	100

Toxicological Data on Ingredients: Ethylene glycol: ORAL (LD50): Acute: 4700 mg/kg [Rat]. 5500 mg/kg [Mouse]. 6610 mg/kg [Guinea pig]. VAPOR (LC50): Acute: >200 mg/m 4 hours [Rat].

Section 3: Hazards Identification

Potential Acute Health Effects:
Hazardous in case of ingestion. Slightly hazardous in case of skin contact (irritant, permeator), of eye contact (irritant), of inhalation. Severe over-exposure can result in death.

Potential Chronic Health Effects:
CARCINOGENIC EFFECTS: A4 (Not classifiable for human or animal.) by ACGIH. MUTAGENIC EFFECTS: Mutagenic for mammalian somatic cells. Non-mutagenic for bacteria and/or yeast. TERATOGENIC EFFECTS: Not available. DEVELOPMENTAL TOXICITY: Not available. The substance may be toxic to kidneys, liver, central nervous system (CNS). Repeated or prolonged exposure to the substance can produce target organs damage. Repeated exposure to a highly toxic material may produce general deterioration of health by an accumulation in one or many human organs.

Section 4: First Aid Measures

p. 1

Eye Contact:
Check for and remove any contact lenses. In case of contact, immediately flush eyes with plenty of water for at least 15 minutes. Cold water may be used. Get medical attention if irritation occurs.

Skin Contact:
Wash with soap and water. Cover the irritated skin with an emollient. Get medical attention if irritation develops. Cold water may be used.

Serious Skin Contact: Not available.

Inhalation:
If inhaled, remove to fresh air. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. Get medical attention immediately.

Serious Inhalation: Not available.

Ingestion:
Do NOT induce vomiting unless directed to do so by medical personnel. Never give anything by mouth to an unconscious person. If large quantities of this material are swallowed, call a physician immediately. Loosen tight clothing such as a collar, tie, belt or waistband.

Serious Ingestion:
Medical Conditions Aggravated by Exposure: Persons with pre-existing kidney, respiratory, eye, or neurological problems might be more sensitive to Ethylene Glycol. Notes to Physician: 1. Support vital functions, correct for dehydration and shock, and manage fluid balance. 2. The currently recommended medical management of Ethylene Glycol poisoning includes elimination of Ethylene Glycol and metabolites. Elimination of Ethylene Glycol may be achieved by the following methods: a. Emptying the stomach by gastric lavage. It is useful if initiated within < 1 of ingestion. b. Correct metabolic acidosis with intravenous administration of sodium bicarbonate, adjusting the administration rate according to repeated and frequent measurement of acid/base status. c. Administer ethanol (orally or by IV (intravenously)) or fomepizole (4-methylpyrazole or Antizol)) therapy by IV as an antidote to inhibit the ormation of toxic metabolites. d. If patients are diagnosed and treated early in the course with the above methods, hemodialysis may be avoided if fomepizole or ethanol therapy is effective and has corrected the metabolic acidosis, and no renal failure is present. However, once severe acidosis and renal failure occured, however, hemodialysis is necessary. It is effective in removing Ethylene Glycol and toxic metabolites, and correcting metabolic acidosis.

Section 5: Fire and Explosion Data

Flammability of the Product: May be combustible at high temperature.

Auto-Ignition Temperature: 398°C (748.4°F)

Flash Points: CLOSED CUP: 111°C (231.8°F). (Tagliabue.)

Flammable Limits: LOWER: 3.2%

Products of Combustion: These products are carbon oxides (CO, CO2).

Fire Hazards in Presence of Various Substances:
Slightly flammable to flammable in presence of open flames and sparks, of heat. Non-flammable in presence of shocks.

Explosion Hazards in Presence of Various Substances:
Risks of explosion of the product in presence of mechanical impact: Not available. Risks of explosion of the product in presence of static discharge: Not available.

Fire Fighting Media and Instructions:
SMALL FIRE: Use DRY chemical powder. LARGE FIRE: Use water spray, fog or foam. Do not use water jet.

Special Remarks on Fire Hazards: Not available.

Special Remarks on Explosion Hazards:
Explosive decomposition may occur if combined with strong acids or strong bases and subjected to elevated temperatures.

Section 6: Accidental Release Measures

p. 2

Small Spill:
Dilute with water and mop up, or absorb with an inert dry material and place in an appropriate waste disposal container. Finish cleaning by spreading water on the contaminated surface and dispose of according to local and regional authority requirements.

Large Spill:
Stop leak if without risk. Do not get water inside container. Do not touch spilled material. Use water spray to reduce vapors. Prevent entry into sewers, basements or confined areas; dike if needed. Eliminate all ignition sources. Call for assistance on disposal. Finish cleaning by spreading water on the contaminated surface and allow to evacuate through the sanitary system. Be careful that the product is not present at a concentration level above TLV. Check TLV on the MSDS and with local authorities.

Section 7: Handling and Storage

Precautions:
Keep away from heat. Keep away from sources of ignition. Empty containers pose a fire risk, evaporate the residue under a fume hood. Ground all equipment containing material. Do not ingest. Do not breathe gas/fumes/ vapor/spray. Wear suitable protective clothing. If ingested, seek medical advice immediately and show the container or the label. Keep away from incompatibles such as oxidizing agents, acids, alkalis.

Storage: Keep container tightly closed. Keep container in a cool, well-ventilated area. Hygroscopic

Section 8: Exposure Controls/Personal Protection

Engineering Controls:
Provide exhaust ventilation or other engineering controls to keep the airborne concentrations of vapors below their respective threshold limit value. Ensure that eyewash stations and safety showers are proximal to the work-station location.

Personal Protection:
Safety glasses. Synthetic apron. Gloves (impervious). For most conditions, no respiratory protection should be needed. However, if material is heated or sprayed and if atmospheric levels exceed exposure guidelines, use an approved vapor (air purifying) respirator.

Personal Protection in Case of a Large Spill:
Splash goggles. Full suit. Boots. Gloves. Suggested protective clothing might not be sufficient; consult a specialist BEFORE handling this product.

Exposure Limits:
STEL: 120 (mg/m3) [Australia] TWA: 100 (mg/m3) from ACGIH (TLV) [United States] CEIL: 125 (mg/m3) from OSHA (PEL) [United States] CEIL: 50 (ppm) from OSHA (PEL) [United States] TWA: 52 STEL: 104 (mg/m3) [United Kingdom (UK)] Inhalation TWA: 10 (mg/m3) [United Kingdom (UK)] SKIN3 Consult local authorities for acceptable exposure limits.

Section 9: Physical and Chemical Properties

Physical state and appearance: Liquid. (syrupy)

Odor: Odorless.

Taste: Mild sweet

Molecular Weight: 62.07 g/mole

Color: Clear Colorless.

pH (1% soln/water): Not available.

Boiling Point: 197.6°C (387.7°F)

Melting Point: -13°C (8.6°F)

Critical Temperature: Not available.

Specific Gravity: 1.1088 (Water = 1)

Vapor Pressure: .06 mmHg @ 20 C; .092 mmHg at 25 C

Vapor Density: 2.14 (Air = 1)

Volatility: Not available.

Odor Threshold: Not available.

Water/Oil Dist. Coeff.: The product is more soluble in water; log(oil/water) = -1.4

Ionicity (in Water): Not available.

Dispersion Properties: See solubility in water, acetone.

Solubility:
Soluble in cold water, hot water, acetone. Slightly soluble in diethyl ether. Miscible with lower aliphatic alcohols, glycerol, acetic acid, acetone and similar ketones, aldehydes, pyridine, similar coal tar bases. Practically insoluble in benzene and its homologs, chlorinated hydrocarbons, petroleum ether.

Section 10: Stability and Reactivity Data

Stability: The product is stable.

Instability Temperature: Not available.

Conditions of Instability: Excess heat, incompatible materials.

Incompatibility with various substances: Reactive with oxidizing agents, acids, alkalis.

Corrosivity: Non-corrosive in presence of glass.

Special Remarks on Reactivity:
Hygroscopic. Absorbs moisture from the air. Avoid contamination with materials with hydroxyl compounds. Also incompatible with aliphatic amines, isocyanates, chlorosulfonic acid, and oleum

Special Remarks on Corrosivity: Not available.

Polymerization: Will not occur.

Section 11: Toxicological Information

Routes of Entry: Absorbed through skin. Ingestion.

Toxicity to Animals:
Acute oral toxicity (LD50): 4700 mg/kg [Rat]. Acute toxicity of the vapor (LC50): >200 mg/m3 4 hours [Rat].

Chronic Effects on Humans:
CARCINOGENIC EFFECTS: A4 (Not classifiable for human or animal.) by ACGIH. MUTAGENIC EFFECTS: Mutagenic for mammalian somatic cells. Non-mutagenic for bacteria and/or yeast. May cause damage to the following organs: kidneys, liver, central nervous system (CNS).

Other Toxic Effects on Humans:
Hazardous in case of ingestion. Slightly hazardous in case of skin contact (irritant, permeator), of inhalation.

Special Remarks on Toxicity to Animals:
Lowest Published Toxic Dose/Conc: TDL [Man] - Route: oral; Dose: 15gm/kg Lethal Dose/Conc 50% Kill LD50 [Rabbit] - Route: dermal; Dose: 9530 ul/kg

Special Remarks on Chronic Effects on Humans:
May cause adverse reproductive effects and birth defects (teratogenic) based on animal test data. No human data has been reported at this time. May affect genetic material (mutagenic)

Special Remarks on other Toxic Effects on Humans:
Acute Potential Health Effects: Skin: May cause skin irritation. May cause more severe response if skin is abraded. A single prolonged exposure is not likely to result in material being absorbed through skin in harmful amounts. Massive contact with damaged skin may result in absorption of potentially harmful amounts Eyes: Vapors or mist may cause temporary eye irritation (mild temporary conjunctival inflammation) and lacrimation. Corneal injury is unlikely or insignificant.. Ingestion: It is rapidly absorbed from the gastrointestinal tract. Oral toxicity is expected to be moderate in humans due to Ethylene Glycol even though tests with animals show a lower degree of toxicity. Excessive exposure (swallowing large amounts) may cause gastrointestinal tract irritation with nausea, vomiting, abdominal discomfort, diarrhea. It can affect behavior/central nervous system within 0.5 to 12 hours after ingestion. A transient inebriation with excitement, stupor, headache, slurred speech, ataxia, somnolence, and euphoria, similar to ethanol intoxication, can occur within the first several hours. As sthe Ethylene Glycol is metabolized, metabolic acidosis and further central nervous system depression (convulsions, muscle weakness) develop. Serious intoxication may develop to coma associated with hypotonia, hyporeflexia, and less commonly seizures, and meningismus. 12 to 24 hours

Section 12: Ecological Information

Ecotoxicity:
Ecotoxicity in water (LC50): 41000 mg/l 96 hours [Fish (Trout)]. 46300 mg/l 48 hours [water flea]. 34250 mg/l 96 hours [Fish (bluegill fish)]. 34250 mg/l 72 hours [Fish (Goldfish)].

BOD5 and COD: Not available.

Products of Biodegradation:
Possibly hazardous short term degradation products are not likely. However, long term degradation products may arise.

Toxicity of the Products of Biodegradation: The products of degradation are less toxic than the product itself.

Special Remarks on the Products of Biodegradation: Not available.

Section 13: Disposal Considerations

Waste Disposal:
Waste must be disposed of in accordance with federal, state and local environmental control regulations.

Section 14: Transport Information

DOT Classification: Not a DOT controlled material (United States).

Identification: Not applicable.

Special Provisions for Transport: Not applicable.

Section 15: Other Regulatory Information

Federal and State Regulations:
Illinois toxic substances disclosure to employee act: Ethylene glycol Illinois chemical safety act: Ethylene glycol New York release reporting list: Ethylene glycol Rhode Island RTK hazardous substances: Ethylene glycol Pennsylvania RTK: Ethylene glycol Minnesota: Ethylene glycol Massachusetts RTK: Ethylene glycol Massachusetts spill list: Ethylene glycol New Jersey: Ethylene glycol Louisiana spill reporting: Ethylene glycol TSCA 8(b) inventory: Ethylene glycol TSCA 4(a) proposed test rules: Ethylene glycol SARA 313 toxic chemical notification and release reporting: Ethylene glycol CERCLA: Hazardous substances.: Ethylene glycol: 5000 lbs. (2268 kg)

Other Regulations:
OSHA: Hazardous by definition of Hazard Communication Standard (29 CFR 1910.1200). EINECS: This product is on the European Inventory of Existing Commercial Chemical Substances.

Other Classifications:

WHMIS (Canada): CLASS D-2A: Material causing other toxic effects (VERY TOXIC).

DSCL (EEC):
R22- Harmful if swallowed. S46- If swallowed, seek medical advice immediately and show this container or label.

HMIS (U.S.A.):

Health Hazard: 1

Fire Hazard: 1

Reactivity: 0

Personal Protection: C

National Fire Protection Association (U.S.A.):

Health: 1

Flammability: 1

Reactivity: 0

Specific hazard:

Protective Equipment:
Gloves. Lab coat. Not applicable. Safety glasses.

Section 16: Other Information

References: Not available.

Other Special Considerations: Not available.

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Last Updated: 05/21/2013 12:00 PM

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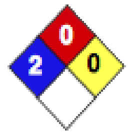


Health	2
Fire	0
Reactivity	1
Personal Protection	E

Material Safety Data Sheet
Potassium carbonate, anhydrous MSDS

Section 1: Chemical Product and Company Identification

Product Name: Potassium carbonate, anhydrous

Catalog Codes: SLP4780, SLP1951, SLP3760, SLP5575

CAS#: 584-08-7

RTECS: TS7750000

TSCA: TSCA 8(b) inventory: Potassium carbonate, anhydrous

CI#: Not available.

Synonym: Salt of Tartar

Chemical Name: Potassium Carbonate

Chemical Formula: K2CO3

Contact Information:

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

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

Order Online: ScienceLab.com

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

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

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

Section 2: Composition and Information on Ingredients

Composition:

Name	CAS #	% by Weight
Potassium carbonate, anhydrous	584-08-7	100

Toxicological Data on Ingredients: Potassium carbonate, anhydrous: ORAL (LD50): Acute: 1870 mg/kg [Rat].

Section 3: Hazards Identification

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

Potential Chronic Health Effects:
CARCINOGENIC EFFECTS: Not available. MUTAGENIC EFFECTS: Not available. TERATOGENIC EFFECTS: Not available. DEVELOPMENTAL TOXICITY: Not available. The substance is toxic to mucous membranes. The substance may be toxic to skin, eyes. Repeated or prolonged exposure to the substance can produce target organs damage.

Section 4: First Aid Measures

Eye Contact:

p. 1

Check for and remove any contact lenses. In case of contact, immediately flush eyes with plenty of water for at least 15 minutes. Cold water may be used. Get medical attention immediately.

Skin Contact:
In case of contact, immediately flush skin with plenty of water. Cover the irritated skin with an emollient. Remove contaminated clothing and shoes. Cold water may be used.Wash clothing before reuse. Thoroughly clean shoes before reuse. Get medical attention.

Serious Skin Contact:
Wash with a disinfectant soap and cover the contaminated skin with an anti-bacterial cream. Seek immediate medical attention.

Inhalation:
If inhaled, remove to fresh air. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. Get medical attention.

Serious Inhalation: Not available.

Ingestion:
Do NOT induce vomiting unless directed to do so by medical personnel. Never give anything by mouth to an unconscious person. If large quantities of this material are swallowed, call a physician immediately. Loosen tight clothing such as a collar, tie, belt or waistband.

Serious Ingestion: Not available.

Section 5: Fire and Explosion Data

Flammability of the Product: Non-flammable.

Auto-Ignition Temperature: Not applicable.

Flash Points: Not applicable.

Flammable Limits: Not applicable.

Products of Combustion: Not available.

Fire Hazards in Presence of Various Substances: Not applicable.

Explosion Hazards in Presence of Various Substances:
Risks of explosion of the product in presence of mechanical impact: Not available. Risks of explosion of the product in presence of static discharge: Not available.

Fire Fighting Media and Instructions: Not applicable.

Special Remarks on Fire Hazards: Not available.

Special Remarks on Explosion Hazards: Not available.

Section 6: Accidental Release Measures

Small Spill:
Use appropriate tools to put the spilled solid in a convenient waste disposal container. Finish cleaning by spreading water on the contaminated surface and dispose of according to local and regional authority requirements.

Large Spill:
Use a shovel to put the material into a convenient waste disposal container. Finish cleaning by spreading water on the contaminated surface and allow to evacuate through the sanitary system.

Section 7: Handling and Storage

Precautions:

p. 2

Keep container dry. Do not ingest. Do not breathe dust. Never add water to this product. In case of insufficient ventilation, wear suitable respiratory equipment. If ingested, seek medical advice immediately and show the container or the label. Avoid contact with skin and eyes. Keep away from incompatibles such as oxidizing agents, metals, acids.

Storage:
Hygroscopic. Keep container tightly closed. Keep container in a cool, well-ventilated area. Do not store above 25°C (77°F).

Section 8: Exposure Controls/Personal Protection

Engineering Controls:
Use process enclosures, local exhaust ventilation, or other engineering controls to keep airborne levels below recommended exposure limits. If user operations generate dust, fume or mist, use ventilation to keep exposure to airborne contaminants below the exposure limit.

Personal Protection:
Splash goggles. Lab coat. Dust respirator. Be sure to use an approved/certified respirator or equivalent. Gloves.

Personal Protection in Case of a Large Spill:
Splash goggles. Full suit. Dust respirator. Boots. Gloves. A self contained breathing apparatus should be used to avoid inhalation of the product. Suggested protective clothing might not be sufficient; consult a specialist BEFORE handling this product.

Exposure Limits: Not available.

Section 9: Physical and Chemical Properties

Physical state and appearance: Solid. (Powdered solid. Deliquescent solid.)

Odor: Odorless.

Taste: Not available.

Molecular Weight: 138.21 g/mole

Color: White.

pH (1% soln/water): Not available.

Boiling Point: Decomposes.

Melting Point: 891°C (1635.8°F)

Critical Temperature: Not available.

Specific Gravity: 2.29 (Water = 1)

Vapor Pressure: Not applicable.

Vapor Density: Not available.

Volatility: Not available.

Odor Threshold: Not available.

Water/Oil Dist. Coeff.: Not available.

Ionicity (in Water): Not available.

Dispersion Properties: See solubility in water.

Solubility: Soluble in cold water.

Section 10: Stability and Reactivity Data

Stability: The product is stable.

Instability Temperature: Not available.

Conditions of Instability: Dust generation, moist air, water, incompatible materials

Incompatibility with various substances:
Reactive with oxidizing agents, metals, acids. Slightly reactive to reactive with moisture.

Corrosivity: Non-corrosive in presence of glass.

Special Remarks on Reactivity:
Hygroscopic. Reacts with water to evolve heat. Incompatible with KCO, chlorine trifluoride, calcium oxide, and magnesium.

Special Remarks on Corrosivity: Not available.

Polymerization: Will not occur.

Section 11: Toxicological Information

Routes of Entry: Eye contact. Inhalation. Ingestion.

Toxicity to Animals: Acute oral toxicity (LD50): 1870 mg/kg [Rat].

Chronic Effects on Humans:
Causes damage to the following organs: mucous membranes. May cause damage to the following organs: skin, eyes.

Other Toxic Effects on Humans:
Hazardous in case of skin contact (irritant), of ingestion, of inhalation. Slightly hazardous in case of eye contact (corrosive).

Special Remarks on Toxicity to Animals: Not available.

Special Remarks on Chronic Effects on Humans: Not available.

Special Remarks on other Toxic Effects on Humans:
Acute Potential Health Effects: Skin: Causes severe skin irritation. Eyes: It is severely irritating to the eyes and its mucous membranes. It may cause corneal injury. It may cause burns and loss of vision. It may cause permanent damage. The amount of tissue damage depends on the length of contact. Ingestion: It causes gastrointestinal irritation with nausea, vomiting, abdominal pain, swollen glottis, increased respiration, and possible burns to the lips, tongue, oral mucosa, hypopharynx, stomach, or esophagus. It may affect the cardiovascular system(circulatory collapse), urinary system, and metabolism. Inhalation: Causes respiratory tract and mucous membrane irritation. Exposure can cause coughing, chest pains, and difficulty breathing (dyspnea).

Section 12: Ecological Information

Ecotoxicity: Not available.

BOD5 and COD: Not available.

Products of Biodegradation:
Possibly hazardous short term degradation products are not likely. However, long term degradation products may arise.

Toxicity of the Products of Biodegradation: The products of degradation are less toxic than the product itself.

Special Remarks on the Products of Biodegradation: Not available.

Section 13: Disposal Considerations

Waste Disposal:
Waste must be disposed of in accordance with federal, state and local environmental control regulations.

Section 14: Transport Information

DOT Classification: Not a DOT controlled material (United States).

Identification: Not applicable.

Special Provisions for Transport: Not applicable.

Section 15: Other Regulatory Information

Federal and State Regulations: TSCA 8(b) inventory: Potassium carbonate, anhydrous

Other Regulations:
OSHA: Hazardous by definition of Hazard Communication Standard (29 CFR 1910.1200). EINECS: This product is on the European Inventory of Existing Commercial Chemical Substances.

Other Classifications:

WHMIS (Canada):
CLASS D-2B: Material causing other toxic effects (TOXIC). CLASS E: Corrosive solid.

DSCL (EEC):
R22- Harmful if swallowed. R37/38- Irritating to respiratory system and skin. R41- Risk of serious damage to eyes. S2- Keep out of the reach of children. S26- In case of contact with eyes, rinse immediately with plenty of water and seek medical advice. S37/39- Wear suitable gloves and eye/face protection. S46- If swallowed, seek medical advice immediately and show this container or label.

HMIS (U.S.A.):

Health Hazard: 2

Fire Hazard: 0

Reactivity: 1

Personal Protection: E

National Fire Protection Association (U.S.A.):

Health: 2

Flammability: 0

Reactivity: 0

Specific hazard:

Protective Equipment:
Gloves. Lab coat. Dust respirator. Be sure to use an approved/certified respirator or equivalent. Wear appropriate respirator when ventilation is inadequate. Splash goggles.

Section 16: Other Information

References: Not available.

Other Special Considerations: Not available.

Created: 10/10/2005 11:40 AM

Last Updated: 05/21/2013 12:00 PM

Material Safety Data Sheet
Fuel Oil

NFPA:

TESORO

SECTION 1. PRODUCT AND COMPANY IDENTIFICATION

Product name	:	Fuel Oil
Synonyms	:	Bunkers, Black Fuel Oil, MFO, Industrial Fuel Oil, 6 Oil, Slurry Fuel Oil, RFO, Refinery Fuel Oil, High Sulfur Fuel Oil, HSFO, IFO-30, IFO-180, IFO-380, IFO-510, IFO-700, Bunker C, Bunker Fuel Oil, Marine Fuel Oil, Decant Oil, Utility Fuel Oil, LSFO, Six Oil, 888100008793
SDS Number	:	888100008793 **Version** : 1.20
Product Use Description	:	Fuel, Intermediate Stream
Company	:	For: Tesoro Refining & Marketing Co. 19100 Ridgewood Parkway, San Antonio, TX 78259
Tesoro Call Center	:	(877) 783-7676 **Chemtrec (Emergency Contact)** : (800) 424-9300

SECTION 2. HAZARDS IDENTIFICATION

Classifications

Flammable Liquid – Category 4
Carcinogenicity – Category 1B
Toxic to Reproduction – Category 1B
Specific Target Organ Toxicity (Repeated Exposure) – Category 2
Acute Toxicity – Inhalation – Category 4
Acute Aquatic Toxicity– Category 3

Pictograms

Signal Word DANGER

Hazard Statements

Combustible liquid.
May cause cancer from prolonged and repeated skin contact.
May damage fertility or the unborn child.
May cause damage to liver, kidney and nervous system through prolonged or repeated exposure.
Harmful if inhaled.
Harmful to aquatic life
Skin and eye irritant.
May contain and release toxic hydrogen sulfide (H2S) gas.

Precautionary Statements

Prevention

Obtain special instructions before use.
Do not handle until all safety precautions have been read and understood.
Keep away from flames and hot surfaces. No smoking.
Wear gloves, eye protection and face protection as needed to prevent skin and eye contact with liquid.
Wash hands or liquid-contacted skin thoroughly after handling.
Do not eat, drink or smoke when using this product.
Do not breathe vapors or mists.
Use only outdoors or in a well-ventilated area

Response

In case of fire: Use dry chemical, CO2, water spray or fire fighting foam to extinguish.
Get medical advice or attention if you feel unwell, are exposed, or become concerned.
If on skin (or hair): Take off immediately all contaminated clothing. Rinse skin with water or shower.
If in eye: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing.
If skin or eye irritation persists, get medical attention.
If inhaled: Remove person to fresh air and keep comfortable for breathing.
Immediately call or doctor or emergency medical provider

Storage

Store in a well ventilated place. Keep cool. Store locked up. Keep container tightly closed . Use only approved containers.

Disposal

Dispose of contents/containers to approved disposal site in accordance with local, regional, national, and/or international regulations.

SECTION 3. COMPOSITION/INFORMATION ON INGREDIENTS

Component	CAS-No.	Weight %
Clarified oils (petroleum), catalytic cracked; Heavy Fuel oil	64741-62-4	100%
Polycyclic aromatic compounds (PACs or PNAs)		Typically 1.5%
Benzo[a]pyrene; Benzo[def]chrysene	50-32-8	Trace to 0.2%
Hydrogen Sulfide	7783-06-4	Trace to 0.2%
Sulfur (for waters within 25 miles of California shores)	17704-34-9	Trace to 0.1%
Sulfur (for waters within 200 miles of American shores)	17704-34-9	Trace to 1.0%
Sulfur (for international waters)	17704-34-9	Trace to 3.5%

SECTION 4. FIRST AID MEASURES

Inhalation	:	Move to fresh air. Give oxygen. If breathing is irregular or stopped, administer artificial respiration. Seek medical attention immediately.
Skin contact	:	Take off all contaminated clothing immediately. Wash off immediately with soap

and plenty of water. Wash contaminated clothing before re-use. If skin irritation persists, call a physician.

Eye contact : Remove contact lenses. Rinse immediately with plenty of water, also under the eyelids, for at least 15 minutes. If eye irritation persists, consult a specialist.

Ingestion : Do NOT induce vomiting. Do not give liquids. Seek medical attention immediately. If vomiting does occur naturally, keep head below the hips to reduce the risks of aspiration. Monitor for breathing difficulties. Small amounts of material which enter the mouth should be rinsed out until the taste is dissipated.

Notes to physician : Symptoms: Dizziness, Discomfort, Headache, Nausea, Disorder, Vomiting, Liver disorders, Kidney disorders, Aspiration may cause pulmonary edema and pneumonitis.

SECTION 5. FIRE-FIGHTING MEASURES

Suitable extinguishing media : Carbon dioxide (CO2), Water spray, Dry chemical, Foam, Keep containers and surroundings cool with water spray.

Specific hazards during fire fighting : Isolate area around container involved in fire. Cool tanks, shells, and containers exposed to fire and excessive heat with water. For massive fires the use of unmanned hose holders or monitor nozzles may be advantageous to further minimize personnel exposure. Major fires may require withdrawal, allowing the tank to burn. Large storage tank fires typically require specially trained personnel and equipment to extinguish the fire, often including the need for properly applied fire fighting foam.

Special protective equipment for fire-fighters : Firefighting activities that may result in potential exposure to high heat, smoke or toxic by-products of combustion should require NIOSH/MSHA- approved pressure-demand self-contained breathing apparatus with full facepiece and full protective clothing.

Further information : Flammable vapor production at ambient temperature in the open is expected to be minimal, as the material is generally wet. However, depending on oil content and conditions, it is possible flammable vapors could accumulate in the headspace of storage containers, presenting a flammability and explosion hazard. Being heavier than air, vapors may travel long distances to an ignition source and flash back. Runoff to sewer may cause fire or explosion hazard.

SECTION 6. ACCIDENTAL RELEASE MEASURES

Personal precautions : Evacuate nonessential personnel and remove or secure all ignition sources. Consider wind direction; stay upwind and uphill, if possible. Evaluate the direction of product travel, diking, sewers, etc. to contain spill areas.

Environmental precautions : Carefully contain and stop the source of the spill, if safe to do so. Protect bodies of water by diking, absorbents, or absorbent boom, if possible. Do not flush down sewer or drainage systems, unless system is designed and permitted to handle such material.

Methods for cleaning up : Take up with sand or oil absorbing materials. Carefully vacuum, shovel, scoop or sweep up into a waste container for reclamation or disposal.

SECTION 7. HANDLING AND STORAGE

Precautions for safe handling : Keep away from fire, sparks and heated surfaces. No smoking near areas where

material is stored or handled. The product should only be stored and handled in areas with intrinsically safe electrical classification.

Hydrocarbon liquids including this product can act as a non-conductive flammable liquid (or static accumulators), and may form ignitable vapor-air mixtures in storage tanks or other containers. Precautions to prevent static-initated fire or explosion during transfer, storage or handling, include but are not limited to these examples:

(1) Ground and bond containers during product transfers. Grounding and bonding may not be adequate protection to prevent ignition or explosion of hydrocarbon liquids and vapors that are static accumulators.
(2) Special slow load procedures for "switch loading" must be followed to avoid the static ignition hazard that can exist when higher flash point material (such as fuel oil or diesel) is loaded into tanks previously containing low flash point products (such gasoline or naphtha).
(3) Storage tank level floats must be effectively bonded.

For more information on precautions to prevent static-initated fire or explosion, see NFPA 77, Recommended Practice on Static Electricity (2007), and API Recommended Practice 2003, Protection Against Ignitions Arising Out of Static, Lightning, and Stray Currents (2008).

Conditions for storage, including any incompatabilities : Keep away from flame, sparks, excessive temperatures and open flame. Use approved containers. Keep containers closed and clearly labeled. Empty or partially full product containers or vessels may contain explosive vapors. Do not pressurize, cut, heat, weld or expose containers to sources of ignition. Store in a well-ventilated area. The storage area should comply with NFPA 30 "Flammable and Combustible Liquid Code". The cleaning of tanks previously containing this product should follow API Recommended Practice (RP) 2013 "Cleaning Mobile Tanks In Flammable and Combustible Liquid Service" and API RP 2015 "Cleaning Petroleum Storage Tanks".

Hydrogen sulfide may accumulate in tanks and bulk transport compartments. Consider appropriate respiratory protection (see Section 8). Stand upwind. Avoid vapors when opening hatches and dome covers. Confined spaces should be ventilated and gas tested prior to entry.

Keep away from food, drink and animal feed. Incompatible with oxidizing agents. Incompatible with acids.

No decomposition if stored and applied as directed.

SECTION 8. EXPOSURE CONTROLS / PERSONAL PROTECTION

Exposure Guidelines

List	Components	CAS-No.	Type:	Value
OSHA	Polycyclic aromatic compounds (or coal tar pitch volatiles – benzene soluble)		PEL	0.2 mg/m3
	Clarified oils (petroleum), catalytic cracked; Heavy Fuel oil	64741-62-4	PEL	5 mg/m3 (as mineral oil mist)
	Hydrogen Sulfide	7783-06-4	STEL	20 ppm
ACGIH	Hydrogen Sulfide	7783-06-4	TWA	1 ppm
		7783-06-4	STEL	5 ppm

	Clarified oils (petroleum), catalytic cracked; Heavy Fuel oil	64741-62-4	TWA	0.2 mg/m3 (as mineral oil) Sum of 15 NTP-listed polynuclear aromatic hydrocarbons 0.005 mg/m3
	Polycyclic aromatic compounds (or coal tar pitch volatiles – benzene soluble)		TWA	0.2 mg/m3

Engineering measures : Use adequate ventilation to keep gas and vapor concentrations of this product below occupational exposure and flammability limits, particularly in confined spaces.

Eye protection : Safety glasses or goggles are recommended where there is a possibility of splashing or spraying.

Hand protection : Gloves constructed of nitrile, neoprene, or PVC are recommended.

Skin and body protection : Chemical protective clothing such as DuPont Tyvek QC, TyChem® or equivalent, recommended based on degree of exposure. The resistance of specific material may vary from product to product as well as with degree of exposure.

Respiratory protection : If hydrogen sulfide concentration may exceed permissible exposure limit, a positive-pressure SCBA or Type C supplied air respirator with escape bottle is required as respiratory protection. If hydrogen sulfide concentration is below H2S permissible exposure limit a NIOSH/ MSHA-approved air-purifying respirator with acid gas cartridges may be acceptable for odor control, but continuous air monitoring for H2S is recommended. Protection provided by air-purifying respirators is limited. Use a NIOSH/ MSHA-approved positive-pressure supplied-air respirator if there is a potential for uncontrolled release, exposure levels are not known, in oxygen-deficient atmospheres, or any other circumstance where an air-purifying respirator may not provide adequate protection. Refer to OSHA 29 CFR 1910.134, ANSI Z88.2-1992, NIOSH Respirator Decision Logic, and the manufacturer for additional guidance on respiratory protection selection.

Work / Hygiene practices : Emergency eye wash capability should be available in the near proximity to operations presenting a potential splash exposure. Use good personal hygiene practices. Avoid repeated and/or prolonged skin exposure. Wash hands before eating, drinking, smoking, or using toilet facilities. Do not use as a cleaning solvent on the skin. Do not use solvents or harsh abrasive skin cleaners for washing this product from exposed skin areas. Waterless hand cleaners are effective. Promptly remove contaminated clothing and launder before reuse. Use care when laundering to prevent the formation of flammable vapors which could ignite via washer or dryer. Consider the need to discard contaminated leather shoes and gloves.

SECTION 9. PHYSICAL AND CHEMICAL PROPERTIES

Appearance	Dark green to brown or black liquid
Odor	Petroleum asphalt odor

Odor threshold	No data available
pH	Not applicable
Melting point/freezing point	32° - 80°C (89.6° - 176°F)
Initial boiling point & range	154 - 372 °C (310° - 702 °F)
Flash point	60°C (140°F) minimum
Evaporation rate	Higher initially and declining as lighter components evaporate
Flammability (solid, gas)	Flammable vapor released by heated liquid
Upper explosive limit	No data available
Lower explosive limit	No data available
Vapor pressure	210 Pa at 25°C
Vapor density (air = 1)	>5
Relative density (water = 1)	>0.9 to 1.2 g/mL
Solubility (in water)	6 to 1400 mg/L at 25°C
Partition coefficient (n-octanol/water)	3.4 to 5 as log Pow at 25°C
Auto-ignition temperature	>176°C (>350 °F)
Decomposition temperature	Will evaporate or boil and possibly ignite before decomposition occurs.
Kinematic viscosity	>300 cST typical at 40°C

SECTION 10. STABILITY AND REACTIVITY

Reactivity : Vapors may form explosive mixtures with air. Hazardous polymerization does not occur.

Chemical Stability Stable under normal conditions.

Possibility of hazardous reactions Can react with strong oxidizing agents and peroxides. Keep away from strong acids and bases.

Conditions to avoid Avoid high temperatures, open flames, sparks, welding, smoking and other ignition sources. Keep away from strong oxidizers.

Hazardous decomposition products Carbon monoxide, carbon dioxide and noncombusted hydrocarbons (smoke).

SECTION 11. TOXICOLOGICAL INFORMATION

Inhalation : Because of its low vapor pressure, this product presents a minimal inhalation hazard at ambient temperature. Upon heating, fumes may be evolved. Inhalation of fumes or mist may result in respiratory tract irritation and central nervous system (brain) effects may include headache, dizziness, loss of balance and coordination, unconsciousness, coma, respiratory failure, and death. The burning of any hydrocarbon as a fuel in an area without adequate ventilation may result in hazardous levels of combustion products, including carbon monoxide, and inadequate oxygen levels, which may cause unconsciousness, suffocation, and death. Irritating and toxic hydrogen sulfide gas may be present. Greater than 15 - 20 ppm continuous exposure can cause mucous membrane and respiratory tract irritation. 50 - 500 ppm can cause headache, nausea, and dizziness. Continued exposure at these levels can lead to loss of reasoning and balance, difficulty in breathing, fluid in the lungs, and possible loss of consciousness. Greater than 500 ppm can cause rapid unconsciousness due to respiratory paralysis and death by suffocation unless the victim is removed from exposure and successfully resuscitated. Greater than 1000 ppm can cause immediate unconsciousness and death if not promptly revived. After-effects from overexposure are not anticipated except what would be expected if the victim was without oxygen for more than 3 to 5 minutes (asphyxiation). The "rotten egg" odor of hydrogen sulfide is not a reliable indicator for warning of exposure, since olfactory fatigue (loss of smell) readily occurs, especially at concentrations above 50 ppm. At high concentrations, the victim may not even recognize the odor before becoming unconscious.

Skin irritation — May cause skin irritation with prolonged or repeated contact. Practically non-toxic if absorbed following acute (single) exposure. Exposure may cause a phototoxicity reaction: liquid or mist on the skin may produce a painful sunburn reaction when exposed to sunlight. Product may be hot which could cause 1st, 2nd, or 3rd degree thermal burns.

Eye irritation — May cause irritation, experienced as mild discomfort and seen as slight excess redness of the eye.

Ingestion — This material has a low order of acute toxicity. If large quantities are ingested, nausea, vomiting and diarrhea may result. Ingestion may also cause effects similar to inhalation of the product. Could present an aspiration hazard if liquid is inhaled into lungs, particularly from vomiting after ingestion. Aspiration may result in chemical pneumonia, severe lung damage, respiratory failure and even death.

Further information — This material contains polynuclear aromatic hydrocarbons (PNAs), some of which are animal carcinogens. Studies have shown that similar products produce skin cancer or skin tumors in laboratory animals following repeated applications without washing or removal. The significance of this finding to human exposure has not been determined. Other studies with active skin carcinogens have shown that washing the animal's skin with soap and water between applications reduced tumor formation. The presence of carcinogenic PNAs indicates that precautions should be taken to minimize repeated and prolonged inhalation of fumes or mists. Dermal application of gas oil to rats resulted in limited evidence of liver damage (i.e., increased liver weight and changes in hepatic serum enzyme activity) and bone marrow toxicity (hypoplasia and decreased hemoglobin.) Petroleum industry experience indicates that a program providing for good personal hygiene, proper use of personal protective equipment, and minimizing the repeated and prolonged exposure to liquids and fumes, is effective in reducing or eliminating the carcinogenic risk of high boiling aromatic oils (polynuclear aromatic hydrocarbons) to humans.
Liver and kidney injuries may occur.
Components of the product may affect the nervous system.

Component:

Clarified oils (petroleum), catalytic cracked; Heavy Fuel oil	64741-62-4	Acute oral toxicity: LD50 rat Dose: 4,320 mg/kg Acute dermal toxicity: LD50 rabbit Dose: 2,001 mg/kg Skin irritation: Classification: Irritating to skin. Result: Mild skin irritation Eye irritation: Classification: Irritating to eyes. Result: Mild eye irritation

Carcinogenicity: Animal experiments showed a statistically significant number of tumors.

Carcinogenicity

NTP	Benzo[a]pyrene; Benzo[def]chrysene (CAS-No.: 50-32-8)
IARC	Benzo[a]pyrene; Benzo[def]chrysene (CAS-No.: 50-32-8)
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.
CA Prop 65	WARNING! This product contains a chemical known to the State of California to cause cancer. Benzo[a]pyrene; Benzo[def]chrysene (CAS-No.: 50-32-8)

SECTION 12. ECOLOGICAL INFORMATION

Additional ecological information : Keep out of sewers, drainage areas, and waterways. Report spills and releases, as applicable, under Federal and State regulations.

SECTION 13. DISPOSAL CONSIDERATIONS

Disposal : Consult federal, state and local waste regulations to determine appropriate waste characterization of material and allowable disposal methods.

SECTION 14. TRANSPORT INFORMATION

CFR

Proper shipping name	: Not regulated if shipped below 140°F (60°C) Elevated temperature liquid, flammable (if shipped above 140°F (60°C)).
UN-No.	: Not regulated if shipped below 140°F (60°C) 3256 if shipped above 140°F (60°C)
Class	: 9
Packing group	: III
Hazard inducer	: (Clarified oils (petroleum), catalytic cracked; Heavy Fuel oil)

TDG

Proper shipping name	: Not regulated if shipped below 140°F (60°C) Elevated temperature liquid, flammable (if shipped above 140°F (60°C)).
UN-No.	: Not regulated if shipped below 140°F (60°C) 3256 if shipped above 140°F (60°C)
Class	: 9
Packing group	: III
Hazard inducer	: (Clarified oils (petroleum), catalytic cracked; Heavy Fuel oil)

IATA Cargo Transport

UN-No.	: Not regulated if shipped below 140°F (60°C) 3256 if shipped above 140°F (60°C)
Class	: Not regulated if shipped below 140°F (60°c) Not permitted for transport (at 140°F (60°C) or higher temperature) 9

IATA Passenger Transport

UN-No.	:	Not regulated if shipped below 140°F (60°C) 3256 if shipped above 140°F (60°C)
Class	:	Not regulated if shipped below 140°F (60°c) Not permitted for transport (at 140°F (60°C) or higher temperature) 9

IMDG-Code

UN-No.	:	Not regulated if shipped below 140°F (60°C) 3256 if shipped above 140°F (60°C)
Description of the goods	:	Elevated temperature liquid, n.o.s. (Clarified oils (petroleum), catalytic cracked; Heavy Fuel oil)
Class	:	Not regulated if shipped below 140°F (60°c) Not permitted for transport (at 140°F (60°C) or higher temperature) 9
Packaging group	:	III
IMDG-Labels	:	9
EmS Number	:	F-A S-P
Marine pollutant	:	No

SECTION 15. REGULATORY INFORMATION

CERCLA SECTION 103 and SARA SECTION 304 (RELEASE TO THE ENVIROMENT)
The CERCLA definition of hazardous substances contains a "petroleum exclusion" clause which exempts crude oil. Fractions of crude oil, and products (both finished and intermediate) from the crude oil refining process and any indigenous components of such from the CERCLA Section 103 reporting requirements. However, other federal reporting requirements, including SARA Section 304, as well as the Clean Water Act may still apply.

TSCA Status	:	On TSCA Inventory
DSL Status	:	All components of this product are on the Canadian DSL list.
SARA 311/312 Hazards	:	Fire Hazard Acute Health Hazard Chronic Health Hazard

SARA III — US. EPA Emergency Planning and Community Right-To-Know Act (EPCRA) SARA Title III Section 313 Toxic Chemicals (40 CFR 372.65) - Supplier Notification Required

Components	CAS-No.
Benzo[a]pyrene; Benzo[def]chrysene	50-32-8

SARA III — US. EPA Emergency Planning and Community Right-To-Know Act (EPCRA) SARA Title III Section 302 Extremely Hazardous Substance (40 CFR355, Appendix A)

Components	CAS-No.

PENN RTK — US. Pennsylvania Worker and Community Right-to-Know Law (34 Pa. Code Chap. 301-323)

Components	CAS-No.
Clarified oils (petroleum), catalytic cracked; Heavy Fuel oil	64741-62-4
Benzo[a]pyrene; Benzo[def]chrysene	50-32-8

MASS RTK — US. Massachusetts Commonwealth's Right-to-Know Law (Appendix A to 105 Code of Massachusetts Regulations Section 670.000)

Components	CAS-No.
Benzo[a]pyrene; Benzo[def]chrysene	50-32-8

NJ RTK — US. New Jersey Worker and Community Right-to-Know Act (New Jersey Statute Annotated Section 34:5A-5)

Components	CAS-No.
Clarified oils (petroleum), catalytic cracked; Heavy Fuel oil	64741-62-4
Benzo[a]pyrene; Benzo[def]chrysene	50-32-8

California Prop. 65 : WARNING! This product contains a chemical known in the State of California to cause cancer.

Benzo[a]pyrene; Benzo[def]chrysene	50-32-8

SECTION 16. OTHER INFORMATION

Further information

The information provided in this Safety Data Sheet is correct to the best of our knowledge, information and belief at the date of its publication. The information given is designed only as guidance for safe handling, use, processing, storage, transportation, disposal and release and is not to be considered a warranty or quality specification. The information relates only to the specific material designated and may not be valid for such material used in combination with any other materials or in any process, unless specified in the text.

Revision Date : 07/26/2012

65, 66, 121, 295, 296, 347, 1003, 1006, 1007, 1009, 1010, 1022, 1054, 1083, 1084, 1085, 1089, 1586, 1888

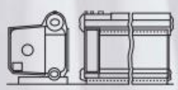
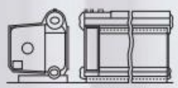
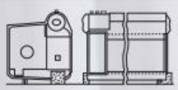
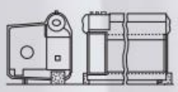
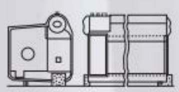
Appendix D - Supplemental Equipment Brochures

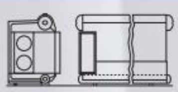
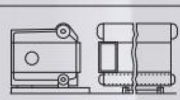
This appendix includes supplemental equipment brochures for several pieces of equipment included in the process. The equipment brochures are presented in the following order:

Boiler
Centrifuge
Destoner
Filter
Refrigerant Chiller

Reboiler:

Water-Tube Package Boilers: Capacities to Meet the Most Demanding Requirements

	Boilers	Capacity Range* (lb/h)	Length	Width	Height	Drum Size
	FM 9-22 26 30 34 39 43 48 52 57	8,200 to 40,000	7 ft 7 in. 8 ft 11 in. 9 ft 11 in. 11 ft 3 in. 12 ft 7 in. 13 ft 11 in. 15 ft 3 in. 16 ft 7 in. 17 ft 11 in.	10 ft 2-7/8 in.	12 ft 4 in.	36 in. Steam Drum 24 in. Lower Drum
	FM 10-52 57 61 66 70 79 FM 101-88	35,000 to 75,000	16 ft 7 in. 17 ft 11 in. 19 ft 3 in. 20 ft 7 in. 21 ft 11 in. 24 ft 7 in. 27 ft 3 in.	10 ft 10-5/8 in. 11 ft 2-3/8 in.	13 ft 6 in.	36 in. Steam Drum 24 in. Lower Drum
	FM 103-70 79 88 97	70,000 to 100,000	21 ft 3-3/16 in. 23 ft 11-3/16 in. 26 ft 7-3/8 in. 29 ft 11 in.	11 ft 9 in.	13 ft 9-3/4 in.	42 in. Steam Drum 24 in. Lower Drum
	FM 106-79 88 97 FM 117-88 97	100,000 to 155,000	23 ft 11-3/16 in. 26 ft 7-3/8 in. 29 ft 3-3/16 in. 26 ft 7-3/8 in. 29 ft 3-3/16 in.	11 ft 9 in. 11 ft 11-1/4 in.	14 ft 3 in. 15 ft 4-1/2 in.	48 in. Steam Drum 24 in. Lower Drum
	FM 120-97 112 124 FM 160-124	155,000 to 260,000	29 ft 3-3/16 in. 33 ft 7-3/8 in. 37 ft 3-3/16 in. 37 ft 3-3/16 in.	12 ft 5-3/8 in. 14 ft 0-3/8 in.	16 ft 10-1/2 in. 20 ft 0-1/2 in.	54 in. Steam Drum 24 in. Lower Drum

	Steam capacity	Steam pressure	Steam temperature
	**HCFM** 200,000 to 350,000 lb/h (25.2 to 44.1 kg/s)	to 1250 psig (7.2 MPa)	to 825F (441C)
	**PFM** 200,000 to 600,000 lb/h (25.2 to 75.6 kg/s)	to 1800 psig (12.4 MPa)	to 900F (482C)

NOTES:
1. All package boilers are of membrane construction.
2. Because of B&W's constant effort to improve design, equipment supplied may differ slightly from that described above.

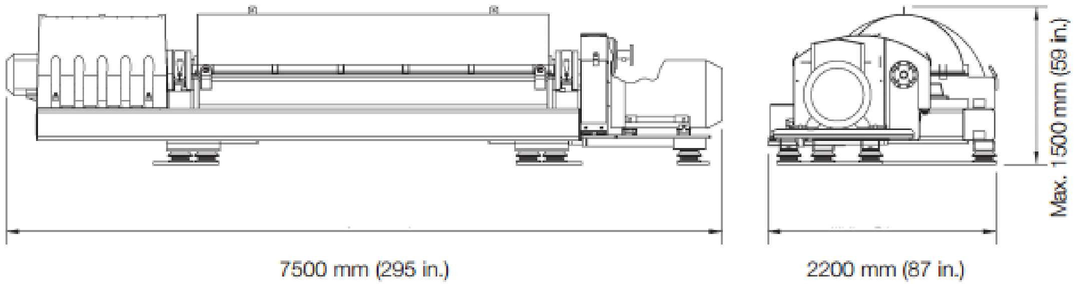
METRIC CONVERSIONS:
inches x 25.4 = mm
inches x 2.54 = cm
feet x 0.3048 = m
lb/h x 0.000126 = kg/s

* Steam capacities shown are saturated steam. Capacities shown will vary depending on conditions and limitations.

5

Centrifuge:

Dimensions



Technical data

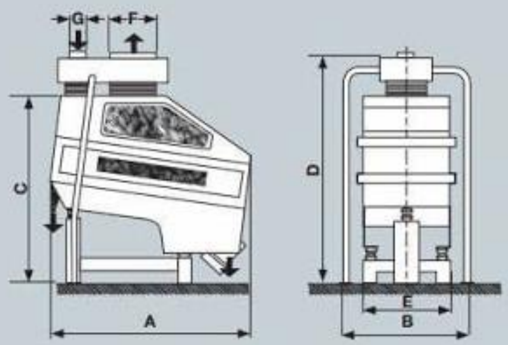
		Foodec 800
Capacity		Depends on application
G-force max.		3243
Bowl material		Duplex stainless steel
Other wetted parts		AISI 316
Weight	kg.	13000 (28860 lbs)
Installed Power	kW	132 – 250 (140 – 330 Hp)
Sound pressure level[1]	dB(A) re. 20ÌPa	89

[1] Declared A-weighted emission sound pressure level in free field over a reflecting plane at 1 m distance from the decanter, operating at maximum bowl speed, tested with water and closed outlet.

Destoner:

Tailor-made solutions.

Wide variety of applications.



Dimensions, technical data, weights, etc.

Type	Dimensions in mm							Screen width	Screen length	Vibrator power requirement	Negative air pressure	Approx. weights in kg			Volume seaworthy packing
	A	B	C	D	E	F	G	cm	cm	kW	mbar	net	gross	sea-worthy	m³
MTSD-65/120 E	1600	1000	1195	1545	660	350	120	65	120	1 x 0.3	12	310	425	485	3.25
MTSD-65/120	1600	1000	1445	1805	660	350	120	65	120	1 x 0.3	12	400	525	590	3.75
MTSD-120/120	1600	1540	1445	1805	1200	500	120	120	120	2 x 0.3	12	600	765	845	5.5

Throughput capacity chart. The throughput capacity data refer to dry grain in the first cleaning section.

Type	Product	Throughput	Aspiration
MTSD-		t/h	m³/min
65/120 E	Soft wheat	6	70
65/120	Soft wheat	6–12	70
120/120	Soft wheat	12–22	130
65/120 E	Durum wheat	4	70
65/120	Durum wheat	4–8	70
120/120	Durum wheat	8–14.5	130
65/120 E	Corn/maize	4.5	70
65/120	Corn/maize	4.5–9	70
120/120	Corn/maize	9–16.5	130

E = 1 screen deck

Filter:

BHS-Sonthofen Inc.
Filtration Division

BHS QUOTATION: **BUDGET-U-00346-BFR320320-F02669-Rev. 0**
DATED: **29 March 2016**

BHS Rubber Belt Filter
Type BFR 320 – 320
Active Filter Area: W x L = 3.05 x 32.0 = 98 m²

BHS Rubber Belt Filter- 90 m²

BHS-Sonthofen Inc.
14300 South Lakes Drive
Charlotte, North Carolina, 28273

Page 1 of 11

Telephone: 704.845.1190
Fax: 704.845.1902
E-mail: barry.perlmutter@bhs-filtration.com

1. FILTER TYPE

Rubber Belt Filter:	BFR 320-320
Filter area:	W x L = 3.05 x 32.0 = 98m²
Main Dimensions: (L X W X H)	36 x 4.5 x 2.8 meters (approximate)
Weight:	To be confirmed
Quantity:	One (1)

1.1 Nozzle table:

Pos.	*Type*	*No*		*Size*	*DIN*
1	Fish tail	1	Slurry	2 x 4"	DIN 2501
2	Wash feed	2	Wash water	6"	DIN 2501
3	Spray bar	2	Cloth Rinse	1 ½ "	DIN 2501
4	Filtrate outlet	3	Filtrate	10"	DIN 2501

1.2 Materials

Product wetted parts (Vacuum box, filtrate pipe, cloth rinse trough, wash devices): PP/FRP

Non-product wetted parts:	carbon steel painted
Seals & gaskets:	EPDM, WS 3820
Transporter belt:	SBR (styrene-butadiene rubber)
Filter cloth:	Polypropylene, per the test report
Bolts & nuts:	stainless steel A 4

1.3 Equipment

Slurry feed device:	fish tail
Cake wash device:	2 single washes
Cake discharge:	wire supported
Fume hood:	not foreseen
Cake discharge chute:	not foreseen
Drip tray:	not foreseen
Painting:	BHS-Standard RAL 5022, Total thickness 150 µm

1.4 Operation utilities

Electricity	55 kW for filter drive
Seal water:	6 m^3/h at 2 bar
Sliding water:	Not required (roller table)
Approximate Cloth + belt rinse:	7 m^3/h at 3 bar (based on one nozzle pipe and to be confirmed during testing)
Approximate Cake wash water:	2 x 80 m^3/h; (To be confirmed during testing)
Instrument air:	pressure air at 6 bar

BHS-Sonthofen Inc.
Filtration Division

2. OPERATION DATA

Testing:	None
Operational temperature:	80°C
Cake thickness:	To be confirmed
Belt speed:	10 - 12 meters/minute

	Normal capacity [m³/h]	***Max design capacity [m³/h]***	***[%] Solids in feed***	***Medium***	***Feed type***
Slurry					fish tail
Cloth rinse	TBA	TBA		Water	1-fold

	Normal capacity [t/h]	***Max design capacity [t/h]***	***Moisture***	***Wash out***	***Remarks***
Filter cake					

3. TECHNICAL DESCRIPTION

a) Mode of functioning

The BHS rubber belt filter is a continuously operating, horizontal vacuum belt filter. It can be used for safely separating fast settling (and also abrasive) solids from suspensions. The different filtrates can be separated simultaneously.

b) Base frame

The filter is designed of modular components consisting of the feed and discharge section as well as of at least one or several intermediate sections, which are firmly bolted to each other.

The filter area can be extended by adding additional modules.

c) Rubber carrier belt / filter cloth

The endless, flexible rubber carrier belt, which serves as a conveyor belt and filter cloth support in the top strand, is led over a drive pulley in the discharge section and a take-up pulley in the feed section. The pulley is driven by a gear motor. The take-up pulley can be adjusted in horizontal direction thus facilitating belt tracking and tensioning.

The surface of the rubber carrier belt is provided with grooves cut at right angles to the direction of travel. The carrier belt also has drainage holes for filtrate extraction into the vacuum box.

The filter cloth is a mechanically stable filter fabric. After cake discharge, assisted by a scraper, the rubber carrier belt and filter cloth separate. Both return to the take-up pulley via various carrying and deflecting rollers.

In order to prevent the filter cloth from running off track, a belt tracking device is installed in feed section of the return strand.

d) Vacuum box / wear belt

The vacuum box is located below the rubber carrier belt and sealed against the belt by a circulating, endless wear belt. Water serves as sliding agent and lubricant to keep the vacuum loss as low as possible.

The vacuum boxes are divided into individual filtrate zones, which are connected to the manifold by vacuum-rated hose lines. This manifold is fitted to the filter frame and is segmented according to process requirements.

e) Belt support

The rubber carrier belt is supported by roller tables which are bolted to the individual frame parts. For this design no sliding water is required. Guide rollers fitted along the entire filter length prevent the belt from slipping sideways.

f) Supply of process media

The slurry is fed through a feed system.

The washing media are fed via nozzle systems and/or overflow channels. These assemblies are movable according to process requirements.

Immediately following the cake discharge, a belt washing device equipped with numerous nozzles is installed to clean the belt on the return strand.

4.0 PERIPHERICAL PARTS (Not Included; sizing to be confirmed after testing)

All parts will be delivered separately, without piping. BHS to work to develop the optimum design for manifolding and/or combining of the vacuum pumps, separator tanks, etc.

4.1 Vacuum Pump (Not Included; sizing to be confirmed after testing)

For the vacuum on the belt filter, a single-stage liquid ring pump with silencer is required, driven by means of an electric motor with v-belt, mounted to the common base frame.

Number:	1 (One per each belt filter)
Make:	To be confirmed
Design:	single-stage water ring pump
Sucking temperature:	approx. 55 deg C
Sucking capacity:	To be confirmed during testing
Intake pressure:	approx. 400 mbar
Process water requirements:	To be confirmed during testing
Water inlet temperature:	20°C
Materials:	grey cast iron
Shaft seal:	stuffing box
Drive:	v-belt
Estimated Motor Required:	To be confirmed during testing

Suitability of the materials to be reconfirmed after clarification of the water quality.

4.2 Water Separator and Collecting Tank (Not Included; sizing to be confirmed after testing)

To separate the water from the discharged air of the vacuum pump.

Number:	1 (One per each vacuum pump)
Design:	horizontal cylindrical vessel
Material:	FRP
Diameter:	To be confirmed during testing

4.3 Filtrate Separator (Not Included; sizing to be confirmed after testing)

For separation of gaseous and liquid phases. The vessel is designed with cylindrical shell and flat ends, 1 lateral input connection, 1 discharge connection in the centre of the bottom, the suction connection on the cover on of the vessel and one pressure gauge connection.

Number:	2 (Two per each belt filter)
Diameter:	sizing to be confirmed after testing
Height:	sizing to be confirmed after testing
Material:	FRP

4.4 Filtrate Pumps (Not Included)

The filtrate pump is not included in the scope of offer. It might be included after clarification of the requirements such as transport height and sucking height.

3.5 PLC Controls (Not Included)

4.6 Options (Not Included)

BHS can include all other components such as tanks, pumps, candle filters and other components to complete the package based upon a final scope P & ID.

5. COMMERCIAL

5.1 Budget Price: US$ 900,000.00

5.2 Price Basis (Material Surcharges & Drawing/Design Changes):
Due to the current volatility in material price surcharges, it will be necessary for BHS to reconfirm the price at time of order or at time of approved drawings, depending upon the scope of supply. The quotation is based upon the current mill base price and monthly surcharge for our equipment and standard piping/skid designs. When drawings and designs are finalized, any changes will be reviewed along with the surcharge in effect at the approval date and the price shall be adjusted accordingly.

5.3. Dispatch: Ex-works, locations to be determined

5.4. Shipment: Estimated 9 months after order

5.5. Validity: Budget price only, non-binding

5.6. Terms of Payment: To be discussed

5.7. Terms & Conditions:
BHS Terms & Conditions. Further, BHS WILL NOT, UNDER ANY CIRCUMSTANCES, BE LIABLE TO PURCHASER, OWNER, CLIENT OR RELATED PARTIES FOR SPECIAL (DIRECT, GENERAL OR INCIDENTAL), INDIRECT, OR CONSEQUENTIAL DAMAGES (INCLUDING BUT NOT LIMITED TO, LOSS OF PROFITS) IN ANY WAY RELATED TO GOODS AND, SERVICES, REGARDLESS OF THE LEGAL OR EQUITABLE THEORY ON WHICH THE DAMAGES ARE SOUGHT. BHS DOES NOT FURTHER ACCEPT INCOTERMS WARRANTIES AND DAMAGES. BHS LIMITS ALL WARRANTIES AND DAMAGES UP TO THE VALUE OF THE CONTRACT.

5.8. Mechanical, Controls and Process Commissioning:
Not included but provided by BHS, according to the BHS Invoicing Rates at time of commissioning. Operation of the filter must be in accordance with the operating and maintenance instructions; especially the maintenance intervals must be observed as indicated and be performed by suitably trained personnel only. This is a prerequisite for any warranty claims.

5.9. Documentation: To be advised

5.10. Exclusions:

- Pumps, tanks and equipment to bring the fluids (slurry/liquids/gases) to the filter
- Fieldwork including wiring, piping, valves, etc.
- Validation documents and procedures
- Items not called out in this proposal are excluded

5. 11. Warranty:

Machinery and Equipment. SELLER warrants that all PRODUCTS, which are machinery and equipment, shall be delivered in substantial conformance to its quoted specifications. SELLER will repair or, in its sole discretion, replace any PRODUCT which is a machine or equipment found by SELLER to be defective if such defect is reported to SELLER within ten (10) days after the earlier of 12 months after commissioning or (ii) 18 months after delivery. All of costs of removal, installation, shipping and similar will be borne by PURCHASER. This limited warranty does not cover damage or deterioration caused by storage of PRODUCTS, normal wear and tear, use under circumstances exceeding specifications or limitations, abuse or neglect, unauthorized repair or alteration, use of parts not provided by SELLER, lack of proper maintenance or damage caused by natural calamities.

PRODUCTS which are parts furnished to replace defective parts on machinery or equipment still under Seller's warranty shall be warranted to the same extent as the original machinery or equipment, but only for a period equal to the balance of the original period or three (3) months, whichever is longer. SELLER will repair or, in its sole discretion, replace any other spare parts made and sold by it, which it finds to be defective if such defect is reported to SELLER within thirty (30) days after delivery to PURCHASER. Parts not made by SELLER or a related party of SELLER, are sold AS IS, WITH ALL FAULTS, and in such cases SELLER shall, to the extent possible, assign to PURCHASER the original manufacturer's warranty.

5.12. Spare Parts: Spare parts are not included.

Respectfully Submitted By:

Barry A. Perlmutter,
President & Managing Director

Refrigerant Chiller:

Water-Cooled Chillers

In many types of larger commercial and industrial buildings, water-cooled electric chillers offer an attractive alternative to air-cooled electric chillers and packaged rooftop units (RTUs). As their name implies, water-cooled chillers use water to absorb heat from the chiller and disperse it through a cooling tower, as opposed to air-cooled chillers and RTUs, which disperse heat only by using air-cooled condensor coils.

Water-Cooled Chiller Characteristics

The use of the cooling tower gives water-cooled systems an efficiency edge over air-cooled systems and RTUs. In addition, unlike RTUs, which circulate cool air through ducts, all chillers circulate chilled water to air-handler units, where fans push air across heat exchanger coils to deliver cooling. Because they circulate water, which is more energy dense than air, water-cooled chillers can offer a more efficient and effective cooling option than RTUs.

Water-cooled chillers are most commonly used in buildings larger than 200,000 square feet, where the cooling load is large enough for increased efficiency gains to offset the higher equipment cost. However, they're also a viable choice in smaller buildings with more than two stories because they don't have to push air through ducts across multiple stories. Potential applications for water-cooled chillers include multistory structures, universities, large office buildings, and hospitals.

© E Source

Figure 1: 100-ton water-cooled chiller. Water-cooled chillers use cooling towers to reject heat through evaporation.

Chiller Terminology

Several terms are used to describe chiller performance and efficiency. Confusion can be minimized by first developing an understanding of the most common terms.

Tons. One ton of cooling is the amount of heat absorbed by one ton of ice melting in one day, which is equivalent to 12,000 Btus per hour, or 3.516 kilowatts (kW) (thermal).

Chiller performance is certified by the Air-Conditioning, Heating, and Refrigeration Institute (AHRI), a manufacturer trade organization, according to its Standard 550/590: Performance Rating of Water-Chilling Packages Using the Vapor Compression Cycle. Two efficiency metrics are commonly used for water-cooled chillers: full-load efficiency and part-load efficiency.

Full-load efficiency. The efficiency of the chiller at peak load and at AHRI standard conditions is measured in kilowatts per ton (kW/ton). A lower kW/ton rating indicates higher efficiency.

Part-load efficiency. The efficiency of the chiller at part load is measured by either integrated part-load value (IPLV) or nonstandard part-load value (NPLV), depending on the particular AHRI part-load test conditions. Both give the efficiency of the chiller using a weighted average formula referencing four operating load points (100 percent, 75 percent, 50 percent, and 25 percent) and are expressed in kW/ton.

What's Available?

Water-cooled chillers are available in a wide range of sizes—from 20 tons to several thousand tons of cooling capacity. New water-cooled chillers commonly use one of three types of compressors: centrifugal compressors, which are the most efficient, followed by screw compressors, and then scroll compressors. The centrifugal category includes magnetic-bearing compressors. These use magnetic fields to levitate the compressor shaft in midair, eliminating the need for traditional oil-lubricated bearings. They generate less noise and vibration than other compressors and offer significantly better part-load efficiencies in some applications.

How to choose. Which type of chiller to choose for a specific application is determined largely by the cooling capacity required and the trade-off between initial costs and operating costs. In general, for conditions that require less than 300 tons of cooling capacity, chillers with screw or scroll compressors are common. Screw chillers dominate the upper end of this capacity range, but magnetic-bearing compressors are gaining ground as they enable variable-frequency operation, which hasn't been a readily available option in the past in this size range. For requirements of more than 300 tons of cooling capacity, chillers with centrifugal compressors are typically used.

Specification considerations. Specifying an efficient water-cooled chiller system can be a challenging process. Many parameters affecting system efficiency and performance need to be considered, such as:

- Chiller efficiency
- Full-load versus part-load chiller operation
- Variable-frequency drive (VFD) versus
- Constant-speed compressors
- Auxiliary component efficiency (pumps and fans)
- Operating strategies
- Interactions between components and operating strategies

Deciding which chiller is the best option for a building requires an in-depth analysis in order to maximize efficiency opportunities. This analysis is best conducted by design consultants and other professionals who can run computer simulations of the various equipment options, load factors, and operating strategies.

ASHRAE 90.1-2007 Addendum m

This addendum reflects continuing improvements in VFD technology, which has improved chiller part-load efficiencies and encourages the use of higher-efficiency equipment. This publication ushered in several changes to the chiller requirements in ASHRAE Standard 90.1, the Energy Standard for Buildings Except Low-Rise Residential Buildings.

The biggest change was to replace a single compliance path with two different paths. Path A affects applications that spend a significant amount of time at full load. Path B affects applications that spend a signification amount of time at part load. This specification encourages the use of chillers with better IPLVs in part-load applications and full-load efficiencies in full-load applications. For either path, minimum requirements for both full load and IPLV must still be met.

	ASHRAE 90.1 before 1/1/2010		ASHRAE 90.1 as of 1/1/2010			
			Path A		Path B	
Water-cooled chiller	Full load (kW/ton)	IPLV (kW/ton)	Full load (kW/ton)	IPLV (kW/ton)	Full load (kW/ton)	IPLV (kW/ton)
Positive displacement chiller						
< 75 tons	0.790	0.676	0.780	0.630	0.800	0.600
≥ 75 and < 150 tons	0.790	0.676	0.775	0.615	0.790	0.586
≥ 150 and < 300 tons	0.717	0.627	0.680	0.580	0.718	0.540
≥ 300 tons	0.639	0.571	0.620	0.540	0.639	0.490
Centrifugal chiller						
< 150 tons	0.703	0.669	0.634	0.596	0.639	0.450
≥ 150 and < 300 tons	0.634	0.596	0.634	0.596	0.639	0.450
≥ 300 and < 600 tons	0.576	0.549	0.576	0.549	0.600	0.400
≥ 600 tons	0.576	0.549	0.570	0.539	0.590	0.400

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Notes: IPLV=integrated part-load value; kW/ton=kilowatt per ton

Table 1: Water-cooled chiller minimum efficiency requirements. The latest version of ASHRAE Standard 90.1 not only contains two compliance paths but also requires the use of more-efficient equipment.

Addendum m also instituted four other changes for water-cooled chillers:

- It required the use of more-efficient equipment in most size categories.
- It changed how efficiency is expressed, from coefficient of performance (COP) to kW/ton to reflect industry practice.
- It created a new size category for centrifugal chillers at or over 600 tons.
- It combined all positive displacement (reciprocating, screw, and scroll) chillers into one category.

All of these changes were rolled into the latest version of ASHRAE Standard 90.1-2010 and were adopted by the International Energy Conservation Code (IECC) of 2009. The new minimum efficiencies are shown in Table 1. Note that there are no U.S. federal minimum efficiency standards for chillers.

VFD Options

While many manufacturers offer chillers with a VFD option, only some offer the magnetic-bearing compressor technology. Scroll chillers aren't available with VFDs, though some manufacturers are now using digital scrolls, which perform better at part load than nondigital scrolls. VFDs can also be added to the chilled and condenser water pumps as well as the cooling tower fans.

Generally, as chillers spend most of their operating time at only 40 to 70 percent load, installing a VFD on the chiller and/or auxiliary equipment in hot, humid climates can produce energy savings. For example, ASHRAE computer simulations run during the development of Addendum m showed a 21 percent efficiency improvement in a large Miami office building cooled by a single 600-ton water-cooled centrifugal chiller with a VFD, compared to a constant-speed chiller. It's important to note that when there are multiple chillers, savings may be less with the amount of decrease depending on the control strategy employed. VFDs aren't recommended for chillers that operate predominantly at full load because they can decrease chiller full-load efficiency by up to 4 percent.

Before purchasing a VFD chiller or auxiliary equipment, it's a good idea to conduct an hourly simulation analysis to evaluate the opportunity for a given application.

Application considerations. The cost-effectiveness of a VFD for a water-cooled chiller is affected by several factors. Applications where VFDs are more likely to be cost-effective include those with the following characteristics:

- Low chiller load factors. In applications where chillers spend a lot of time at low loads, VFDs will save the most energy and have the best chance of a quick payback.
- Long cooling hours. Facilities that log more annual cooling hours are able to recoup the cost of cooling system improvements more quickly than those with limited or seasonal operating hours, such as a K–12 school.
- Presence of multiple chillers. Many facilities have two or more chillers that can be staged as load changes. This can create an ideal opportunity to install one or more VFD chillers to improve capacity control. Using a VFD on only one chiller allows you to more fully load the non-VFD chillers and use the VFD chiller to make up the difference in needed capacity. Using a VFD on all chillers in a plant allows you to balance run hours on all the equipment while still reaping the energy-efficiency benefits of VFDs.
- Presence of a building automation system. Because VFD chiller plants can be operated in different ways, a building automation system can help building staff determine whether operating practices are helping or hindering overall plant efficiency.

It's possible to retrofit a VFD on an existing water-cooled centrifugal chiller in the field. However, care must be taken to integrate the capacity and other controls correctly, and it's advisable to enlist the services of an experienced design professional to ensure success.

Economics

Water-cooled screw and scroll chiller costs vary by manufacturer, location, and technology options. A survey of the major manufacturers shows an average cost of approximately $250 to $350 per ton for the chiller itself, depending on capacity.

For centrifugal chillers over 400 tons, prices range from $200 to $500 per ton for the chiller itself; for centrifugal chillers less than 400 tons, prices range from $250 to $600 per ton for the chiller itself. A VFD can add from $30 to $80 per ton (see Table 2). The cost to retrofit a VFD on an existing centrifugal chiller would be the cost of the VFD plus approximately 30 percent.

Estimating general installed costs for a water-cooled centrifugal chiller is difficult because rules of thumb don't apply. Centrifugal chillers are sometimes referred to as "infinitely configurable" as they offer more options than other chillers, and costs don't always follow linearly with size. They also use specialized motors and starters, the cost of which can often be more than the chiller itself. Without accounting for specific application details, you could estimate the total installed cost for a new chiller plant at $1,500 to $1,800 per ton, including the chiller.

Additional capital cost savings. While VFDs add significant capital cost to a chiller plant, installing a VFD chiller can allow you to reap capital cost savings in other ways:

- Install fewer chillers. Because VFD chillers operate efficiently at low loads, it's often possible to install fewer, larger chillers that can be regulated to match loads. This also saves on costs for piping, pumps, controls, and real estate.
- Eliminate the pony chiller. Many plants include a small "pony" chiller used to meet night or weekend loads. Because a VFD chiller can operate efficiently down to 10 percent of its full-load capacity, there's less need for a pony chiller.
- Install a smaller emergency generator. In critical facilities such as hospitals and data centers, where the emergency power generator is sized to keep the cooling system running through a power interruption, the soft-start capability of a VFD chiller can reduce the size and cost of the generator.

Chiller options	Dollars per ton
Screw and scroll chillers	$250 – $350
Centrifugal chillers < 400 tons	$250 – $600
Centrifugal chillers > 400 tons	$200 – $500
Adding a VFD to a new centrifugal chiller	$30 – $80

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Note: VFD=variable-frequency drive

Table 2: Average cost for water-cooled chillers. Chiller costs vary significantly, making a "back-of-the-envelope" estimation difficult.

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