Liquor-Based Canned Cocktail Production:

Fizzy with the Rizzy

Final Technical Report

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On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

ADVISOR

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Table of Contents

Executive Summary

Our team has designed a process to develop a liquor-based canned cocktail, Fizzy with the Rizzy*,* that will be carbonated, clear in color, and flavored with Stevia at 8% ABV in a 12 oz can and be sold in three different flavors: lemon-lime, cranberry, and strawberry. It will be packaged in cases of 12 at a projected scale of approximately 500,000 gallons of canned cocktail product or 444,000 cases a year. In order to eliminate the unpleasant taste derived from malt-based alcoholic seltzers, the canned cocktail will have a distilled liquor base, allowing the better tasting cocktail to be sold at a premium wholesale price of $15 per case. High-gravity fermentation of the yeast, followed by fractional distillation, flavoring, carbonation, and canning will be the basis of the design. This final report details the fermentation, distillation, flavoring, carbonation, and canning design as well as evaluates the economic viability of this production design. From our economic analysis, our small scale distillery will earn a gross profit of approximately $4 million per year and have an internal rate of return of 28.3%, suggesting this design is viable for implementation.

Introduction

Hard seltzer sales, such as White Claw, are growing at a faster rate than beer sales, due to its popularity among Gen Z and Millenials who have established a drinking culture with many hard seltzer brands. Trends such as the Smirnoff Ice challenge and colloquialisms such as "No laws when you're drinking Claws," contribute to the growing sales of canned seltzers and the expansion of beer product lines to include flavored seltzers (Goldfine). The trending drink along with the onset of the pandemic has further skyrocketed sales. The pandemic contributed to a heightened apprehension to consume alcohol in public spaces, and generated a shift towards at-home drinking as well as online food and beverage shopping to avoid viral exposure (*Ready To Drink Cocktails Market Size Report, 2022-2030*, n.d.). Despite the decrease in social distancing procedures with increased vaccine availability, consumers are still driven to consume convenient alcoholic beverages that can easily fit into their busy lifestyles (*Ready To Drink Cocktails Market Size Report, 2022-2030*, n.d.). Thus, canned cocktails have high market potential and potential for growth due to their established pandemic popularity and inherent convenience. Furthermore, canned cocktails have largely marketed themselves to health-conscious populations and the gluten-free community who are shifting towards drinking low-calorie fruit-flavored alcoholic beverages (*Ready To Drink Cocktails Market Size Report, 2022-2030*, n.d.).

As people have grown accustomed to drinking canned cocktails in the comfort of their homes, there is a growing desire for more sophisticated liquor-based products that can offer a better-tasting cocktail adjacent beverage. Most common seltzers have a lingering aftertaste from the malt-base that many consumers find unsettling. Our product aims to improve the taste by using a distilled liquor base instead. While this change will increase production cost, many consumers would be willing to pay a premium to remove the unpleasant aftertaste, as demonstrated by the success of High Noon and Devil's Backbone canned cocktails that have a vodka base and are retailed at a higher price than malt-based hard seltzers such as White Claws and Trulys. Additionally, in developing a liquor base production design there is broad versatility and a wide range of products that can be marketed from a more streamlined process. Our lemon-lime, strawberry, and cranberry flavorings can be added to the universal liquor base and carbonated water, and can be sold as different cocktails. We envision this product being consumed both at home and at formal events, where a more polished, mobile drink can replace live mixing of cocktails that may cause anxiety about the transmission of covid.

Previous Work

High Gravity Fermentation

Very high gravity (VHG) fermentation is unique as it involves using a high concentration sugar media, increasing osmotic pressure on the yeast cells, and reducing the water requirement over typical fermentation media. VHG fermentation reduces downstream distillation costs as a result of a higher alcohol content produced from the fermentation process. Current research studies have optimized fermentation parameters of VHG fermentation including, yeast strain flocculation, nitrogen and nutrient supplementation, aeration and agitation, and media type. Cruz et al. statistically analyzed operating conditions for optimization of a very high gravity fed-batch fermentation of a mixture of sugarcane molasses and juice to apply to laboratory experiments that obtained an ethanol concentration of 17.2 volume percent (Cruz, 2021).

Our VHG fermentation design is modeled after the Cruz et al. study and uses the same sugarcane molasses and juice media. Additionally, we used their ethanol yield data to determine the necessary fermentation periods and final ethanol content from fermentation. We used their optimal fermentation conditions of 80.6℉, 15 %v/v cell concentration, 2.5 lb/gal substrate concentration, and a feeding time of 5 hours for our design and scaled up their parameters for a fermentation period of 28 hours. Various studies have shown that fermentation times can be decreased when VHG fermentation is used in conjunction with aeration, however, our fermentation time was modified to conform to regular work hours, and accelerated fermentation is unnecessary for our final product specifications (Ingledew, 2011).

Discussion

Fermentation

Originally our team considered using refined sugarcane based media for the fermentation, but decided to switch to sugarcane molasses and juice due to its relatively low bulk cost, well documented kinetics, and fewer required additional nutrients. We also decided to use very high gravity (VHG) fermentation, as a higher yield of ethanol can be made, thus reducing our distillation utilities costs. However, due to the increased ethanol production, a flocculating yeast strain needed to be used as it is resistant to high ethanol content and osmotic pressure. As VHG fermentation uses a high concentration of sugar media, it was further justified to use the lower costing sugarcane molasses and juice media. In order to preserve sugarcane juice for fermentation, it must be kept in a cooled environment. Considering our size of fermentation, we opted for a walk-in-cooler where the sugarcane juice is kept for a weekly batch basis.

To decrease the cost of fermentation materials, viable yeast will also be reused. In order to reuse viable yeast, the cells first need to be separated from the media. Our team considered using a hydrocyclone for separations due to its relatively low cost compared to centrifugation and lack of moving parts, but we were not able to find hydrocyclone equipment that is compatible with our scale and food safety requirements. Thus, our team opted to use the more standard food grade disc-stack centrifugation.

Our team also determined that the cost of CO_2 capture from fermentation and reuse within our process for carbonation and canning was not profitable. CO_2 capture solutions are becoming more common in the brewing industry, but currently there are no economically feasible solutions for CO_2 capture for a brewery making less than 100,000 barrels annually. Since our distillery is only producing around 16,000 barrels per year no economically profitable options exist and we therefore opted to simply vent the CO_2 produced into the atmosphere as our process generates relatively low CO_2 amounts, similar to most distilleries who also vent their CO_2 byproduct. While not the optimal solution by any means, it turned out to be the only solution for our scale.

We decided to use three fermentors in our batch scheduling, where there will only ever be a maximum of two fermentors run at once. This allows for each fermentor to have a full workday for maintenance and repairs if the need arises in between fermentation cycles. The scheduling was determined to accommodate typical working hours, 7:00 AM - 4:00 PM, and to allow time for draining and cleaning in place (CIP) procedures. CIP was determined to be an ideal sterilization method, because dismantling of the fermentor is not needed and it is sufficient to maintain food safety. When deciding what chemicals to use for CIP, we opted for non-caustic chemicals as opposed to caustic which can be used on soft metals and are commonly used for breweries.

Distillation

Our team considered using multiple distillation columns to remove volatile impurities such as methanol, from the desired ethanol distillate. However, we discerned that the production of methanol would be negligible and well below the maximum tolerable concentration for human consumption of 0.0835 lbs methanol/gal ethanol, thus only one column is necessary (Paine, 2001). To provide heat to the column a reboiler is required. We considered a variety of heat exchanger types: shell and tube, plate, and finned plate types. Our team ultimately decided to use a shell and tube heat exchanger as indirect heating by steam would not contaminate our product and would allow the tube side to be easily cleaned if fouling occurred. This paired with a moderate operating pressure and narrow boiling mixture point allows us to pick a vertical thermosyphon heat exchanger which will allow energy costs to be lower since natural convection will handle all of the material transfer that needs to be accomplished (Serth, 2007). The distillate condenser on the other hand is a pump fed unit, as the cooling water does not passively cycle itself. It was also made in a shell and tube design to facilitate the cleaning of any fouling that may occur.

We additionally considered running the column in a batch-wise or continuous fashion, but ultimately decided to operate under continuous conditions. Batch distillation is typically used in smaller scale production to decrease costs associated with purchasing and operating a continuous feed column, but needs to account for additional time for startup and shutdown processes. Batch distillation offers more flexibility in handling variations in feed streams and target ethanol content. However, since our distillery will only be required to produce a distilled spirit from one base recipe, higher flexibility in the distillation unit is not required. Additionally, in batch distillation, a set volume of liquid is evaporated and thus product purity changes over the span of the distillation and needs to be accounted for. Feeding continuously to the distillation column creates a product of constant purity making the downstream flavoring, carbonation, and canning processes more streamlined. We additionally created our fermentation batch schedule in a manner that allows for continuous feed to the distillation column.

Our team also debated between pot still and fractional distillation. Pot still distillation has low efficiency and requires multiple distillations to meet our product specifications, whereas fractional distillation has increased product purity in a single pass and couples well with continuous feed. With continuous feed from our fermentation process, at 15.5 mol% ethanol, the final specifications from AspenPlus V11 modeling of a fractional distillation column yielded a distillate of 83 mol% ethanol and bottoms of 0.03 mol% ethanol.

Flavoring, Carbonation, & Canning

In terms of our final product, we decided to create a carbonated beverage clear in color. We considered buying carbonated water, but the cost to produce it was more than ten times cheaper than purchasing and shipping costs. For carbonating our beverage, we decided to mix carbonated water with the liquor base, flavorings, and a sweetener all in one mixer to streamline production and reduce cleaning costs for the single mixer. Our team also considered using extracts as our flavoring component, but ultimately decided to use natural flavoring as it requires no added preservatives, is clear in color, and requires less volume so it can be easily mixed with the carbonated water. Additionally, only one flavor will be made per day to avoid multiple cleanings. Finished cans will be stored in house until all flavors have been made where it will be transported to a packaging system.

The full process flow diagram is detailed in Appendix Figure A1.

Design

Fermentation

Fermentation Medium

The feed products used for fermentation include water, sugarcane juice, sugarcane molasses and brewer's yeast. SafSpirit™ HG-1, a strain of *Saccharomyces cerevisiae,* will be used in this fermentation due to its high flocculation and high ethanol tolerance. To inoculate the yeast prior to each fermentation, 279 gallons of distilled water will be used to rehydrate 108 pounds of yeast in a mixing tank stirred constantly for two hours (Cruz, 2021). Viable yeast cropped from a finished fermentation cycle can be reused in the next fermentation cycle instead of using new dry yeast. Yeast will be reused up to 5-6 times to ensure the efficiency of the reused yeast does not drop too low, and viable yeast will be determined by color, described in a later section.

The fermenting medium is a combination of sugarcane molasses and juice. The target concentration of reducible sugars in the juice and molasses mixture is 2.5 lb/gallon. It was assumed that the purchased sugarcane molasses and juice had total reducible sugar concentrations of 6 and 1.05 lb/gallon, respectively. This resulted in a mixture of 29% molasses and 71% juice by volume. Prior to being fed into the fermentor, the media mixture will be acidically pretreated to destroy unwanted bacteria and solids in a jacketed tank. For pretreatment and preparation of the fermentation media, a pH meter will be used to measure the pH of the fermentation media, and the pH balance will be maintained by calcium ions, which are food-safe and won't kill the yeast cells. The pH of the mixture will be lowered to around 2-3 through small volume additions of calcium ions, via calcium chloride. Inside the pretreatment tank the acidic mixture will be heated to 185℉ using low pressure steam for 30 minutes. The ash content in the molasses and juice will settle and be cropped off leaving the remaining solid free liquid. To raise the pH to 4.5 for use in the fermentation, calcium carbonate will be added to raise the pH. Both of the pH modifiers will be added in small quantities as needed while pH is monitored using the pH meter.

Fermentation Conditions

651 gallons of fermentation media will be fed into the reactor initially containing the inoculum in a fed-batch manner with a feed time of 5 hours and a flow rate of 2.17 gallons per minute. During fermentation, the fermentors will be at atmospheric pressure and a temperature of 80.6°F. A mixture of propylene glycol and water is used to maintain constant fermentation temperature by circulating through the dimpled glycol jacket of the conical fermentor. The glycol mixture will be 40% propylene glycol and 60% water by volume. The heat of reaction will be 428,308 BTU per fermentation cycle, where we assume the sugar consumption kinetics at 28 hours (Cruz, 2021). Since cold crashing of the fermentor is not required in spirit production, unlike beer brewing, the glycol mixture will only be chilled to 60℉.

Products

Byproducts of the fermentation process include carbon dioxide, trub, and viable yeast. As the yeast cells consume sugars and produce ethanol they also release CO_2 as a byproduct. In one fermentation cycle, 7,423 pounds of CO_2 are produced and vented from the top of the fermentor to the atmosphere through a spunding valve. The high flocculation of the yeast strain used causes the yeast to sediment at the bottom of the conical fermentor where it can then be drained off slowly through a butterfly valve. The yeast will settle in three different layers, dead yeast called trub, viable yeast, and poorly flocculating yeast. The layers can be distinguished by variations in color. A sight glass will be used while draining the yeast to obtain the three separate layers. The trub will be a darker brown color and will be drained off first into a holding tank. The high nutritional composition of trub makes it a possible byproduct to be sold to agricultural industries as livestock feed. Next, the viable yeast which will be a lighter beige color will be drained to be used again in the next fermentation cycle as the inoculum. The viable yeast will be cropped off and filtered using a stacked disk centrifuge to remove the residual fermented liquid and stored for repitching. The top layer of lower flocculating sedimented yeast won't be used in a following fermentation cycle as it would decrease the fermentation productivity. The low performing yeast can either be a waste stream or combined with the trub as a byproduct. Liquid loss in the fermentation step due to yeast separation of bottom cropped was assumed to be in line with lager production data due to the use of flocculating yeast and bottom cropping in lagers 1.5 - 2.5 volume percent loss (Barnes, 1976).

The trub byproduct will be sent to an evaporator in order to evaporate the excess fermented liquid to result in a final high nutritional syrup product. Evaporation extends the shelf life of the agricultural feed byproduct enabling it to be bought and shipped to a larger range of consumers.

The desired product from fermentation is the fermented liquid at 15.3 vol% ethanol that will be distilled to obtain the final high proof liquor, 80 vol% ethanol, to be used in our canned product. Each fermentation cycle will produce 930 gallons of ethanol that are sent to the distillation column.

Sterilizing Tank

Mixture of sugarcane molasses and juice will be mixed together and heated in a jacketed tank for the removal of ash and suspended particles.

Fermentor

The requirements of the fermentor are dictated by the food safety of the product and the characteristics of the fermentation process in general. In order to produce a food safe product, the fermentor must safely contain the fermentation process and allow for sufficient CIP procedures. To satisfy the needs of ethanol fermentation the tank must be non-reactive, allow for heat dissipation and control, and facilitate the use of high gravity distillation. To meet the non-reactivity and cleaning requirements, the tank will be constructed from 304 stainless steel, with the interior polished to a 2.36 E-5 inch sanitary finish. 304 stainless steel is food safe, non-reactive to the fermentation, and the polished finish allows for reliable cleaning and minimizes any biological deposit formation. To clean the tank during CIP, the fermentor is equipped with a rotary jet head to dislodge deposits and cover the interior of the tank in a cleaning solution.

The fermentor uses multiple layers of stainless steel sheet to form insulation pockets that are filled with thermal polyurethane, which assists the pillow-plate glycol cooling in maintaining the temperature of the fermentation. A spunding valve set to the desired fermentation pressure, atmospheric for this fermentation, is used to vent the produced CO_2 and prevent an increase of pressure due to the gas production. The conical bottom of the fermentor also assists in the high gravity fermentation, as it increases the ease of separation between the dead yeast mass, the mash liquid, and the reusable yeast cells.

The overall specifications of the fermentor are a 30 bbl volume, 2.4 E-4 inch polished finished, 0.16 inch 304 stainless steel inner shell, brushed finish 0.08 inch 304 stainless steel outer shell, minimum 3 in thermal polyurethane insulation, and an overall unit size of 11 ft tall by 4.6 ft wide. A 30 bbl fermentor volume was chosen because it can hold the total volume needed to be held in the fermentor, 930 gallons, with headspace.

Fermentation Tank Cooling

To fulfill the cooling requirements of the fermentation process as well as supplement the built-in cooling system on the fermentors, an external glycol chiller will be used to recycle the coolant. From the overall fermentation, the chiller heat duty over the 28 hours is 428,308 BTU, or 16,140 BTU/hour. From this heat requirement, an outdoor air-cooled unit was selected, and one chiller will accompany each fermentor, connected through insulated, flexible fluid lines. The outdoor air-cooled unit releases heat into the air. The selected chiller is capable of cooling 21,400 BTU an hour, and as an outdoor unit it will save internal floorspace.

Disc Stack Centrifuge

After the fermentation process, the cropped yeast slurry, containing the viable yeast and residual fermented liquid, must be filtered in order to separate the liquid and viable yeast cells. Due to the rapid sedimentation of the high flocculating yeast, bottom cropping can be used as the primary form of separation lowering the volume needed to be centrifuged and decreasing energy consumption. This step is used to obtain viable yeast for re-cropping in order to reduce inoculum costs. The centrifuge must also be sanitary and be cleaned in order to maintain a food safe product.

Filtration

After cropping the yeast, the resulting liquid must be further filtered. While the bottom cropping is able to efficiently separate larger particulate matter from the mash liquid, small particulate matter may be retained in the product. To protect further downstream equipment, fine filtration is needed. This filtration will be accomplished by an in-line bag filtration system that can match the flow rate out of the fermentor. For this, a stainless steel #4 bag filter system was chosen, as it can meet the desired filtration levels through different size pores within the bag filter (2.0 E-5, 3.9 E-5, 2.0 E-4 inches), as well as handle the flow rates needed.

Holding Tanks

The various holding tanks within the process must be of sufficient capacity while also being non-reactive. These tanks would hold any product and any materials proceeding to be processed. Cleaning will occur regularly to ensure standard cleaning habits.

Sugarcane molasses and juice will be stored in quantities large enough to supply a full week of fermentations. The sugarcane molasses does not require refrigeration and will be stored in a 1,500 gallon holding tank. The sugarcane juice will be obtained in 1,000 gallon totes and stored in a walk-in cooler to prevent spoilage.

Liquid Pumps

As there are multiple stages within the fermentation process and various tanks and units used, pumps will be necessary in order to move fermentation liquid throughout the process. Separate pumps will be needed to transfer fluid out of the fermentation tanks, from the centrifuge, to the holding tanks, and to the distillation column. Based on the flow rates needed, the sanitation requirements, and pump sizing formulas, peristaltic pumps were selected for all of the pumps except for the CIP pump, which will be a high flow centrifugal pump.

The peristaltic pumps, by design, allow for easy disassembly and cleaning. They are also suitable for providing negative pressure to pull liquid from tanks, assisting operation. The centrifugal pump is needed for the high pressure and flow requirements of the CIP process. This pump will be constructed from stainless steel, to contribute to the sanitary requirements and ease of cleaning.

Piping

In order to transport fluid between the various process units (fermentors, pumps, etc.), piping will be utilized. The piping must also be non-reactive, modular, and able to be efficiently cleaned. To meet all of these requirements, 304 stainless steel piping with tri-clamp flanges will be used to connect the process units. The 304 stainless used in the piping makes them non-reactive, while the tri-clamp system allows for easy installation and removal of the pipe sections for cleaning. The size of the pipes will be dictated by the equipment purchased, as these sizes exceed the requirements calculated. For example, the highest flow rate pipe in the system is the pipe on the outlet of the fermentor, and its minimal size was calculated to be 0.95 in internal diameter, as shown in Calculation 1 in the appendix. The corresponding tri-clamp fitting on the bottom of the fermentor is a 1.5 inch diameter clamp, with a 1.36 inch internal diameter, greatly exceeding the required 0.95 inch.

Valving

To change flows between process units, as well as adjust flow rates within the system, multi-position sanitary valves are used. The size of these valves will be by their respective tri-clamps, as the vast majority of the valves used will be ball valves, which minimally restrict flow through a pipe. The only precision flow regulation valve will be the one that meters flow from the holding tanks to the column, which will be covered in the distillation section of the capstone.

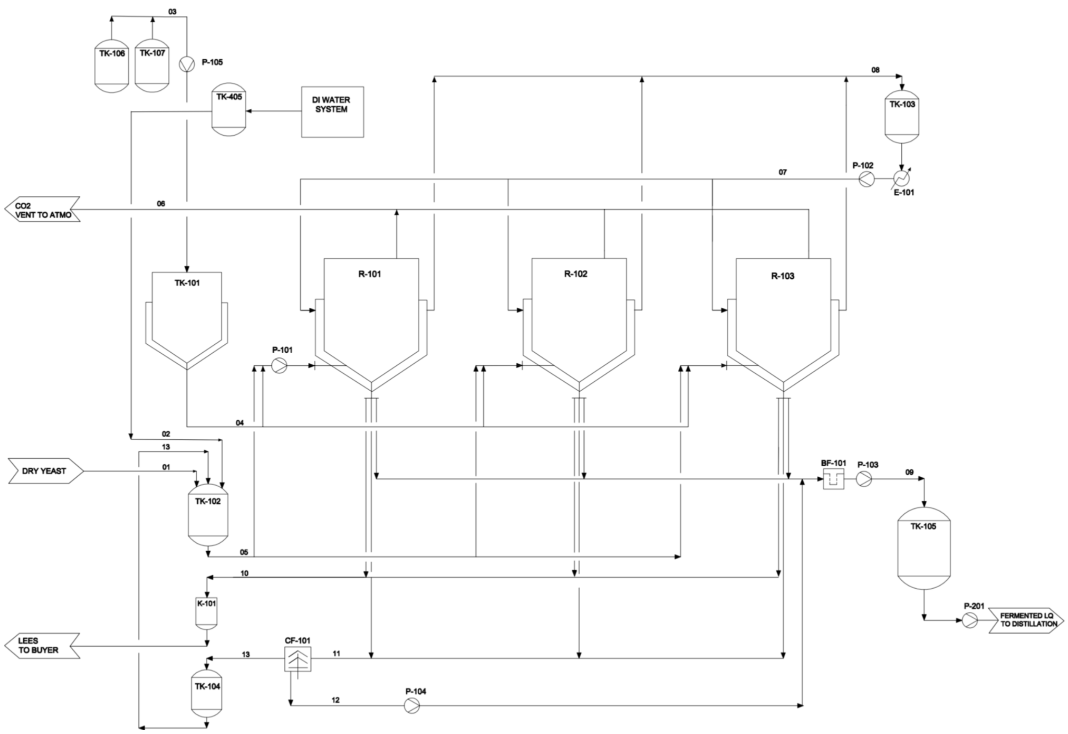

Figure 1. Fermentation Block Flow Diagram

Table 1. Fermentation Equipment Table

Equipment Type	Usage	PFD Label	Relevant Details		Annual Energy Usage (MMBTU)	Grass Root Cost	Inflation Cost
Centrifuge	Hydrocyclone	C-101				$ 80,000	$ 118,081
Cooling Fridge	Sugarcane Juice	F-101			10.5		$ 35,000
Drivers	Centrifuge	D-101			24.258	$ 80,300	$ 118,524
	Innoc/Sugar	D-102				$ 18,700	$ 27,601
	Glycol	D-103				$ 18,700	$ 27,601
	Distillate	D-104				$ 18,700	$ 27,601
	Centri-Distillate	D-105				$ 18,700	$ 27,601
	Molasses Feed	D-106				$ 18,700	$ 27,601
	Sugarcane Feed	D-107				$ 18,700	$ 27,601
Heater	Evaporator	K-101	264	gal	13.31	$ 28,100	$ 41,476
Heat Exchanger	Glycol	E-101	1	ft^2	13.11	$ 26,200	$ 38,672
Pumps	Innoc/Sugar	P-101	1	hp	0.11	$ 66,400	$ 98,007
	Glycol	P-102	1	hp	0.288	$ 66,400	$ 98,007

	Distillate	P-103	1	hp	0.0387	$ 66,400	$ 98,007
	Sugarcane Feed	P-104	1	hp	0.019	$ 66,400	$ 98,007
	Molasses Feed	P-105	1	hp	0.0455	$ 66,400	$ 98,007
	Centri-Distillate	P-106	1	hp	0.0018	$ 66,400	$ 98,007
Reactor	Fermentor	R-101	930	gal		$ 50,500	$ 74,539
	Fermentor	R-102	930	gal		$ 50,500	$ 74,539
	Fermentor	R-103	930	gal		$ 50,500	$ 74,539
Storage Tanks	Sugars	Tk-101	700	gal	2357	$ 107,000	$ 157,934
	Inoculum	Tk-102	300	gal		$ 107,000	$ 157,934
	Glycol	Tk-103	2,500	gal		$ 107,000	$ 157,934
	Dried Lees	Tk-104	4,000	gal		$ 107,000	$ 157,934
	Fermented	Tk-105	1,000	gal		$ 107,000	$ 157,934
	Sugarcane Feed	Tk-106	1,400	gal		$ 107,000	$ 157,934
	Molasses Feed Tank	Tk-107	1,000	gal		$ 107,000	$ 157,934
Total							$ 2,434,557

Scheduling

Fermentation will be run for 28 hours, with two fermentors at most running at one time. Inoculation will take approximately 1 hour, and draining and CIP will take 1 hour each. The weekly fermentation schedule, CIP steps, and design are detailed below (Table 2, Table 3, Figure 4).

Table 2. Weekly Fermentation Batch Schedule

F1 = fermentor 1, F2 = fermentor 2, F3 = fermentor 3

	Sunday	**Monday**	**Tuesday**	**Wednesday**	**Thursday**	**Friday**	**Saturday**
7:00 AM	Prep	Prep	Prep	Prep	Prep	Prep	Prep
8:00 AM	Inoculation	Inoculation	Inoculation	Inoculation	Inoculation	Inoculation	Inoculation
9:00 AM	Inoculation	Inoculation	Inoculation	Inoculation	Inoculation	Inoculation	Inoculation
10:00 AM	F1 Start	F2 Start	F3 Start	F1 Start	F2 Start	F3 Start	F1 Start
11:00 AM							
12:00 PM							
1:00 PM							

2:00 PM	F3 End	F1 End	F2 End	F3 End	F1 End	F2 End	F3 End
3:00 PM	Drain	Drain	Drain	Drain	Drain	Drain	Drain
4:00 PM	CIP	CIP	CIP	CIP	CIP	CIP	CIP

Table 3. CIP Schedule for Fermentation

*Adapted from (*Hartvigsen, n.d.)

Step	Time (min)	Temperature (F)
Pre-Rinse	2	130
Non-Caustic Burst	1	140
Pause	5	-
Non-Caustic Burst	1	140
Pause	5	-
Non-Caustic Burst	1	140
Pause	5	-
Another Rinse	2	Ambient
Sanitize	20	Ambient
Final Rinse	4	Ambient
Total	**46**	

Distillation

Distillation Column

The distillation column conditions were determined by the product requirements (a distillate of 80 vol% ethanol) while also needing to work well with the fermentation schedule and downstream processing. To keep up with the output of the fermentors, the feed into the column will be 125 gal/hr. Because the distillate product is a high concentration of 80 vol% ethanol, the column will be constructed in a fractionating design and operate continuously in order to efficiently distill to our desired specifications. The column will have 14 real stages assuming 80% Murphree efficiency with the feed being injected at the middle of the column, which we modeled in AspenPlus V11. The 6 plates above the feed will be bubble plates, while the 6 plates below the feed will be sieve plates. The bubble plates have higher plate efficiency while the lower sieve plates have a resistance to fouling that may occur from the feed. The reboiler and condenser account for the remaining 2 stages. The final distillate ethanol concentration for this design is 82 mol% or 80 vol%.

The overall dimensions of the column will be 30 ft in height, and 3.3 feet in diameter. These physical dimensions were also determined using AspenPlus V11 and its column hydraulics tool. The AspenPlus V11 operating parameters are detailed in Table 4. The column will operate at ambient pressure, to prevent potential pressure build up within the column. The column will be constructed of stainless steel and copper to assist in sanitation and improve product taste. Copper adds to the product taste by removing sulfur compounds generated during fermentation, whereas stainless steel is cheaper and easier to clean. Copper reacts with poor tasting sulfides in the distilled vapor, producing copper sulfate. This reaction consumes a minute amount of copper from the still, but cleans up the flavor profile of the beverage. Heat duties will be fulfilled by a reboiler and condenser, which will be discussed in their own sections.

Table 4. Column Operating Parameters for AspenPlus V11 Simulation

Parameter	Quantity	Units
Column Pressure	14.7	psig
Inlet Temp	77	℉
Distillate Temp	172.8	℉
Bottoms Temp	197.4	℉
Real Trays	14	Trays
Reflux Rate	10	mol reflux/mol distillate
Column Diameter	3.3	ft
Column Height	30	ft

Reboiler

The reboiler in the system must add enough heat to the column to maintain the VLE in each stage of the column. Based on the AspenPlus V11 calculations, the heat duty of the reboiler is 1.47 MMBTU/hr and will require 114 sqft. The reboiler will be a 6 foot long exchanger with 73 one inch tubes, which pack into an approximately 1 foot diameter housing. It is a thermosyphon design and constructed of stainless steel in order to minimize corrosion and resist fouling. The column liquid will be on the tube side for easy maintenance, and indirect steam will be supplied for heating on the shell side at 72.5 psig and 320℉. The thermosyphon construction means there are less equipment requirements, as the heat transfer is driven through passive convection.

Condenser

The condenser in the system must add enough heat to the column to maintain the VLE in each stage of the column as well as producing a liquid product. Based on the AspenPlus V11 calculations, the heat duty of the condenser is 1.36 MMBTU/hr and will require 94 sqft. Our condenser design will be a 5 foot long exchanger with 53 one inch tubes, which pack into an approximately 1 foot diameter housing. It is a shell and tube fed liquid design, with cooling water fed into the shell side of the exchanger. The distillate will be on the tube side for fouling reasons, and the cooling water on the shell side.

Pumps

As there are multiple process units and flows within the distillation section, pumps will be necessary in order to move various liquids throughout the process. Separate pumps will be needed to circulate cooling water through the condenser, inject feedstock into the column, and transport distillate and bottoms away. Based on the flow rates needed, the sanitation requirements, and pump sizing formulas, peristaltic pumps were selected for all of the pumps except for the CIP pump, which will be a high flow centrifugal pump.

The peristaltic pumps, by design, allow for easy disassembly and cleaning. They are also suitable for providing negative pressure to pull liquid from tanks, assisting operation. The centrifugal pump is needed for the high pressure and flow requirements of the CIP process. This pump will be constructed from stainless steel, to contribute to the sanitary requirements and ease of cleaning.

Valves

To change flows between process units, as well as adjust flow rates within the system, multi-position sanitary valves must be used. The size of these valves will be by their respective tri-clamps, as the vast majority of the valves used will be ball valves, which minimally restrict flow through a pipe. The only precision flow regulation valve will be the one that meters flow from the holding tanks to the column, which will be a computer controlled regulatory valve.

Pipes

In order to transport fluid between the various process units (column, pumps, etc.), piping will be utilized. The piping must also be non-reactive, modular, and able to be efficiently cleaned. To meet all of these requirements, 304 stainless steel piping with tri-clamp flanges will be used to connect the process units. The 304 stainless used in the piping makes them non-reactive, while the tri-clamp system allows for easy installation and removal of the pipe sections for cleaning. The size of the pipes will be dictated by the equipment purchased, as these sizes outclass the requirements calculated. For example, the highest flow rate pipe in the system is the input of the column, and its minimal size was calculated to be 0.36 inch internal diameter, as shown in Calculation 1 in the appendix. This will be rounded up to a 0.5 inch diameter pipe to work with generic pipe sizing. For ease of installation, some of the piping will be made up of sterile flexible tubing.

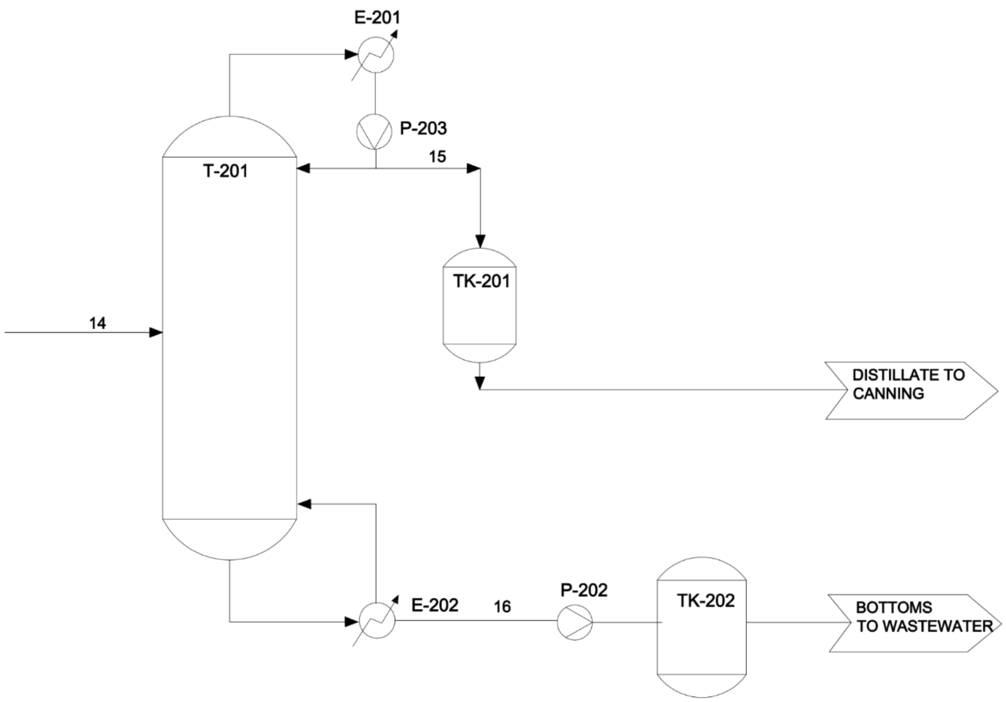

Figure 2. Distillation Block Flow Diagram

Table 5. Distillation Equipment Table

Equipment Type	Usage	PFD Label	Relevant Details		Annual Energy Usage (MMBTU)	Grass Root Cost	Inflation Cost
Drivers	Distillation Feed	D-201				$ 18,700	$ 27,601
	Bottoms	D-202				$ 18,700	$ 27,601
	Distillate	D-203				$ 18,700	$ 27,601
Heat Exchanger	Reboiler	E-201	94.1	ft^2	4022.81		$ 20,500
	Condenser	E-202	136.1	ft^2	3736		$ 21,600
Pumps	Distillation Feed	P-201	1	hp	0.42	$ 66,400	$ 98,007
	Bottoms	P-202	1	hp	0.22	$ 66,400	$ 98,007
	Reflux Pump	P-203	1	hp	2.213	$ 66,400	$ 98,007
Tower	Column	T-201	14	trays	495.11		$ 172,000

Storage Tanks	Distillate Storage	Tk-201	2,500	gal	$ 107,000	$ 157,934
	Bottoms Storage	Tk-202	350,000	gal	$ 264,000	$ 389,668
Total						$ 1,138,528

Scheduling

The distillation will be run over 8 hours during the day and 1 hour is allotted for startup and shutdown. The reboiler will be cleaned weekly and the condenser and column will be cleaned monthly. The distillation schedule is shown in Table 6, and will be run after each batch fermentation. While there is scheduling overlap with fermentation, with the automated column controls an employee only needs to perform a checklist and start the unit, afterwhich the column will run itself until shutdown with minimal oversight other than to make sure the unit is running smoothly. The daily startup and shutdown procedures minimize the operating costs of the column for our small scale distillery and prevent buildup of impurities in the column that would threaten food safety.

Table 6. Distillation Schedule

7:00 AM	Startup
8:00 AM	Run
9:00 AM	
10:00 AM	
11:00 AM	
12:00 PM	
1:00 PM	
2:00 PM	
3:00 PM	Shutdown
4:00 PM	Cleaning

Flavoring, Carbonation, & Canning

Carbonation Machine

Seltzers require about 0.05 lb/gal of CO_2, meaning we will require 2,955 gallons of liquid CO_2 a year (*The Science of (and Guide To) At-Home Carbonation*, n.d.). For our recipe, this will be combined with 450,000 gallons of water a year, meaning we will need to produce around 40 gallons of carbonated water per hour to meet our standard. The stainless steel HF1500 requires 7507 BTU/hr to run and will be connected to the canning machine and will feed into the holding vessel to ensure very minimal carbonation will be lost through transferring (*Alibaba Carbonation Machine*). The machine will not produce any excess sparkling water to ensure no large pressure build up as well as no loss of carbonation through any transferring.

Canning Machine

While we need to produce 5.3 million cans of product, we plan to run the canning machine only during work hours. With these time constraints, we need to produce 1555 cans per hour. The Stainless Steel 304 YLG12-1 has 12 canning heads that can seal up to 1,800 cans per hour, which would sufficiently meet the production requirements for this machine, requiring 11,942 BTU/hr of power to run each station. It has three different parts: Rinsing, Filling, and Sealing (*Alibaba Canning Machine*). CO_2 will first be fed to rinse out the cans before filling, and then will be fed again once the liquid product has been filled in the can. The machine will then seal the can and it will be sent to the labeling machine.

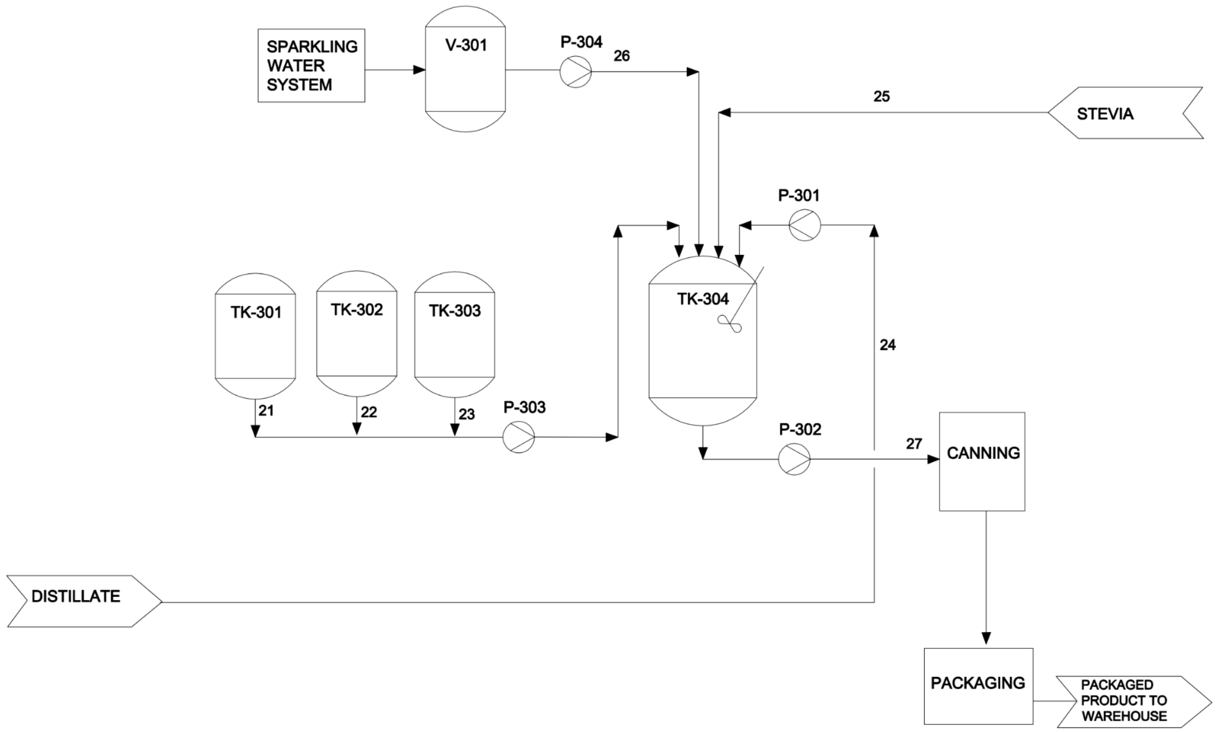

Figure 3. Canning/Mixing Block Flow Diagram

Table 7. Canning/Mixing Equipment Table

Equipment Type	Usage	PFD Label	Relevant Details		Annual Energy Usage (MMBTU)	Grass Root Cost	Inflation Cost
Drivers	Canning	D-301				$ 18,700	$ 27,601
	Flavoring	D-302				$ 18,700	$ 27,601
	Sparkling Water	D-303				$ 18,700	$ 27,601
Mixer	Impeller	M-301			3	$ 127,000	$ 187,454
Pumps	Distillate	P-301	1	hp	2.213	$ 66,400	$ 98,007
	Canning	P-302	1	hp	0.1297	$ 66,400	$ 98,007
	Flavoring	P-303	1	hp	0.07	$ 66,400	$ 98,007
	Sparkling Water	P-304	1	hp	0.3	$ 66,400	$ 98,007
Storage Tanks	Lemon/Lime	Tk-301	500	gal		$ 107,000	$ 157,934
	Strawberry	Tk-302	500	gal		$ 107,000	$ 157,934
	Cranberry	Tk-303	500	gal		$ 107,000	$ 157,934
	Mixing Tank	Tk-304	1,500	gal		$ 107,000	$ 157,934
Vessel	Carbonation	V-301	13,000	gal		$ 544,000	$ 802,952

	Storage			
Other	Carbonation Machine	Z-301	25.75	$ 60,400
	Canning Machine	Z-302	40.96	$ 17,900
	Packaging Machine	Z-303	10	$ 24,900
Total				$ 2,200,174

DI Water System

Deionized water is required for fermentation as well as cleaning the other processes, so having a DI water system will be essential for our distillery. The WIRIX-DI10 produces 10 gallons/min of DI water with a filter replaced per thousand gallons of water created assuming the water's total dissolved solids (TDS) do not exceed 400 ppm. The system has a 1000 gallon tank, pumping with a 60 psi outlet. It also contains built in ion exchange resin with two cation vessels each with 2.5-ft^3 of strong acid for 50,000 total grains generated with 4-lbs 32% HCl. Each Anion vessel has 2.5-ft^3 with 45,000 total grains with 6-lbs 50% NaOH with built in resin regeneration.

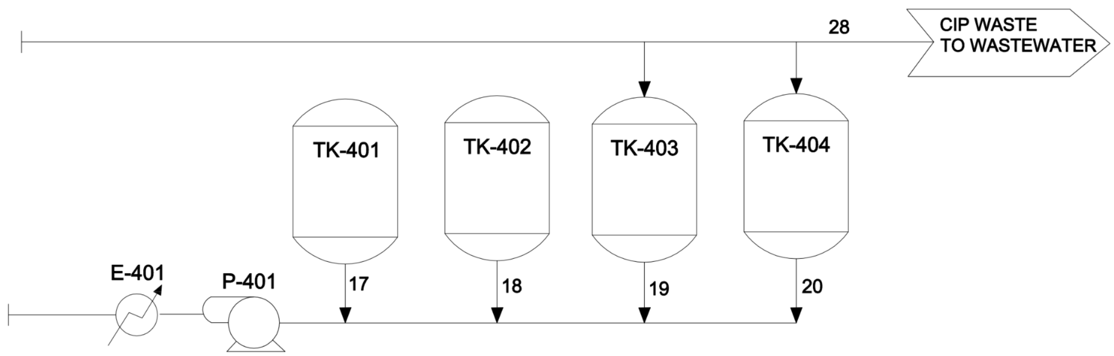

Figure 4. CIP Block Flow Diagram

Table 8. DI Water System/CIP Equipment Table

Equipment Type	Usage	PFD Label	Relevant Details		Annual Energy Usage (MMBTU)	Grass Root Cost	Inflation Cost
Driver	CIP	D-401				$ 18,700	$ 27,601
Heat Exchanger	CIP	E-401	24.4	ft^2	36.7	$ 26,200	$ 38,672
Pump	CIP	P-401	1.54	hp	1.34	$ 50,500	$ 74,539
Storage Tanks	Pre Rinse	Tk-401	300,000	gal		$ 244,000	$ 360,148
	Non-Caustic	Tk-402	100,000	gal		$ 155,000	$ 228,782
	Sterilizer	Tk-403	60,500	gal		$ 132,000	$ 194,834
	Final Rinse	Tk-404	500	gal		$ 107,000	$ 157,934
	DI Storage	Tk-405	1,000,000	gal		$ 244,000	$ 360,148
Other	DI Water System	Z-401					$ 156,000
Total							$ 1,598,657

Table 9. Final Product Recipe

Ingredient	Quantity	Unit
Sparkling Water	10.8	fl. oz
Alcohol	1.2	fl. oz
Natural Flavoring	0.036	fl. oz
Stevia	0.07	oz
Aluminum Can	1	can

Process Economics

To evaluate the economics of our designed distillery, we first incorporated initial investments to build the distillery. We assumed land would be purchased for \$230,000 for 3.43 acres based on a land listing right outside Raleigh, NC, and calculated the fixed capital investment (FCI) using the grass roots method conservatively (*0 Pecan Ln, Clayton, NC 27527 - Land for Sale*, n.d.). The grass roots method was used to calculate the FCI and determine the initial cost of creating the plant including building the facility and purchasing all equipment. Using CAPCOST, the FCI was calculated to \$5,099,800, however, this was calculated using a Chemical Engineering Plant Cost Index (CEPCI) of 542 which does not account for inflation. To account for inflation, a CEPCI index of 800 was used and our final FCI cost was \$7,371,916.

To determine the cost of labor, C_{OL}, the equation below was used to determine the number of positions needed to run our distillery. We assumed the number of non-particulate processing steps (P) was 2, and the number of nonparticulate processing steps (N_{np}) was 9, resulting in the number of positions (N_{OL}) to be 12. An additional position is required to monitor the fermentors during the night shift. From Indeed.com, the salary for a plant operator in Raleigh is \$55,718, meaning total labor cost would equate to \$724,334.

$$N_{OL} = \left(6.29 + 31.7P^2 + 0.23N_{np}\right)^{0.5}$$

When determining the cost of raw materials, C_{RM}, each block of the process was accounted for, detailed in the table below, resulting in a total material cost of \$2,007,561.

Table 10. Raw Material Table

Block	Material	Price ($/lb)	Flow rate (lb/hr)	Annual Cost
Fermentation	Yeast	$ 29.48	1.95	$ 197,177
	Molasses	$ 0.13	255.05	$ 113,639
	Sugarcane Juice	$ 0.26	427.46	$ 381,209
Canning/Mixing	Stevia	$ 8.26	6.8	$ 192,707
	Natural Flavoring	$ 47.49	3.65	$ 594,112
	CO_2	$ 0.19	6.56	$ 4,275
	Aluminum Sleek Cans	$ 4.49	31.19	$ 479,997
	Cardboard Boxes	$ 0.46	28.47	$ 44,445
Total Cost				**$ 2,007,561**

The total cost of utilities, C_{UT}, for running the canned cocktail facility was determined through a combination of CAPCOST, AspenPlus v12, as well as hand calculations for the heat exchangers. The breakdown by utilities process component is shown below. The cost to run the DI water system is a fixed cost given by Water innovations of $5 per 1000 gallons of water produced. Our estimated 645,000 gallons of water produced a year will cost about $3,226. The total utilities cost per year is $203,172.

Table 11. Utilities Table

Utilities	Process	Rate ($/MMBTU)	Power per Year (MMBTU)	Cost
Low Pressure Steam	Inoculum Pretreatment, Evaporator, Heat Exchanger, Reboiler	$ 4.79	6442.93	$ 30,862
Electricity	Canning Machine, Carbonation Machine, Centrifuge, Cooling, Distillation Column, Pumps	$ 20.04	646.27	$ 12,951
Cooling Water	Condenser	$ 0.42	3736	$ 1,562
Other	DI Water System, CIP Material, Glycol Cooling			$ 157,797
Total Costs				**$ 203,172**

Finally, the waste costs, C_{WT}, comprises the bottoms of the distillation column and the waste supply of the CIP. This can be broken down into non-hazardous waste and hazardous waste. The total cost breakdown can be seen below, where the main expenses are from the distillation bottoms waste and the CIP excess.

Table 12. Waste Management Table

Type	**Waste**	**Price ($/lb)**	**Flowrate (lb/hr)**	**Annual Cost**
	Bottoms Waste	$ 0.02	7.58	$ 424.00
Non-hazardous	Rinse Water (CIP)	$ 0.02	3	$ 168.00
	Peracetic Acid Waste (CIP)	$ 0.14	3.01	$ 1,405.00
Hazardous	Non Caustic Solution	$ 0.14	2.98	$ 1,391.00
Total Cost				**$ 3,388.00**

Totaling the operating costs and the FCI, the cost of manufacturing can be broken down into three categories: direct, fixed and general. The equation used to calculate is seen below which includes the factor of depreciation.

$$COM_D = (0.21)FCI_L + (1.9975)C_{OL} + C_{UT} + C_{WT} + C_{RM}$$

In the table below is the breakdown of each category and the percentage it holds for the cost of manufacturing of $5,209,080.

Table 13. Cost of Manufacturing Table

Category	Costs
Direct	$ 3,543,423
Fixed	$ 1,485,420
General	$ 180,237
Total Cost of Manufacturing	$ 5,209,080

Regarding our revenue, our two sources include our main product, the canned cocktails which will be sold as cases of twelve 12-oz cans, at a wholesale price of $15 and a byproduct of evaporate lees that will be sold at $12 per pound as feed stock. This wholesale price was estimated by the cost of 12-packs of beer products which are sold for around $11 (*Domestic Beer*

Price List, n.d.). Due to our premium distilled quality as well as our higher ABV, the higher wholesale price is justified. This brings out total revenue a year, at $7,066,275, as seen in the table below. The cost of production for each case is approximately $6.61/case.

Table 14. Revenue Table

Product	Total Production	Unit	Wholesale	Annual Revenue
Canned Cocktail	444445	cases	$ 15.00	$ 6,666,675.00
Lees	33,300	lbs	$ 12.00	$ 399,600.00
Total				$ 7,066,275.00

To determine if this process is economically viable, a discounted cash flow can be determined, which estimates the value of an investment using its expected future cash flows. The working capital is 10% of the FCI, which is 737,191. With a 20 year plan, a 7-year straight line depreciation and a taxation of 28.25% (21% corporate, total income tax of 4.75%, and a corporate income tax of 2.5%), this project seems economically viable. This includes a conservative estimate of 2 years for construction where the first year would account for paying the land and 50% of the FCI, the following would be the remaining FCI, and the opening year would be the working capital (estimated at 10% of the total FCI). The internal rate of return (IRR) is 28.3% and the plant will begin making profit after 1 year. These values are quite small for the growing market so another scenario was determined. Additionally, from the scenario 1 graph, the discounted cash flow drops significantly after 10 years and becomes insignificant after 16 years. After 20 years, our plant would have a cash flow of $19,982.

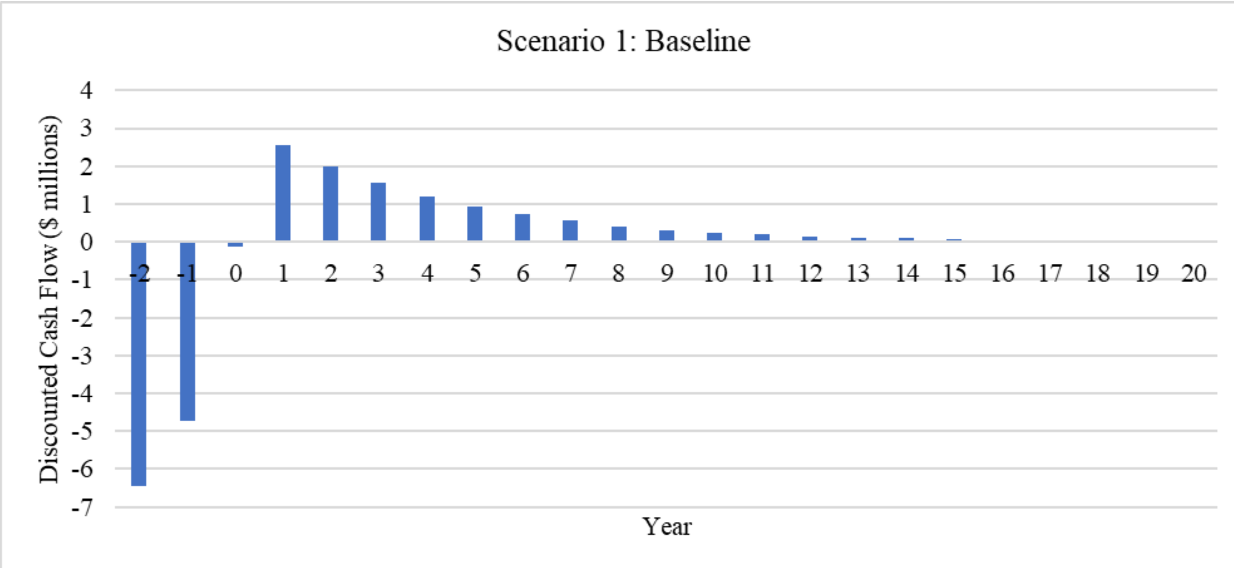

Figure 5 . Discounted Cash Flow for Initial Scenario

Scenario 2

We also modeled an improved scenario, with a higher revenue and a lower plant life would produce a larger cash flow. A local canned cocktail company, Waterbird, has a variety pack sold at 15% for 6 cans, 6.5% ABV. By changing our packaging numbers from 12 cans per case to 6 cans per case, our product can be charged at the slightly lower wholesale price matching what Waterbird sells their 6 packs for of $10.00 per 6 cans, resulting in a higher revenue with the same starting materials. This gives our revenue upwards of $9.28 million.

Table 15. Revenue for Lower Quantity and Lower Plant Life

Product	Total Production	Unit	Wholesale	Annual Revenue
Canned Cocktail	888,890	cases	$ 10.00	$ 8,888,900.00
Lees	33,300	lbs	$ 12.00	$ 399,600.00
Total				$ 9,288,500.00

Additionally, given our plant's lower profitability in 20 years, a 10 year plan with a 4-year straight line depreciation can be used to give a higher IRR of 39.25% and a final present value of $164,380, both much higher than the initial scenario. This plant would be profitable within the first year. This scenario gives the best overall projected outcome.

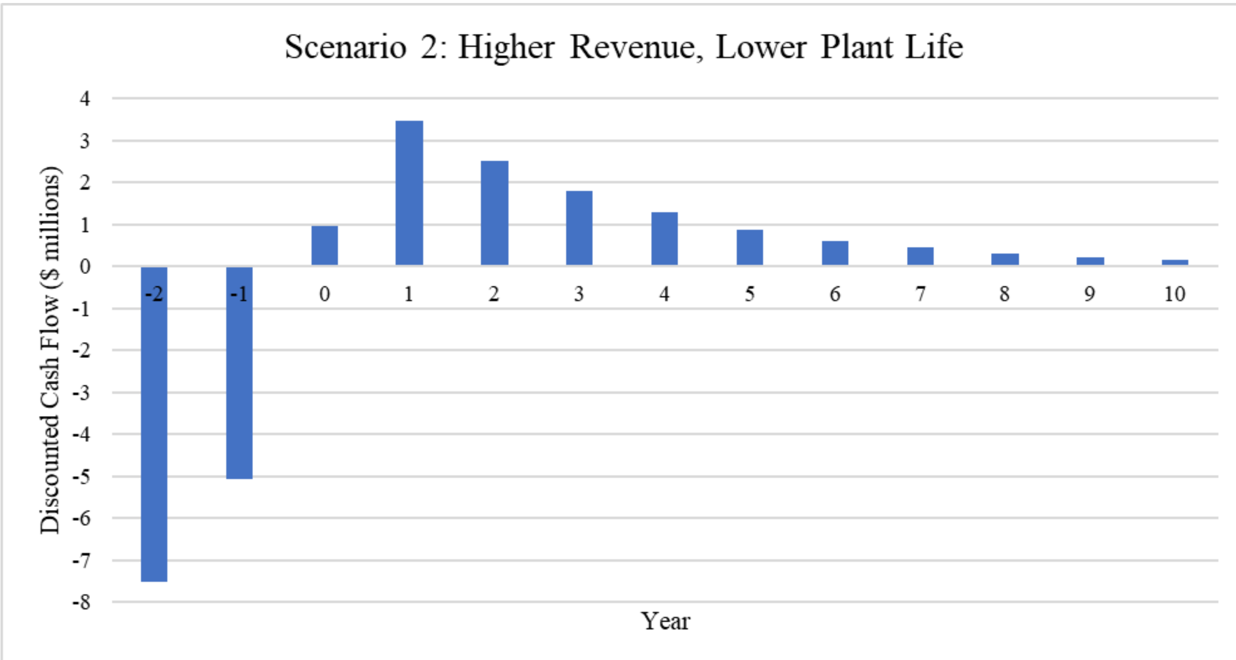

Figure 6. Discounted Cash Flow for Lower Quantity and Lower Plant Life

Safety and Environment

Chemical Compatibility

Reactivity matrixes were created using the AiCHe Chemical Reactivity Workbook. Detailed below are some of particular hazards and chemical compatibility issues to be aware of.

Fermentation

Calcium carbonate which will be used in small quantities to raise the pH of the fermentation media is reactive with water and calcium chloride. The reaction of calcium carbonate and water produces gaseous products that can result in pressurization. The use of calcium carbonate as a pH modifier involves it being intentionally mixed into the fermentation media that contains water. Therefore, the addition of calcium carbonate into the sugarcane mixture will only be done in very small quantities within the mixing vessel that is vented to the atmosphere to prevent pressure buildup due to gasses released during reaction with water.

Similar precautions will be taken when Calcium Chloride is used as a pH modifier for the fermentation media. Calcium chloride reacts with water to form gaseous and possibly corrosive products. Additionally calcium chloride and calcium carbonate are incompatible with each other and react exothermically producing gaseous products that can create pressurization. Therefore the pH modifiers will be stored far apart and in dry areas to prevent potential mixing.

Y : Compatible
N : Incompatible
C : Caution
SR : Self-Reactive
* : Changed by user

NFPA Health	NFPA Flammability	NFPA Instability	NFPA Special	Fermentation Compatibility Chart	CALCIUM CARBONATE	CALCIUM CHLORIDE	CARBON DIOXIDE	ETHANOL	METHANOL	SUCROSE	WATER
				CALCIUM CARBONATE							
				CALCIUM CHLORIDE	N						
				CARBON DIOXIDE	Y	Y					
2	3	0		ETHANOL	Y	Y	Y				
1	3	0		METHANOL	Y	Y	Y	Y			
				SUCROSE	Y	Y	Y	Y	Y		
				WATER	C	C	Y	Y	Y	Y	

Figure 7. Fermentation Chemical Compatibility

CIP

The compatibility of the CIP chemicals was evaluated against the other chemicals used in the CIP cycle as well as ethanol, sugar, carbon dioxide, and the potential residues within the vessel being cleaned. Sodium Silicate is the general form of sodium metasilicate, a component in the non caustic cleaner, and is incompatible with water. The reaction is a potentially explosive exothermic reaction that releases flammable gas. Sodium metasilicate is soluble in water and is used in a aqueous solution during the CIP cycle, however due to the potential hazards the preparation of the non caustic cleaner presents the preparation must be done carefully ensuring that the concentration of sodium metasilicate isn't too high. During CIP cycles in the fermentors, the ventilation system to the atmosphere – used during fermentation to vent carbon dioxide – will remain open to prevent any buildup in pressure.

Y : Compatible
N : Incompatible
C : Caution
SR: Self-Reactive
*: Changed by user

NFPA Health	NFPA Flammability	NFPA Instability	NFPA Special	Fermentation Compatibility Chart	CALCIUM CHLORIDE	CARBON DIOXIDE	ETHANOL	METHANOL	SODIUM HYDROXIDE, SOLID	SUCROSE	WATER
				CALCIUM CHLORIDE							
				CARBON DIOXIDE	Y						
2	3	0		ETHANOL	Y	Y					
1	3	0		METHANOL	Y	Y	Y				
3	0	1		SODIUM HYDROXIDE, SOLID	N	Y	N	N			
				SUCROSE	Y	Y	Y	Y	N		
				WATER	C	Y	Y	Y	C	Y	

Figure 8. CIP Chemical Compatibility

Distillation and Canning

No significant chemical incompatibilities are present for the compounds used in the distillation and canning processes.

Procedures

The main potential hazards present in this process are related to the volatility of ethanol. Precautions to limit potential ignition sources include, grounding all tanks, machinery, and loading vehicles, avoiding use of plastic vessels that can accumulate charge, instillation of class 1 / div 1 electronics within the distillation unit, and restriction of handheld electronics within high vapor areas of the plant. Furthermore, to reduce the source risk, adequate ventilation will be required in all units with the distillation unit to prevent any volatile vapor accumulation and all emergency relief will be vented outside of the structure. Distilled liquor will be stored away from heat sources in grounded storage tanks. The quantity stored on site will be limited to prevent increased threat level of a potential explosion or fire.

Additionally, there are hazards associated with mechanical equipment such as the canning and boxing machines, forklifts, and delivery trucks.

Equipment Failure

Reactor

Reactors can fail due to both operating conditions and user mistakes. With an exothermic reaction, the reactor is dependent on sufficient cooling to operate, as well as sufficient agitation within the reactor, both helping prevent hotspots. They are also highly dependent on the user, as incorrect components or reaction can lead to a build up of pressure due to failure of properly venting enough of the CO_2 or the lack of sufficient cooling water could heat the reactor to temperatures completely unsuitable for yeast viability causing a crash in fermentation prior to reaching the desired ABV.

Storage Tanks

Due to the volume of liquid being used, the storage tanks in the process will see a large amount of static load and possibly cyclic loading. Together, these can cause an overall tank failure. The tanks may also corrode due to the material contained, as well as the gas pocket contained above the liquid. Pressurized containers can explode if they fall and need to be secured to a wall.

Pipes

The pipes being used in this plant have failure modes related to the degradation of the wall construction. With the chemicals being used, the pipes can fail due to internal corrosion as well as fouling. The pipes can also fail due to possible cyclic loading that could lead to structural stresses.

Valves

The silicone production process uses a multitude of valves, varying in internal design and overall size. These valves can fail due to the wear between moving parts, possibly leading to leaks or total failure. They can also fail due to internal fouling or corrosion, which can lead to a breach in containment or valve failure.

Pumps

Pumps are prone to failures as they both contain rotating equipment as well as high pressure. Mechanical degradation can occur due to cavitation and corrosion. They can fail due to this mechanical degradation, which could lead to the equipment stopping or deadheading within the pump. The pressure contained can also build, and lead to containment failure through cyclic loading.

Cooler

Coolers can fail due to mechanical degradation as well as corrosion/fouling. These can lead to inadequate heat transfer, containment failure, and possible internal chemical mixing.

Distillation Column

The distillation column needs its parameters to be highly regulated, and as such can suffer from related failures. Physical damage to the column and trays can occur due to large pressure changes, cyclic loading, and excessive vibration. Containment vessels can also be damaged due to tray plugging and contamination.

Heater

Heaters, due to their exothermic nature, can have catastrophic failure modes. Combustion heaters can explode due to unburnt fuel, caused by a buildup of fuel within the heater vessel. The heating vessel itself can also fail, caused by conditions such as cyclic loading, corrosion, or fouling.

Environmental Concerns

Waste water produced during fermentation and used in CIP cycles cannot be released into the environment without treatment. Treatment will not occur on site; therefore, wastewater will be temporarily stored on site and then be transported to a treatment facility. Soil and water surrounding the plant will be tested for contamination to identify possible leaks or spills. Ideally carbon dioxide produced would be collected and cleaned for canning to limit the emission of greenhouse gasses from our facility. However, carbon capture for a microdistillery scale is not economically viable.

Waste

Fermentation Waste

Carbon dioxide will be vented out of the system. Capturing the carbon dioxide was considered, but the costs associated with drying and cooling the exhaust were determined to be too costly and our relatively small scale makes recycling of CO_2, sadly, inefficient. Luckily, the amount of carbon dioxide vented to the atmosphere is small enough that we do not surpass state or federal venting regulations and so can vent the CO_2 from our system without additional costs or procedures. North Carolina doesn't have any limits or caps on CO_2 emissions as the Supreme Court issued a ruling stating that the EPA cannot put state-level caps on carbon emissions under the 1970 Clean Air Act as of July 2022. Additionally, while not ideal to be releasing CO_2 into the atmosphere, our design attempts to limit the amount of CO_2 released at 5 pounds of CO_2 per case of 12 cans. This equates to 0.42 pounds per drink. To give this number some context, the average human exhales about 2.3 pounds of carbon dioxide on an average day making our drinks quite a small overall impact on the environment.

Distillation Waste

The only main source of waste in our distillation process is the bottoms products. The bottoms of our distillation consists of a mixture of 0.03 mol% ethanol which was not removed during distillation and water. Additionally, there may contain trace amounts of glycerol, lactic acid, acetic acid, and succinic acid in the bottoms of the column. After distillation is complete, the bottoms waste will be collected and sent to the city of Cary's wastewater treatment plant – approximately 10 miles away from our plant – where the ethanol content and other impurities will be removed. North Carolina Department of Environment, Health, and Natural Resources (1998) states that, "solutions containing less than 24% of ethanol, propanol or isopropanol," can be directly handled by the wastewater treatment plants. This means that our bottoms waste needs no treatment or dilution before being disposed of.

Because we are not handling the waste disposal ourselves, there is a cost associated with the disposal process. According to the city of Raleigh's utilities rates, Raleigh charges $15.68 per CCF of wastewater outside the city limits with a meter size of ⅝ inches (City of Raleigh, 2023). For each hour the distillation column is run, 90.3 gallons of bottoms waste is produced. Scaling this up to a yearly value, assuming our distillation column is running as expected for 7 hours a day, 7 days a week, for 48 weeks, determines that the process will be generating 213,000 gallons or 284 CCF of waste per year. This means that it will cost around $4,550 per year to dispose of the bottoms waste. While a yearly cost of almost $5,000 dollars may seem like a lot to dispose of the waste, it was found that sending our waste to Cary's wastewater treatment plant was not only cheaper, but also ensured that our waste was disposed of in the proper manner rather than handling the waste in-house.

Societal Considerations

Consumption of alcohol has remained steady with 55-71% of the US population consuming alcoholic beverages at least on an occasional basis since 1939 (Inc, 2022). Despite specific religious groups that do not drink alcohol, more non-alcoholic products on the market, and an increase in individuals abstaining from alcohol, there is still a large drinking population in the United States to make a profit. Due to the large and steady portion of the population that consumes alcohol, the health impacts of ethanol consumption is well-studied. Ethanol is a psychoactive substance that can result in dependency with chronic use and is a causative factor of over 200 diseases and health conditions such as liver cirrhosis, cardiomyopathy, and gastritis, and over consuming alcohol can lead to alcohol poisoning and death (*Alcohol*, n.d.). Alcohol dependence, or alcoholism, is a disease in which continued and excessive drinking causes dependency and withdrawal symptoms with cessation of consumption (Becker, 2008). Alcoholism not only impacts individual health, but impacts societal functioning making it a public health priority and an important consideration in the decision to manufacture alcoholic beverages.

Producing and selling alcoholic products requires additional federal and state permits that vary by state. At the federal level, a permit to manufacture spirits as well as to buy distillation equipment are needed (*Distillate - State Alcohol Laws for North Carolina*, n.d.). In order to distill, a distillation permit is required in the state of North Carolina, which has an application fee of $300 (*Permit Types - NC ABCC*, n.d.). In order to transport, sell, package, and label alcoholic beverages, a Spirituous Liquor Warehouse license is required with no additional cost. Applying for, paying, and waiting for approval and permits pose a major hurdle to the establishment of distilleries. Furthermore, selling distilled spirits and mixed beverages has a 7% combined general rate of sales and use tax compared to 4.75% tax on beer and wine (*Spirituous Liquor | NCDOR*, n.d.). Relatively, North Carolina has a high tax on beer compared to other states, but distilled spirits will still cost more than beer and wine products, increasing consumer proclivity to avoid distilled products that cost more. Due to the appeal of a better tasting beverage than malt-based alcoholic beverages, our design should entice consumers to overlook the higher price of the distilled product.

Another consideration is the prevalence of underage drinking especially with sweeter and fruity alcoholic beverage cocktails. Underage drinking is dangerous as it can impair neurological development and increases the likelihood of binge drinking and alcohol poisoning as well as alcoholism in adulthood (Harding et al., 2016). Due to the legal consequences and attempts to conceal underage drinking, inebriated driving is more likely and can result in deaths. Other factors that contribute to underage drinking are college environments and other drug use such as marijuana in an individual's social group. In order to reduce the likelihood of underage drinking, our product will be labeled as an alcoholic product for individuals aged 21 and over and marketing for this product will be clearly for adults of legal drinking age.

Conclusions and Recommendations

Our final design encompasses fermentation, distillation, flavoring, carbonation, canning, and safety, environmental, and societal considerations. Fermentation will be run over 28 hours in batches, with no more than two fermentors running at once, with a high-flocculating yeast strain and high gravity fermentation media composed of molasses and sugarcane juice. Our distillation column will distill to 80 vol% ethanol and our final product will be diluted with sparkling water, natural flavoring, and Stevia to a final concentration of 8% ABV. We accounted for safety and environmental concerns with the various byproducts and chemicals in our process, and societal concerns such as alcoholism.

Our final recommendation is to move forward with this design as its overall profits and feasibility, as well as relatively low safety and environmental concerns, make it an intriguing business opportunity. The next steps for this plant design are to test the entire process at a small scale to evaluate safety, efficiency, and taste quality, acquire necessary state and federal licenses, and build the plant. Future groups may look into alternative methods to minimize venting of carbon dioxide, different fermentation methods to minimize costs associated with the yeast strain and media components, and costs associated with shipping locally, nationally, and worldwide. Furthermore, our team assumed no product was lost downstream of the fermentation process, thus future groups should account for possible product loss in the distillation, mixing, and canning processes.

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Appendix

Table A1. Nomenclature Table

Symbol	Meaning
ABV	alcohol by volume
oz	ounces
VHG	very high gravity
CO_2	carbon dioxide
AM	ante meridiem
PM	post meridiem
CIP	cleaning in place
mol%	mole percent
bbl	barrel
in	inch
ft	foot
BTU	British thermal unit
gal	gallon
hp	horsepower
sqft	square feet
$	US dollars
%	percent

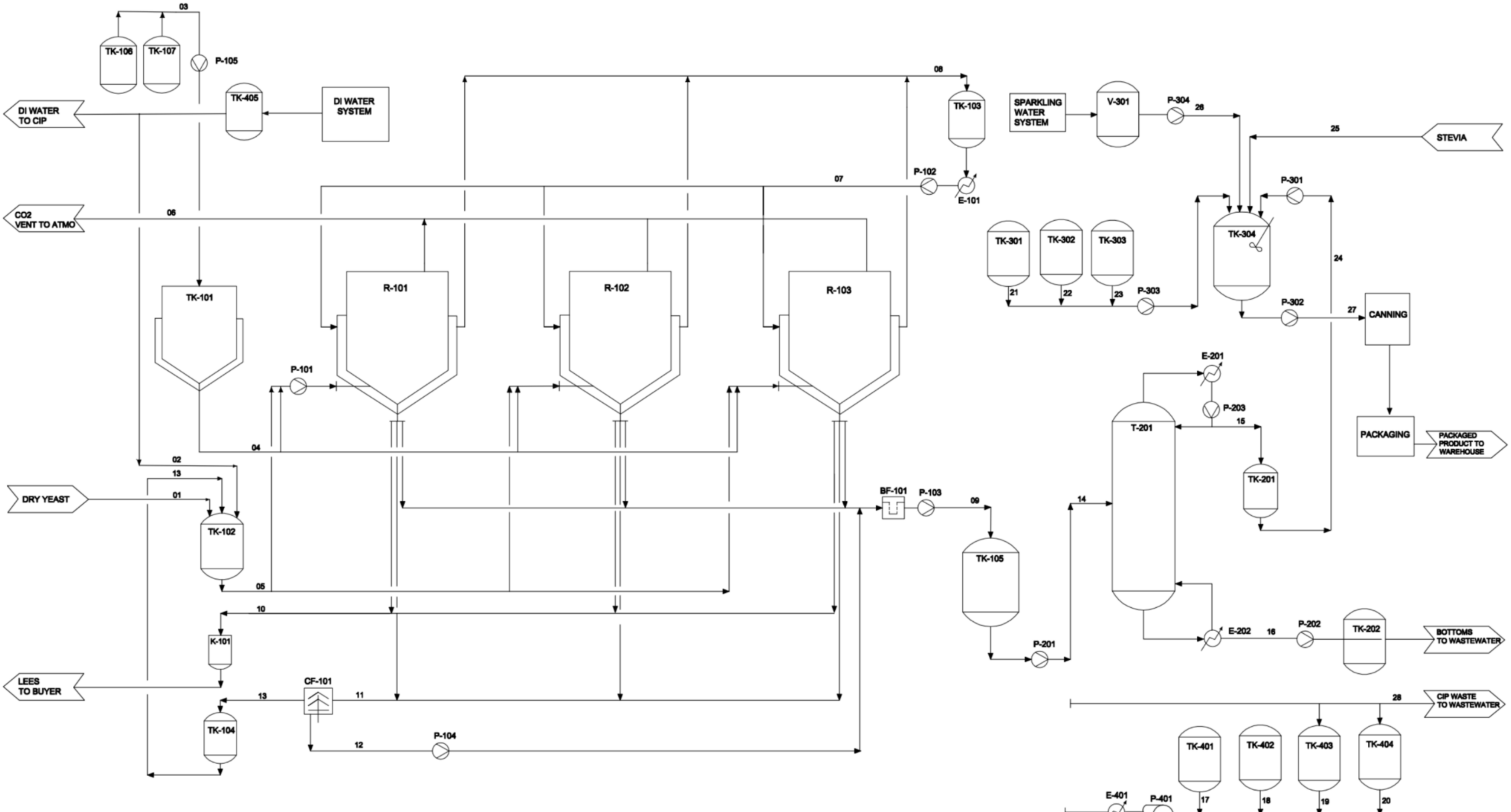

Figure A1. Overall Process Flow Diagram

Table A2. Stream Table

NUMBER	01	02	03	04	05	06	07	08	09	10	11	12	13	14
NAME	DRY YEAST	DI WATER	SUGAR FEED	PRE-TREATED FEED	INNOCULUM	FERMENTOR OFF GAS	GLYCOL SUPPLY	GLYCOL RETURN	FERMENTED LIQUID	LEES	VIABLE YEAST SLURRY	FERMENTED LIQUID	YEAST FOR RE-CROP	FERMENTED LIQUID
FLOW RATE	97.24 LB/BATCH	279 GAL/BATCH	651 GAL/BATCH	651 GAL/BATCH	279 GAL/BATCH	50,600 GAL/BATCH	2,978 GAL/BATCH	2,978 GAL/BATCH	907 GAL/BATCH	11.6 GAL/BATCH	11.6 GAL/BATCH	11.6 GAL/BATCH	324 KG/BATCH	127 GAL/HR
COMPOSITION (VOL %)	YEAST: 100	WATER: 100	MOLASSES: 29.4 JUICE: 70.6	MOLASSES: 29.4 JUICE: 70.6	WATER: 100 HYDRATED YEAST	CO2: 100	GLYCOL: 40 WATER: 60	GLYCOL: 40 WATER: 60	ETHANOL: 15.3 WATER: 84.7	DEAD YEAST ETHANOL: 15.3 WATER: 84.7	VIABLE YEAST ETHANOL: 15.3 WATER: 84.7	ETHANOL:15.3 WATER 84.7	VIABLE YEAST	ETHANOL:15.3 WATER 84.7

14	15	16	17	18	19	20	21,22,23	24	25	26	27	28
FERMENTED LIQUID	DISTILLATE	BOTTOMS	PRE RINSE SUPPLY	NON CAUSTIC SUPPLY	SANITIZER SUPPLY	RINSE WATER SUPPLY	FLAVORING	CANNING ALCOHOL	SWEETENER	CARBONATED WATER	CANNING MIX	CIP WASTE
127 GAL/HR	49 GAL/HR	89 GAL/HR	334 GAL/CYCLE	249 GAL/CYCLE	301 GAL/CYCLE	89 GAL/HR	0.44 GAL/BATCH	14.6 GAL/BATCH	0.68 LBS/BATCH	131 GAL/BATCH	142 GAL/BATCH	583 GAL/CYCLE
ETHANOL:15.3 WATER 84.7	ETHANOL: 80 WATER: 20	ETHANOL: 2 WATER: 98	WATER: 100	WATER 249 GAL NON CAUSTIC 23.4 LBS	WATER 301 GAL PAA 1 LBS	WATER: 100	FRUIT EXTRACT: 100	ETHANOL: 80 WATER: 20	STEVIA: 100	WATER: 100	ETHANOL: 10 WATER: 89.7 FLAVORING: 0.3	WATER: 57 NON CAUSTIC: 43

Calculation 1: *Fermentor Pipe sizing example*

Fluid Velocity(u) = 2 m/s

Sourced from Brannan

Required flow(Q) = 3.31 m^3 over 1 hour, or 0.001 m^3/s

Utilized Equation: $$u = \frac{Q}{\pi \times \frac{D^2}{4}}$$

Resulting Diameter: 0.012 m (0.95 inches)