

# **Design of a Non-Alcoholic Beer and Alcoholic Kombucha Manufacturing Process**

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On our honor as University Students, we have neither given nor received unauthorized aid on  
this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

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## TABLE OF CONTENTS

<b>1. Executive Summary</b>	<b>4</b>
<b>2. Introduction</b>	<b>5</b>
<b>3. Previous Work</b>	<b>8</b>
<b>4. Discussion</b>	<b>9</b>
<b>4.1 Fermentation</b>	<b>9</b>
<b>4.2 Reverse Osmosis</b>	<b>9</b>
<b>4.3 Design Basis</b>	<b>10</b>
4.3.1 Location and Capacity	10
4.3.2 ABV Percentages	10
<b>5. Beer Design</b>	<b>11</b>
<b>5.1 Pre-Fermentation</b>	<b>11</b>
5.1.1 Milling	11
5.1.2 Mashing and Lautering	11
5.1.3 Boiling and Clarifying	14
5.1.4 Cooling	15
5.1.5 Process Flow Diagrams (PFD) and Stream Tables	16
5.1.6 Scheduling	18
<b>5.2 Fermentation</b>	<b>19</b>
5.2.1 Fermentation Medium and Conditions	19
5.2.2 Fermentation Tank	22
5.2.3 Products	22
5.2.4 Heat Duty	22
5.2.5 Process Flow Diagram and Stream Table	24
5.2.6 Scheduling	26
<b>5.3 Reverse Osmosis</b>	<b>26</b>
5.3.1 Membrane	26
5.3.2 Scheduling	28
5.3.3 Process Flow Diagram and Stream Table	29
<b>5.4 Distillation</b>	<b>30</b>
5.4.1 Distillation Column	30
5.4.2 Condenser	30
5.4.3 Reboiler	31
5.4.4 Column Specifications	31
5.4.5 Heat Exchangers	33
5.4.6 Overall Scheduling	33

<b>5.5 Post Distillation</b>	<b>34</b>
5.5.1 Brite Tank	34
5.5.2 Beer Final Product Composition	36
5.5.3 Canning	36
5.5.4 Pasteurization	37
<b>6. Kombucha Design</b>	<b>38</b>
<b>6.1 Steeper</b>	<b>38</b>
<b>6.2 Fermentation</b>	<b>40</b>
6.2.1 Fermentation Conditions	40
6.2.2 Fermentation Tank	41
6.2.3 Products	41
6.2.4 Process Flow Diagram and Stream Table	42
6.2.5 Scheduling	43
6.2.6 Overall Scheduling	43
<b>6.3 Mixer</b>	<b>44</b>
<b>6.3 Kombucha Final Product Composition</b>	<b>46</b>
<b>6.4 Canning</b>	<b>46</b>
<b>7. Ancillary Equipment Design</b>	<b>47</b>
<b>7.1 Pump Design</b>	<b>47</b>
<b>7.2 Heat Exchanger Design</b>	<b>47</b>
<b>7.3 Glycol Chiller</b>	<b>48</b>
<b>7.4 Steam Generator</b>	<b>48</b>
<b>7.5 Storage Tanks</b>	<b>48</b>
<b>7.6 Walk-Behind Forklifts</b>	<b>48</b>
<b>8. Economic Analysis</b>	<b>49</b>
<b>8.1 Capital Costs</b>	<b>49</b>
8.1.1 Pumps	49
8.1.2 Heat Exchangers	50
8.1.3 Miscellaneous Auxiliary Equipment	51
8.1.4 Holding Tanks	53
8.1.5 Beer Equipment	55
8.1.6 Kombucha Equipment	56
8.1.7 Total Capital Costs	57
<b>8.2 Operating Costs</b>	<b>58</b>
8.2.1 Raw Materials	58
8.2.2 Utilities	60
8.2.3 Labor	62
8.2.4 Miscellaneous	63

<b>8.3 Projected Revenues</b>	<b>64</b>
<b>8.4 Cash Flow and Return on Investment (ROI) Analysis</b>	<b>65</b>
<b>8.5 Alternative Scenarios for Profitability</b>	<b>67</b>
<b>9. Safety, Environmental, and Societal Considerations</b>	<b>72</b>
<b>9.1 Safety Considerations</b>	<b>72</b>
9.1.1 Chemical Compatibility	72
9.1.2 CIP Compatibility	74
9.1.3 Equipment & Process Hazards	75
<b>9.2 Environmental Considerations</b>	<b>77</b>
9.2.1 Water Pollution	77
9.2.2 Air Pollution	78
9.2.3 Spent Grains and Tea Leaves	78
<b>9.3 Societal Considerations</b>	<b>79</b>
9.3.1 Public American Health	79
9.3.2 Marketing Towards Underaged Drinkers	79
<b>10. Conclusions &amp; Recommendations</b>	<b>81</b>
<b>11. Acknowledgements</b>	<b>82</b>
<b>References</b>	<b>83</b>
<b>Appendix</b>	<b>97</b>
<i>Appendix I: Process Flow Diagrams</i>	<i>97</i>
<i>Appendix II: Aspen</i>	<i>99</i>
<i>Appendix III: Sample Calculations</i>	<i>100</i>
<i>Appendix IV: References for Equipment and Raw Material Cost</i>	<i>101</i>

## 1. Executive Summary

Beer and kombucha are popular drinks that have been around for millennia, and the production of the two have evolved as technologies have advanced throughout the years. In the past few decades, there have been two growing markets for alternatives; specifically, non-alcoholic beer and alcoholic kombucha. By producing beer, extracting the ethanol through reverse osmosis and distillation, and mixing the extracted ethanol with kombucha, our team has designed a process that caters to both of these promising markets in one synthesized process.

The initial portion of our design produces a light lager with an initial alcohol by volume (ABV) of 4.2%. The intermediate portion that deals with the transport of ethanol uses reverse osmosis through a semi-permeable membrane to extract an ethanol/water mixture from the beer, then distillation to create a more pure ethanol solution. This ethanol solution is then added to kombucha that is also produced, increasing the kombucha's ABV from 1.5% to 5.5%. In the end, we produce 5.6 million 6-packs (12 oz) of non-alcoholic light lager and 3.65 million 6-packs (12 oz) of hard kombucha on a yearly basis.

After completing an economic analysis on our process, taking into account realistic wholesale prices and conservative startup costs, we determine an internal rate of return of 25%, signifying a viable investment in a constantly growing industry. We also present alternative scenarios of production that increase the internal rate of return and make this process even more economically appealing. This report also acknowledges the ramifications that come with creating a brewery. We acknowledge the safety, environmental, and social concerns that may affect people outside of the plant in a multitude of ways.

## 2. Introduction

Beer has played a significant role in human history ever since its inception around 7000 B.C., when the Chinese first mastered the art of brewing it (Raihofer et al., 2022). Not only did it serve to intoxicate the drinker, but it was usually the only safe drinking source in a region where clean water was scarce. Over generations, the art of brewing beer has developed and improved tremendously with new technologies, while keeping the same traditional knowledge. More recently, “near beer” was heavily promoted during the early days of the Prohibition era in the United States (Ruf, 2022). The brewers would make beer as usual and then boil off the remaining alcohol to have an alcohol by volume (ABV) of less than 0.5%. Its popularity died off after the repeal of prohibition, but concerns of alcoholism in the 1990’s prompted Anheuser Busch to launch O’Doul’s, the first well known near-beer brand in the United States (Ruf, 2022), thereby laying the groundwork for the NA beer industry.

Kombucha, a fizzy sweet-and-sour drink made from tea and yeast with the addition of alcohol (Wang et al., 2022, p. 1), can be traced back to China around A.D. 200 and is well known for its healing properties. Popularity in the United States grew in the 1990's as people began to share testimonies of the health benefits of consuming kombucha (Tan, 2018). In 1995, George Thomas Dave started selling his own brewed kombucha at a local store. This kickstarted the kombucha industry in the U.S. and resulted in the \$900 million company, GT’s Living Food, which is the largest retailer in kombucha today (Sorvino, 2019). In 2010, kombucha was taken off the shelves in Whole Foods following the discovery that the alcohol content was over 0.5% (The Denver Post, 2010). After evaluation and concerns over the new taste, many kombucha producers separated to develop the hard kombucha industry (Troitino, 2017).

Thus, the non-alcoholic beer and hard kombucha industries are two rapidly growing markets. Non-alcoholic beer sales have “climbed ninety percent over the last decade” (S. Smith, 2022). Additionally, over the next seven years, hard kombucha sales are expected to have a compound annual growth rate of 23.76% (Maximize Market Research, 2023). Focusing on non-alcoholic beverages, many people are leaning towards them as a healthier alternative to alcoholic ones: non-alcoholic beer contains fewer calories and sugars than alcoholic beer (Maximize Market Research, 2022) and has been shown to help “maintain blood electrolyte homeostasis during exercise” (Castro-Sepulveda et al., 2016). Current target demographics for non-alcoholic beer include those who want to reduce alcohol intake, those who abstain from alcohol for religious or health reasons, and those who enjoy the ritual of drinking but do not want to experience the effects of alcohol. Despite the market growth and demonstrated interest, however, non-alcoholic drinks are currently not prevalent or available mainstream due to the relatively expensive production process (Salanta et al., 2020). While the process technology has been researched, it has not been implemented yet on a widespread, commercial scale because the process is not profitable.

These relatively new and growing industries allow us to take part in creating new technologies by creating an upscale process to enhance non-alcoholic beer and use the removed alcohol to make hard kombucha for consumers. For the first product, we will be brewing a non-alcoholic lager with a 0.5% ABV. Typically, a lager is distinguished by its mild and smooth flavor, characterized by a light and crisp taste, with more carbonation and less bitterness than ales (Eddings, 2022). Lager is typically fermented with “bottom yeasts” carried out at lower temperatures than ales (Briggs et al., 2004, p. 5). In general, the non-volatile components found in beer encompass inorganic salts, sugars, amino acids, nucleotides, polyphenols, and hop resins,

as well as macromolecules like polysaccharides, proteins, and nucleic acids (Hough et al., 1982, p. 776). Including the non-volatile components mentioned, apart from ethanol and carbon dioxide, fermenting yeast cells also produce a broad range of secondary metabolites as part of the volatile components of beer (Olaniran et al., 2017, p. 13).

For the secondary product, we will be fermenting kombucha and adding the ethanol removed from the NA beer to create hard kombucha with an ABV of 5.5%. We will use black tea leaves, white sugar, and raspberry juice sweetener to reach a flavor which bears a resemblance to a crisp, dry cider with its fruity richness and a tangy, acidic edge (No.1 Living, n.d.). Kombucha consists of various organic acids, sugars, vitamins, amino acids, biogenic amines, purines, pigments, lipids, proteins, hydrolytic enzymes, ethanol, caffeine, carbon dioxide, polyphenols, anions, minerals, and D-saccharic acid-1, 4-lactone (DSL), along with bacterial metabolites (Bishop et al., 2022, p. 17).



### **3. Previous Work**

To address the potentially lucrative non-alcoholic beverage market, a number of dealcoholization methods have been developed in recent years. Two such methods include thermal and membrane separation. Thermal separation involves vacuum distillation to separate the alcohol from the beverage based on differences in their volatilities, whereas membrane separation, most notably reverse osmosis (RO) membrane filtration, involves pushing a beverage across a semipermeable membrane and separating water and ethanol from the rest of the beverage based on particle size selectivity (Jackowski & Trusek, 2018). However, there is a fundamental problem with these methods concerning their large-scale implementation feasibility. These dealcoholization methods, while valid processes, are too expensive by themselves to be implemented on a commercial scale. Companies currently trying to produce non-alcoholic drinks view the process as a standalone entity by making them exclusively, therefore failing to take into account the profitability of catering to two separate audiences: people who want alcoholic drinks and people who want non-alcoholic drinks. If the current approach by these companies continues to be taken, beverage companies will continue to fail at making profitable non-alcoholic beverages and will continue to ignore the demographics of people interested in novel non-alcoholic and alcoholic beverages, leading to wasted potential areas for profit.

## **4. Discussion**

### ***4.1 Fermentation***

Fermentation is a process in which a microorganism breaks down a substance. In this project, fermentation occurs without oxygen in order to create ethanol. The selected yeast strain is WLP840, a form of *S. pastorianus* (a lager yeast). This yeast ferments slower than ale yeast and at lower temperatures, since it is bottom fermenting. One other quality of bottom fermentation is that the yeast settles at the bottom of the fermenter, giving a clearer final product.

A secondary fermentation occurs when the beer, called “green beer”, is given time to mature and develop its flavor profile. In the case of a lager, this occurs in a step called lagering where the beer is held at near freezing (~33-34 F) temperatures. This process can last from weeks to months depending on the recipe.

### ***4.2 Reverse Osmosis***

Reverse osmosis is a purification process that involves using pressure to push a mixture through a semipermeable membrane to selectively filter particles out. In this process, reverse osmosis is used to remove ethanol particles from the beer, effectively de-alcoholizing the beer. The membrane used is the AFC99 membrane in which the ethanol and water particles pass through in the permeate, leaving the remaining water, beer proteins, and trace ethanol in the retentate.

This method was selected as opposed to other methods such as distillation because it more effectively preserves flavor and aroma. This allows for the recipe of non-alcoholic beer to follow that of regular beer recipes. In contrast, distillation would require a novel recipe to be developed through trial and error. In the scope of this project, developing a recipe and simulating the entire process would likely be unachievable.

### ***4.3 Design Basis***

#### *4.3.1 Location and Capacity*

Our plant is located in Waukesha, Wisconsin. This particular location was chosen for three primary reasons: property cost, population and industry growth, and access to water. In particular, the City of Waukesha recently transitioned its water system in September 2023 to treated Lake Michigan water supplied by the City of Milwaukee in place of its former deep aquifer, which became depleted and resulted in elevated levels of naturally occurring radium and other contaminants (Great Water Alliance, 2023). Thus, with a new water system in place, we decided Waukesha would be an ideal location to suit our production capacity.

The scale of our NA beer production was determined based on the output of other large-scale companies selling similar products. For instance, Athletic Brewing Company is one of the most prominent NA breweries in the United States. In 2021, they sold \$37 million dollars from NA beer (Barkho, 2023), corresponding to a declared 104,000 barrels of beer (Kendall, 2022). Therefore, we chose to target producing 100,000 barrels of NA beer, which is in-line with a medium- to large-scale sized brewery.

The scale of our alcoholic kombucha production was dependent upon fermentation calculations from the beer process to see how much ethanol was produced. Based upon our amounts, we decided to produce 66,288 barrels of kombucha to maximize the amount of product we could make.

#### *4.3.2 ABV Percentages*

For the NA beer, an ABV percentage at the legal maximum of 0.5% (Code of Federal Regulations, 2024a) was targeted. For the hard kombucha, an ABV of 5.5% was targeted, which lies in the typical range of hard kombuchas sold online and in grocery stores.

## **5. Beer Design**

### ***5.1 Pre-Fermentation***

#### *5.1.1 Milling*

During this process, malted barley grain is crushed in order to open the malt husk and expose the starchy endosperm so that fermentable sugars are more easily reached (Reddy, 2022). For each batch, 1825 lbs of Rahr 2-row malted barley is used (Howdy Brewer, n.d.), according to a recipe by Ballast Point (Ballast Point, n.d.). The unit used in this process is the MILL91AS-MB Model, with a processing speed of 2,000 lbs/hr with a mill gap of 1 mm (More Beer, n.d.). There will be a 7.5% grain loss in this process due to moving the milled grain to the next unit operation (Jenkins, 2023), which results in a total of 1688 lbs/batch of grain.

#### *5.1.2 Mashing and Lautering*

The mashing process allows the malt enzymes to break down carbohydrates into fermentable sugars and create the wort mixture, which is made up of water, sugar, enzymes, and proteins (R. Anderson, 2006, p. 398). The lautering process separates the components of malt that was dissolved from the insoluble parts, like the husk and leftover grain (Krottenthaler et al., 2009, p. 181). Lautering consists of two parts: recirculation and sparging. During recirculation, the wort is recycled which allows the small floating particles in the wort to become trapped in the grain bed (B. Smith, 2023). During sparging, water is added to rinse the spent grain and recover as much sugar as possible for the wort (Altitude Brewing & Supply, 2018). This is done by draining the wort to within 1 in above the grain bed, which is typically 20 in (Brewman, 2021) (R. Anderson, 2006, p. 182), and adding water at the same rate as the wort leaving the reactor.

The unit being used is the 60 BBL Commercial Mash/Lauter Tun from ABS. The reactor is made from 304 stainless steel, with a diameter of 8 ft 3 in and a height of 6 ft 3 in. Inside the reactor, there is a rake and plow made with 304 stainless steel, which will operate at 14 RPM, which helps with mixing the mash and pushing spent grains out. Additionally, there is a false bottom with slits to allow liquid to pass through while keeping the solids in the reactor. Outside the reactor is a jacket made of polyurethane which has a thickness of 3.2 in. Steam will be passing through this jacket at 10 psi to maintain the temperature of the wort.

The feed inputs for the mashing process, in addition to the milled grain, are 487 lbs/batch of flaked rice and 5,672 lbs/batch of strike water at 161 F. The feed input for the lautering process is 11,826 lbs/batch of sparging water at 172 F. The products for this unit include 18,507 lbs/batch of wort and 1,090 lbs/batch of waste product, made up of spent grain, water, and sugar. Efficiency in this design is a measure of the amount of sugar extract recovered in the wort compared to the amount of extract available in the malt. The mashing and lautering efficiencies are 94.7% and 95% respectively.

The energy requirements of mashing are two-fold: energy is required to heat the strike water as well as to keep the mixture at 161 F. The strike water will be heated by a hot liquor tank. The tank that will be used is a 120 BBL Hot/Cold Liquor Tank from ABS Commercial. This tank is 19 ft 5 in tall with a diameter of 7 ft 11 in. The hot liquor tank is stainless steel, jacketed, and insulated with 3.2 inches of polyurethane. The heat duty of raising the temperature of strike water from 70 F to 161 F is 1.2 MMBtu per batch. This gives a yearly heat duty of 2,000 MMBtu. The amount of steam required to heat the strike water to 161 F for a 60 minute timespan is 0.34 lbs/s (2,033,752 lbs/yr) of 10 psi steam. The other half of the energy requirements is the energy required to heat the grain to 161 F and keep it at that temperature. This requirement was

calculated by determining the heat duty of raising the temperature of the grains from 70 F to 161 F. The heat capacity of water was used to compensate for the energy requirement to keep the mixture hot as well as the fact that the heat capacity of grain, especially under a high moisture content (Cao et al., 2010, p. 245), has a nonlinear dependence on temperature which can make energy calculation difficult to perform without specific experimental data on the mixture used in this recipe. This energy requirement was found to be 0.46 MMBtu per batch or 767 MMBtu per year. The amount of steam required to keep the strike water at 161 F for the 60 minute mashing duration is 0.13 lbs/s (779,850 lbs/yr) of 10 psi steam.

The energy requirements of sparging are similar to that of mashing. First, there is the energy to heat the sparge water. Second, there is the energy to keep the mixture at 172 F. The sparge water will be heated by the same hot liquor tank as mentioned above (120 BBL Hot/Cold Liquor Tank from ABS Commercial). The energy requirement of heating room temperature (70 F) water to the desired temperature (172 F) is 2.8 MMBtu per Batch or 4674 MMBtu per year. The amount of steam required to heat the strike water to 172 F for a 60 minute timespan is 0.79 lbs/s (4,751,962 lbs/yr). Calculating the energy requirements to keep the mixture at 172 F was done utilizing similar assumptions as the mashing energy requirements. The heat duty was calculated by determining the energy input needed to raise the temperature of the mash mixture from 161 F to 172 F using the heat capacity of water. This assumption, as the previous one made in the mash section, should provide a conservative estimate of the energy requirements. The heat duty required came out to be 0.20 MMBtu per batch or 334 MMBtu per year. The amount of steam required to keep the strike water at 172 F for the 4.5 hour lautering duration is 0.057 lbs/s (339,358 lbs/yr) of 10 psi steam.

### 5.1.3 Boiling and Clarifying

The boiling process is necessary to stop enzymatic activity, remove unwanted volatiles, like DMS, and concentrate the wort through evaporation (Benson, 2020). Also, other components are added to this process: hops, yeast nutrient, and clarifier. Hops develop the flavor and color; yeast nutrient prepares the wort for fermentation; clarifier helps to rid protein and Beta glucans (Benson, 2020). The clarifying process helps further separate the wort and the hot trub – hop fragments and solid protein particles (De Clerck, 1957). This is done by draining the wort and pumping it back into the reactor at a high velocity to create a centripetal force which will draw all the floating components to the center into a trub cone.

The unit being used is the 60 BBL Commercial Kettle/Whirlpool from ABS. The reactor is made from 304 stainless steel, with a diameter of 8 ft 3 in and a height of 6 ft 3 in. Inside the reactor, there is a calandria which acts as an internal shell and tube heat exchanger to aid in a more evenly distributed boiling process (Barrel Brothers Brewing Company, 2017). Outside the reactor is a jacket made of polyurethane which has a thickness of 3.2 in. Steam will be passing through this jacket at 10 psi to maintain the temperature of the wort. Finally, there is a whirlpool inlet with a diameter of 1.5 in, which will flow in at 11.5 ft/s (Kunze, 2014).

The feed inputs, in addition to the wort, are 8.7 lbs/batch of Hallertaur hops, 0.7 lbs/batch of yeast nutrient, and 0.4 lbs/batch of Irish moss clarifier. The products for this unit include 15,452 lbs/batch of wort and 2,732 lbs/batch of hot trub. Boiling and clarifying efficiency are 100% and 85% respectively, with a boiloff loss of 2%.

For boiling, the energy requirements come from both heating the wort to its boiling point as well as keeping the wort boiling. First, since wort is primarily a water/sucrose mixture, the heat capacity of water/sucrose mixtures was utilized. This gave a per batch energy requirement

of 1.8 MMBtu (3007 MMBtu per year). The amount of steam at 10 psi required to heat this wort up to 212 F from 172 F for the 60 minute heat up time is 0.51 lbs/s (3,057,659 lbs/yr). Second, calculating the heat duty to keep the solution boiling was determined using heat loss from water vaporization as well as heat loss through the insulation. The heat loss from vaporization was by far the larger contributing factor. In total, 0.34 MMBtu of heat duty is required per batch (573 MMBtu per year). The amount of steam at 10 psi required to keep the wort boiling for 30 minutes is 0.19 lbs/s (1,164,808 lbs/yr).

#### *5.1.4 Cooling*

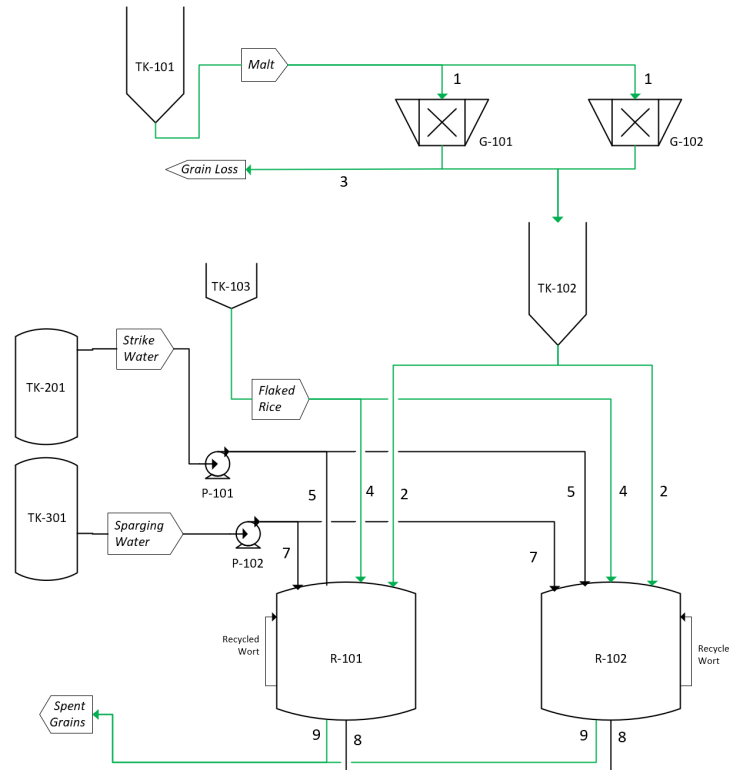
Once the wort is finished boiling and clarifying, it needs to be cooled to fermentation temperature. This will be done through a countercurrent shell and tube heat exchanger. This heat exchanger is expected to cool each batch down in a 30 minute time span. The coolant being utilized will be a 35% glycol 65% water mixture at 25 F (leaving at 77 F). The energy requirement of this shell and tube unit operation is 5.5 MMBtu per batch (9,143 MMBtu per year). The amount of coolant needed to provide this energy is 64 lbs/s (191,750,130 lbs/yr).



### 5.1.5 Process Flow Diagrams (PFD) and Stream Tables

**Figure 5.1.5.1.**

*Milling, Mashing and Lautering Process Flow Diagram*



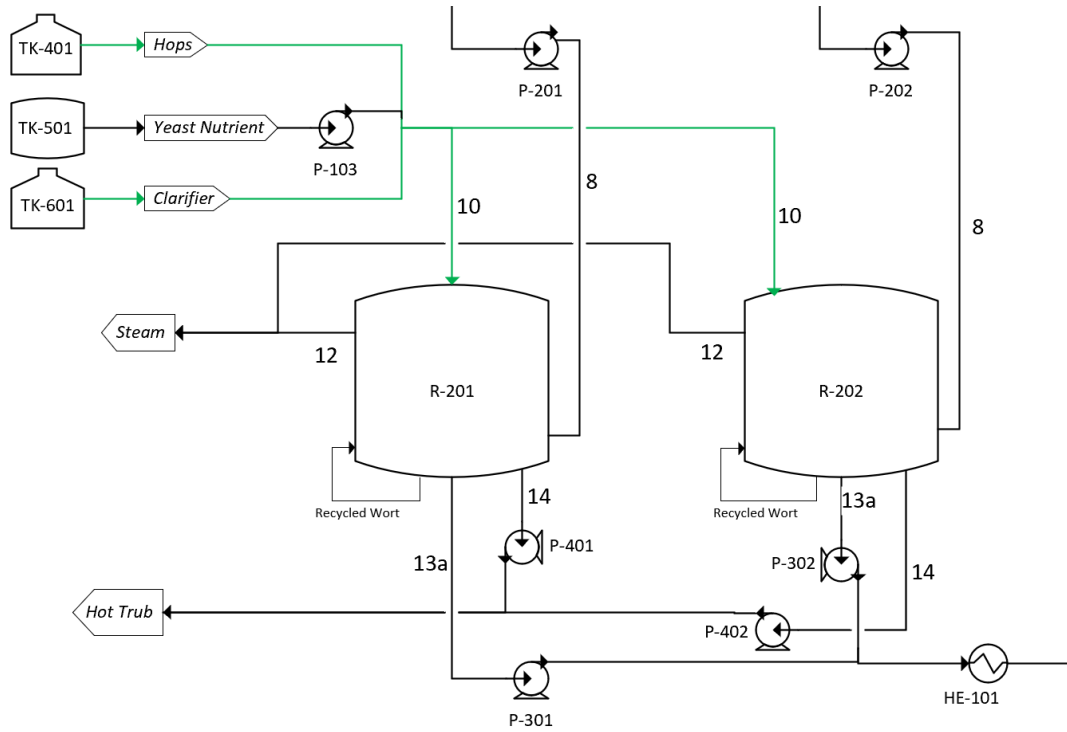
**Table 5.1.5.1.**

*Milling, Mashing, and Lautering Stream Table*

Stream Number	1	2	3	4	5	7	8	9
Temperature (F)					161	172	168	
Total lbs/batch	1,825	1,688	137	487	5,672	11,826	18,507	1,090
<b>Component Flow Rate (lbs/batch)</b>								
Water	0	0	0	0	5,672	11,826	16,623	875
Malted Grain	1,825	1,688	137	0	0	0	0	116
Flaked Rice	0	0	0	487	0	0	0	0
Sugar	0	0	0	0	0	0	1,884	99

**Figure 5.1.5.2.**

*Boiling and Clarifying PFD*



**Table 5.1.5.2.**

*Boiling and Clarifying Stream Table*

Stream Number	8	10	12	13a	14
Temperature (F)	168			212	
Total lbs/batch	18,507	10	332	15,452	2,732
<b>Component Flow Rate (lbs/batch)</b>					
Water	16,623	0	332	13,847	2,444
Sugar	1,884	0	0	1,601	283
Hops	0	8.7	0	0	5.5
Yeast Nutrient	0	0.7	0	0.6	0
Clarifier	0	0.4	0	0	0.3
O2	0	0	0	0.2	0
Solids	0	0	0	3.4	0

**Table 5.1.5.3.***Pre-Fermentation Energy Table*

<b>Equipment</b>	<b>PFD Label</b>	<b>Annual Energy Usage (MMBtu)</b>	<b>Total Steam Flow Rate (lbs/yr) (10psi)</b>	<b>Total Glycol/Water Flow Rate (lbs/yr)</b>
Strike Water Tank	TK-201	2,000	2,033,752	-
Sparging Water Tank	TK-301	4,674	4,751,962	-
Mash/Lauter Tank	R-101	1,101	1,119,208	-
Boiler/Clarifier	R-201	3,580	4,222,467	-
Preferment Heat Exchanger	HE-101	9,143	-	191,750,130

*5.1.6 Scheduling*

The miller will send the malt to a storage unit, so that when needed, only the desired amount for a batch is sent to the next process step. The pre-fermentation schedule after milling is shown below. The complete mashing and lautering (ML) process will take 6 hours, as shown in Figure 5.1.6.1: filling for 15 minutes, mashing for 1 hour, lautering for 3.5 hours, draining for 15 minutes, and the remaining hour allotted for cleaning. The complete boiling and clarifying (BC) unit will take 3.5 hours, as shown in Figure 5.1.6.2: filling for 15 minutes, boiling for 1.5 hours, clarifying for 30 minutes, draining for 15 minutes, and cleaning for an hour.

To realistically optimize this process, we plan on running four total lines. Two will run 14 batches a week and two will run 8 batches a week. Each line will have one 60 BBL Mash/Lauter Tun and one 60 BBL Kettle/Whirlpool, with two lines that will feed into one 120 BBL fermenter.

**Figure 5.1.6.1.**

*Mashing and Lautering Schedule*

8:00 AM	Filling
8:15 AM	Mashing
8:30 AM	
8:45 AM	
9:00 AM	
9:15 AM	Lautering
9:30 AM	
9:45 AM	
10:00 AM	
10:15 AM	
10:30 AM	Draining
12:45 PM	
1:00 PM	Cleaning
1:15 PM	
1:30 PM	
1:45 PM	

**Figure 5.1.6.2.**

*Boiling and Clarifying Schedule*

2:00 PM	Filling
2:15 PM	Boiling
2:30 PM	
2:45 PM	
3:00 PM	
3:15 PM	
3:30 PM	Clarifying
3:45 PM	
4:00 PM	Draining
4:15 PM	
4:30 PM	Cleaning
4:45 PM	
5:00 PM	
5:15 PM	

**5.2 Fermentation**

*5.2.1 Fermentation Medium and Conditions*

The fermentation occurs through a liquid beer yeast (WLP840) at a high pitching rate of 22.5 billion yeast cells per liter (as per the recipe). While over-pitching is definitely a concern, under-pitching is definitely a much greater problem. Under-pitching can cause off flavors and stuck fermentations. Though this can be alleviated by adding more yeast, any setbacks in a large-scale setting affects the entire facility and causes a monetary loss. Over-pitching can lead to quicker fermentations and light-bodied flavor. For the purposes of this project, these downsides aren't as terrible as the intended product is a light lager. The wort is around 10% (w/w) sugar with an oxygen content of around 14 mg/L.

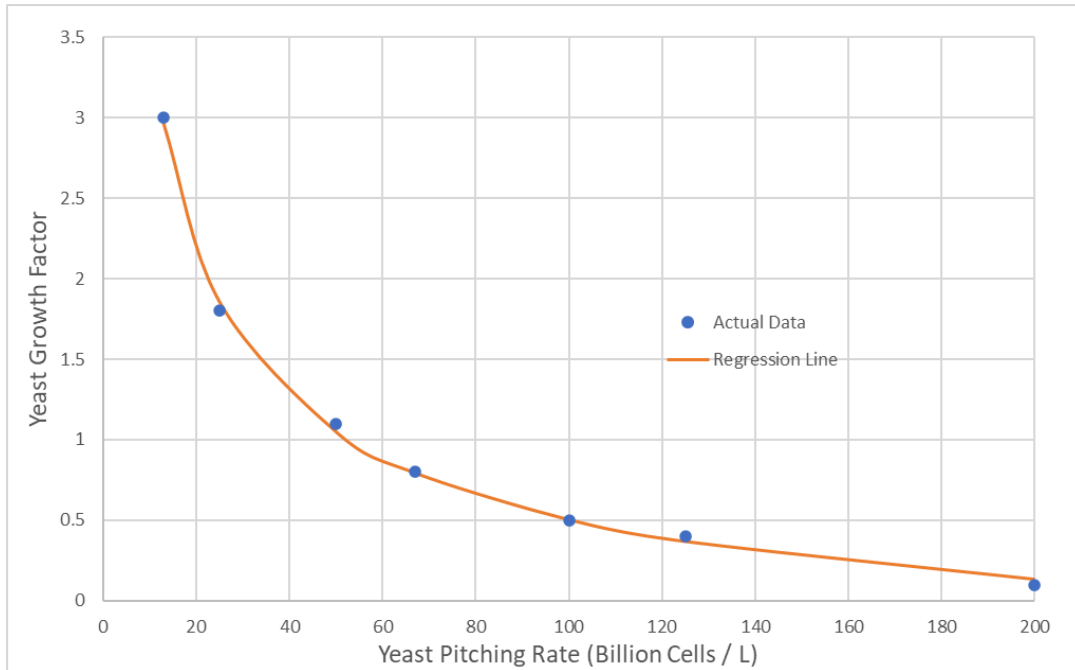
The fermentation occurs in multiple stages where it starts at 50 °F for three days, goes to 53 °F for three days, goes to 55 °F for three days, and then moves to a diacetyl rest tank where it stays for 5 days at 70 °F. Next, the “green beer” is reduced to 33 F and kept at that temperature

for 10 days. In reality, this number is subject to change and was only estimated to provide a baseline for scheduling and energy calculations.

During fermentation, the volume of the wort in the vessel should remain the same before removing the trub, which was used as a baseline for calculations (Doull & Barnett, 1930). The first component calculated was cold trub. Cold trub is created when the beer is cooled before fermentation but isn't removed until after fermentation. This is because some trub, especially cold, may help with the fermentation (Stika, 2008). This also makes it so yeast and trub is removed in the same step. The amount of cold trub created is based on rough estimates with the range being 17-35 grams of cold trub produced per barrel of beer (Deman, n.d.). The number used was the average of the range, 26 g/bbl. Trub is around 85% water: this value can be used to estimate the water loss to the trub (Mathias et al., 2015). The amount of yeast to be added is known via the recipe, but the growth of the yeast was estimated using tabulated data (White & Zainasheff, 2010). This data was interpolated to find the growth rate of the yeast used based on the inoculation rate (cells/gram) (Figure 5.2.5.1). The recipe used for this process provides an original gravity (OG). This OG was plugged into the equation for Final Gravity (FG) (Loader, 2024). The ABV was then calculated with FG and OG (Autodesk Instructables, n.d.). Using the ABV, the amount of produced ethanol was calculated. Lastly, the composition of the final beer product was estimated using research that estimated beer composition (Buiatti, 2010). This gives a fully fleshed out beer exit stream.

**Figure 5.2.5.1.**

*Yeast Growth Factor vs Pitching Rate*



The blow off stream compositions and flow rates were calculated next. This stream is blown off CO<sub>2</sub>. The CO<sub>2</sub> can be estimated using the conversion of sucrose to CO<sub>2</sub> and ethanol (Doull & Barnett, 1930). This conversion is used in conjunction with the amount of CO<sub>2</sub> in the beer to find the remaining amount of CO<sub>2</sub> to be blown off (as wort can only hold so much CO<sub>2</sub>). Once these streams are all fully defined, the last stream is the fermentation entrance stream. The amount of yeast starter needed was scaled up from the recipe. The amount of oxygen to be added is around 14 ppm as this is recommended for lagers (The Electric Brewery, n.d.). The amount of water can be calculated by adding the water in the exit streams. The sugar is the final calculation which can be found by closing the material balance.

The stream entering the fermenter will be at a rate of 30,905 lbs/batch composed of 1.2 lbs/batch yeast nutrient starter, 27,694 lbs/batch of water, 0.4 lbs/batch of O<sub>2</sub>, 6.7 lbs/batch of cold trub solids, and 3,202 lbs/batch of sugar. The amount of liquid yeast to be added is 279

lbs/batch. The exiting beer from the fermenter is 29,772 lbs/batch composed of 27,453 lbs/batch of water, 991 lbs/batch of ethanol, 1,184 lbs/batch of beer solids and proteins, and 145 lbs/batch of CO<sub>2</sub>. The waste streams are composed of 609 lbs/batch of sediment at the bottom of the tank and 803 lbs/batch of blowoff waste.

### *5.2.2 Fermentation Tank*

The selected design equipment will be a 145 BBL conical fermentation tank from ABS for the primary fermentation. This will be used for 9 days plus an extra day of leeway for cleaning, transferring, and any other source of time setback. This tank, after accounting for headspace, will be able to hold 120 BBL of wort/beer. The tank's dimensions are 22 ft tall with a diameter of 7 ft 5 in.

For diacetyl rest, the selected tank is a 143 BBL Brite Tank from ABS Commercial. Accounting for headspace, this gives a 120 BBL size. The tank will be used for 5 days plus one extra day of leeway for cleaning, transferring, and any other source of time setback. The tank's dimensions are 18 ft tall with a diameter of 7 ft 5 in. This tank has smaller dimensions than the primary fermentation tank because the bottom of the primary is cone shaped.

The secondary fermentation/lagering tank is 145 BBL (120 BBL once headspace is accounted for) horizontal lagering tank from ABS Commercial. The tank will be used for 9 days plus one extra day of leeway. The tank is 8 ft 6 in high (7 ft 1 in diameter) and 19 ft 3 in long.

### *5.2.3 Products*

The final product of the fermentation step is a 4.2% ABV light lager.

### *5.2.4 Heat Duty*

The primary fermentation tank is where most of the sucrose utilization occurs. Therefore, the heat of reaction of glucose turning into carbon dioxide and ethanol was found from literature

and used to determine energy requirements of the unit operation. In addition, the reactor needs to be heated from 50 F to 55 F. This heat duty was subtracted from the heat of reaction as the energy needed to raise the temperature 5 degrees will be provided by the yeast reactions. In the end, the heat duty was found to be 0.48 MMBtu per batch (402 MMBtu per year). Again, the same glycol/water coolant solution will be used. This will come out at a flow rate of 0.034 lbs/s (21,899,747 lbs/yr). Of course, this is only the flow rate averaged over the nine days of fermentation. In reality, the flow rate will fluctuate a lot more especially during the growth phase.

The diacetyl rest tank will be at room temperature. The temperature will be raised to a point where the yeast is expected to barely react. Thus, maintaining the temperature is not a concern for this part of the operation, so heat duty was not calculated.

Once in the secondary tank, the beer needs to go from 72 F to 33 F. This gives an energy requirement of 1.2 MMBtu per batch (966 MMBtu per year). The amount of coolant required to achieve this over 8 hours is 6.3 lbs/s (150,520,691 lbs/yr).

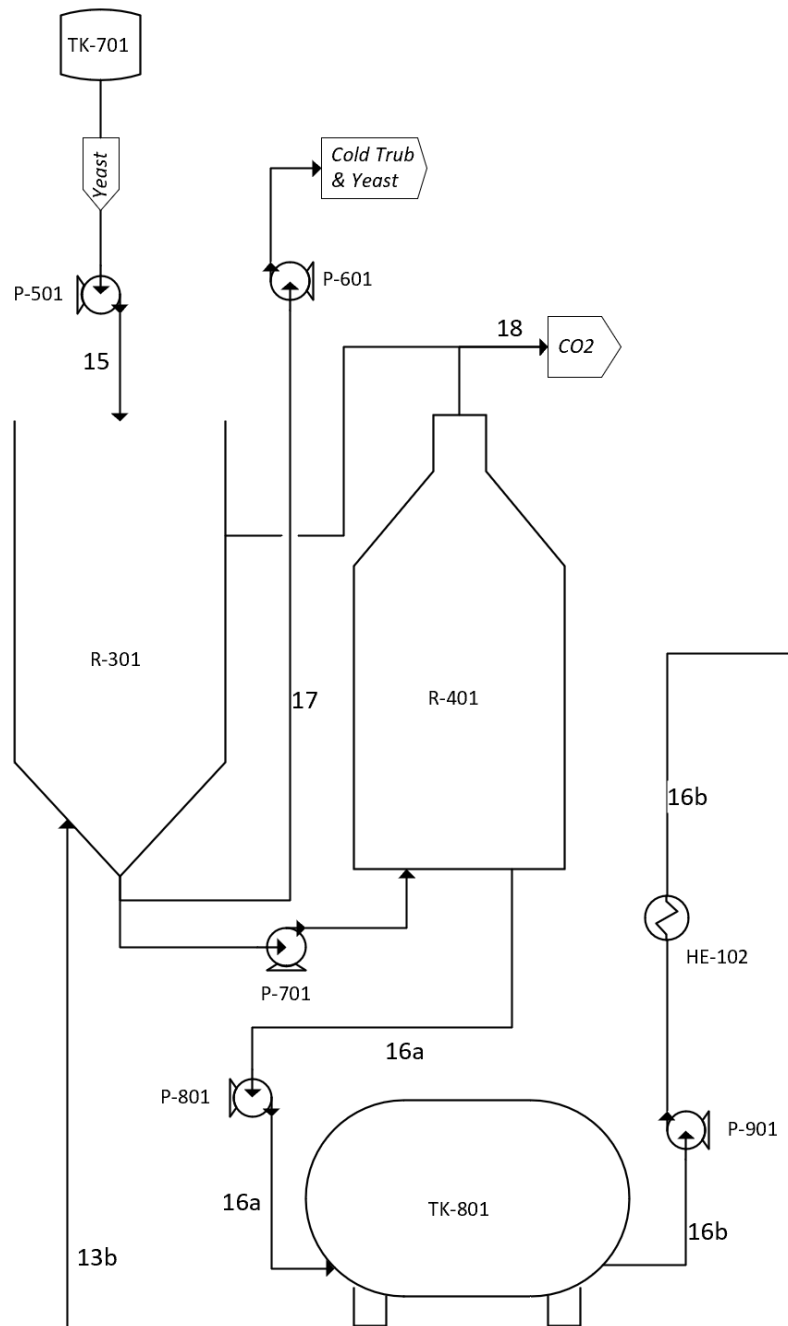
After lagering, the beer enters the RO process. This stream must be heated from 33 F to 59 F in a shell and tube heat exchanger. The heat duty to do so is 0.81 MMBtu per batch (1497 MMBtu per year). The heat for this stream will be provided by the 10 psi steam at a flow rate of 0.92 lbs/s (690,239 lbs/yr).



5.2.5 Process Flow Diagram and Stream Table

Figure 5.2.5.1.

Beer Fermentation PFD



**Table 5.2.5.1.***Fermentation Stream Table*

<b>Stream Number</b>	<b>13b</b>	<b>15</b>	<b>16a</b>	<b>17</b>	<b>18</b>
Temperature (F)	50	50	72	55	55
Total lbs/batch	30,905	279	29,772	609	803
<b>Component Flow Rate (lbs/batch)</b>					
Water	27,694	0	27,453	0	0
Ethanol	0	0	991	0	0
CO2	0	0	145	0	803
Proteins, Carbohydrates, Flavor	0	0	1,184	0	0
Saturated Yeast	0	279	0	0	0
Yeast Nutrient	1.2	0	0	0	0
Cold Trub (Extract)	6.7	0	0	609	0
Sugar	3,202	0	0	0	0
O2	0.4	0	0	0	0

**Table 5.2.5.2.***Fermentation Energy Table*

<b>Equipment</b>	<b>PFD Label</b>	<b>Annual Energy Usage (MMBtu)</b>	<b>Total Steam Flow Rate (lbs/yr) (10psi)</b>	<b>Total Glycol/Water Flow Rate (lbs/yr)</b>
Primary Fermenter	R-301	402	-	21,899,747
Lagering Tank	TK-801	966	-	150,520,691
Pre-RO Heat Exchanger	HE-102	679	690,239	-

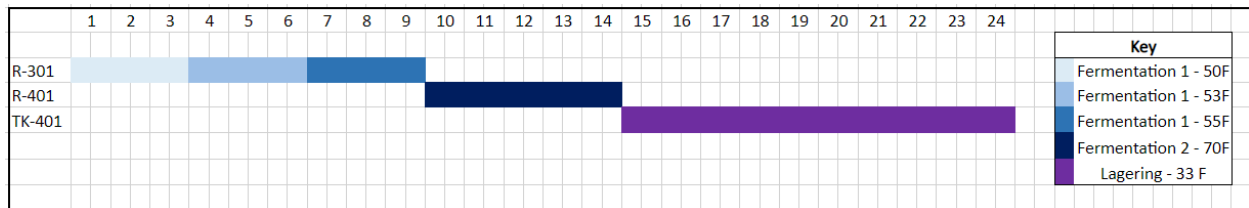
### 5.2.6 Scheduling

The fermentation schedule is shown in Figure 5.2.6.1, which starts after a batch of wort is sent from the pre fermentation area. The first fermentation is broken up into three phases, each lasting 3 days at different temperatures: 50° F, 53° F, and 55° F. It takes half an hour for the beer to drain out and fill the brite tank where secondary fermentation occurs. Here, the beer ferments for 5 days at 70° F, then it is sent to the lagering tank for 9 days, with an additional day for filling, draining and cleaning.

To minimize cost and wasted space, we planned the fermentation cycles so that 17 fermenters are filled by the time the first one is drained, cleaned, and refilled. A similar method was used to calculate the brite tanks used. By the time the first fermenter is able to be refilled, 17 brite tanks are filled.

**Figure 5.2.6.1.**

*Beer Fermentation Schedule*



### 5.3 Reverse Osmosis

#### 5.3.1 Membrane

The membrane being used in the RO process is the AFC99 membrane. The membrane material is an aromatic polyamide film, which shows higher retention and higher selectivity for the permeation of ethanol than cellulose acetate membranes, the other most commonly used type of membrane for RO (López et al., 2002, p. 6600). The membrane configuration is tubular, with 18 tubes per module. Each tube has a nominal inner diameter of 12.3 mm, with the total

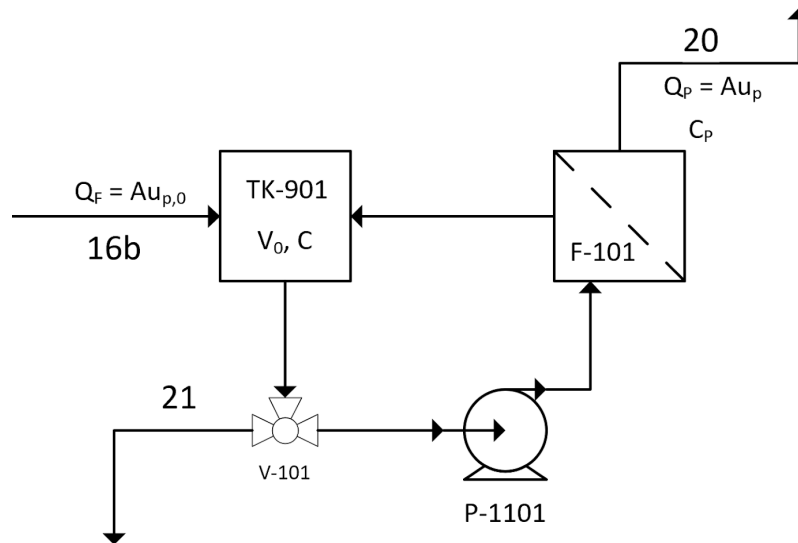
membrane surface area in each module equaling  $2.6 \text{ m}^2$ . The shell of the module is made out of 1.4404 stainless steel. 204 membrane systems will be purchased to accommodate production needs.

The units for this step include a feed tank where the beer from the fermenter is filled, along with a set of AFC99 membrane modules in parallel. The volume level in the feed tank is maintained constant by adding water to the feed tank in a diafiltration process, which allows for more ethanol separation at the end of the process.

A material balance on a batch diafiltration process was used to complete calculations. A schematic of a reverse osmosis batch diafiltration process is shown in Figure 5.3.1.1, where F-101 represents the reverse osmosis membrane unit.

**Figure 5.3.1.1.**

*Batch Diafiltration PFD*



The differential material balance equation is shown in Equation 5.3.1.1. Equation 5.3.1.2 represents constant volume diafiltration, where  $Q_F$  represents the volumetric flow rate of the feed stream and  $Q_p$  represents the volumetric flow rate of the permeate stream. Solving the differential

material balance with Equation 5.3.1.2 yields Equation 5.3.1.3. In the equations,  $V$  represents volume,  $C$  represents concentration,  $A$  represents membrane area,  $u_p$  represents flux, and  $\sigma$  represents diafiltration volume.

$$\text{(Equation 5.3.1.1)} \quad V_0 \frac{dC}{dt} = -Au_{p,0}C_p = -Au_{p,0}(1 - \sigma)C$$

$$\text{(Equation 5.3.1.2)} \quad Q_F = Q_p$$

$$\text{(Equation 5.3.1.3)} \quad \frac{C}{C_0} = \exp\left(-\frac{V}{V_0}(1 - \sigma)\right)$$

Experimental data from a research paper on apple cider dealcoholization found that using the AFC99 membrane, for a diafiltration volume of 3.2, 75% of ethanol was removed by the membrane (López et al., 2002, p. 6604). Using this experimental data and Equation 5.3.1.3, under the assumption that this data applies for scale-up, a diafiltration volume of 4.9 was determined, and the amount of water needed to be added and the exiting permeate and retentate stream flow rates were obtained.

The feed stream to RO is 29,772 lbs/batch of beer, with 147,657 lbs/batch of water being added in total during diafiltration. 98.6% of the entering ethanol, or 873 lbs/batch of ethanol, exits in the permeate stream along with 146,538 lbs/batch water, with the remaining water, ethanol, and beer proteins remaining in the retentate stream. The CO<sub>2</sub> is assumed to leave the stream completely during the RO process, as carbonation is lost through the pressurized process, and is added back into the product during an upcoming brite tank step.

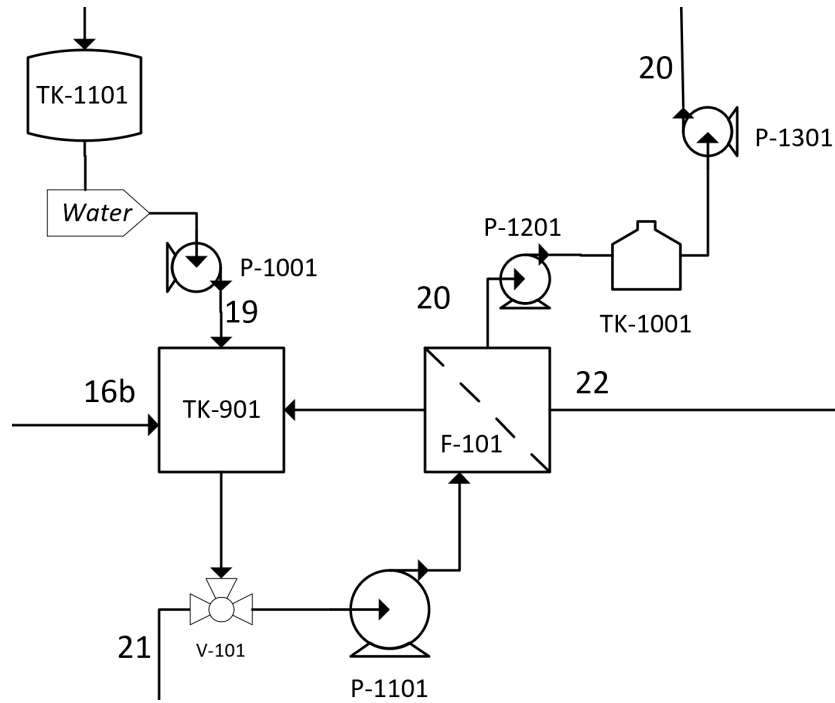
### 5.3.2 Scheduling

The RO step is done in a batch diafiltration process. Within each batch, the diafiltration is considered a continuous process to maintain the constant feed tank level. For RO, 18 batches will run per week, as shown in Figure 5.4.6.1.

### 5.3.3 Process Flow Diagram and Stream Table

**Figure 5.3.3.1.**

*Reverse Osmosis PFD*



**Table 5.3.3.1.**

*RO Stream Table*

Stream Number	16b	19	20	21	22
Temperature (F)	59		59	59	
Pressure (psi)	653		15	15	
Total lbs/batch	29,772	147,657	147,411	29,873	145
<b>Component Flow Rate (lbs/batch)</b>					
Water	27,453	147,657	146,538	28,571	0
Ethanol	991	0	873	118	0
Beer proteins	1,184	0	0	1,184	0
CO2	145	0	0	0	145

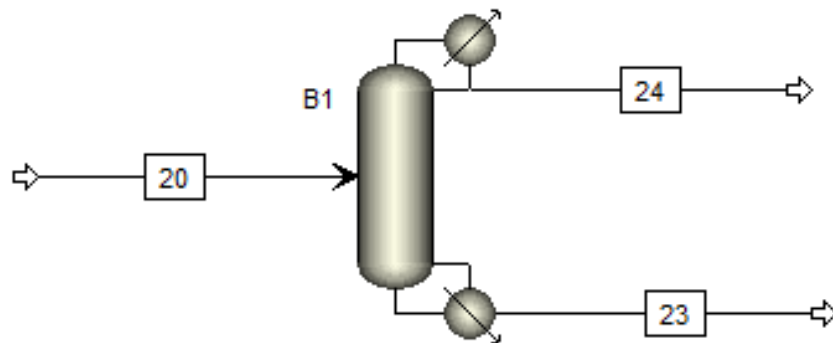
## 5.4 Distillation

### 5.4.1 Distillation Column

A distillation column separates the ethanol from the water. The permeate stream from RO enters the column at 185 F and atmospheric pressure, with an enthalpy flow of -98.4 MMBTU/hr. The column was chosen to consist of 12 stages, with the feed stream entering above stage 6, as the result of simulation iterations modeled in Aspen Plus. A diagram is shown below in Figure 5.4.1.1:

**Figure 5.4.1.1.**

*Distillation Column Diagram in Aspen Plus*



### 5.4.2 Condenser

The distillate rate was specified to be 200 lbs/hr, with a reflux ratio of 10. A total condenser is used, with the condenser pressure being 1 atm. The distillate stream is liquid phase, at a temperature of 180.4 F, a pressure of 1.01325 bar, with an ethanol mass fraction of 0.427 and a water mass fraction of 0.573, a volumetric flow of 1.805 L/min, and an enthalpy flow of -985.7 MBTU/hr. With this column, 98.0% of the ethanol entering the column leaves in the distillate and is sent to the kombucha process. The heat duty for the total condenser was calculated in Aspen Plus to be -1,620 MBtu/hr.

### 5.4.3 Reboiler

The reboiler located at the bottom of the column operates at atmospheric pressure. The bottoms stream is liquid phase, at a temperature of 212.0 F, with an ethanol mass fraction of  $1.22 \times 10^{-4}$  and a water mass fraction of 0.999878, a volumetric flow of 119.477 L/min, and an enthalpy flow of -97.0 MMBTU/hr. The heat duty requirement for the reboiler was calculated in Aspen Plus to be 2,040 MBtu/hr.

The ethanol and water separation is detailed in a distillation stream table, shown in Table 7 below. Although the distillation process was modeled continuously in Aspen Plus, a pseudo-batch schedule in accordance with the fermentation and RO batch processes directly preceding this step was used to obtain values in lbs/batch for the distillation column.

**Table 5.4.3.1.**

*Distillation Stream Table*

<b>Stream Number</b>	<b>20</b>	<b>23</b>	<b>24</b>
Temperature (F)	185	212	180
Pressure (psi)	14.7	14.7	14.7
Total lbs/batch	14,712	14,512	200
<b>Component Flow Rate (lbs/batch)</b>			
Water	14,625	14,510	115
Ethanol	87	2	85

### 5.4.4 Column Specifications

The distillation unit will consist of 12 stages in total with sieve trays. The tray material is stainless steel. A table with detailed column specifications along with a corresponding schematic diagram are shown below:



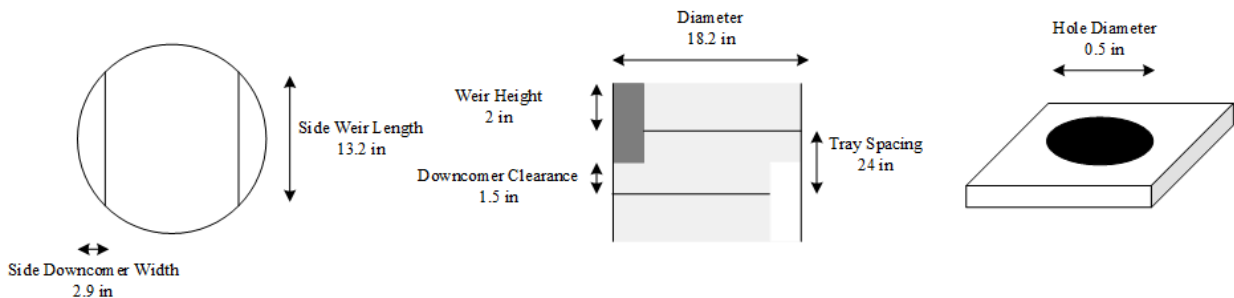
**Table 5.4.4.1.**

*Distillation Column Specifications*

<b>Column Specification</b>	
Number of stages	12
Type of tray	Sieve
Tray material	Stainless steel
Tray diameter (inches)	18.2
Tray spacing (inches)	24
Hole diameter (inches)	0.5
Number of holes per tray	106
Weir height (inches)	2
Downcomer clearance (inches)	1.5
Side downcomer width (inches)	2.9
Side weir length (inches)	13.2
Deck thickness (inches)	0.14

**Figure 5.4.4.1.**

*Distillation Column Design Specifications*



### 5.4.5 Heat Exchangers

The stream leaving RO and entering the column needs to be heated to 185 F. This requires 4.1 MMBtu/hr (continuous process) of heat (35,870 MMBtu per year). This energy will be provided by the bottoms product of the distillation column.

The steam leaving the bottoms product will be reused in the RO process in order to save on raw materials cost. Therefore, it needs to be cooled from 212 F to 59 F. This requires 4.9 MMBtu/hr of cooling (43,000 MBtu per year). However, once the pre-RO stream is used to heat exchange with this stream, only 0.82 MMBtu/hr of cooling is required (7,146 MMBtu per year). The amount of coolant required to cool this stream is 5.3 lbs/s or 165,806,649 lb/yr.

Table 5.4.5.1 below displays the energy requirements for the distillation column. As a note, HE-103 has no utility shown because it is a feed/bottoms exchanger. A diagram of HE-103 and the other heat exchangers can be found in Appendix I.

**Table 5.4.5.1.**

*Distillation Energy Table*

<b>Equipment</b>	<b>PFD Label</b>	<b>Annual Energy Usage (MMBtu)</b>	<b>Total Steam Flow Rate (lbs/yr) (10psi)</b>	<b>Total Glycol/Water Flow Rate (lbs/yr)</b>
Pre-Distillation Heat Exchanger	HE-103	35,870	-	-
Distillation Reboiler	HE-105	17,870	18,168,550	-
Distillation Condenser	HE-104	14,191	-	329,280,120
Post-Distillation Heat Exchanger	HE-106	1,497	-	165,806,649

### 5.4.6 Overall Scheduling

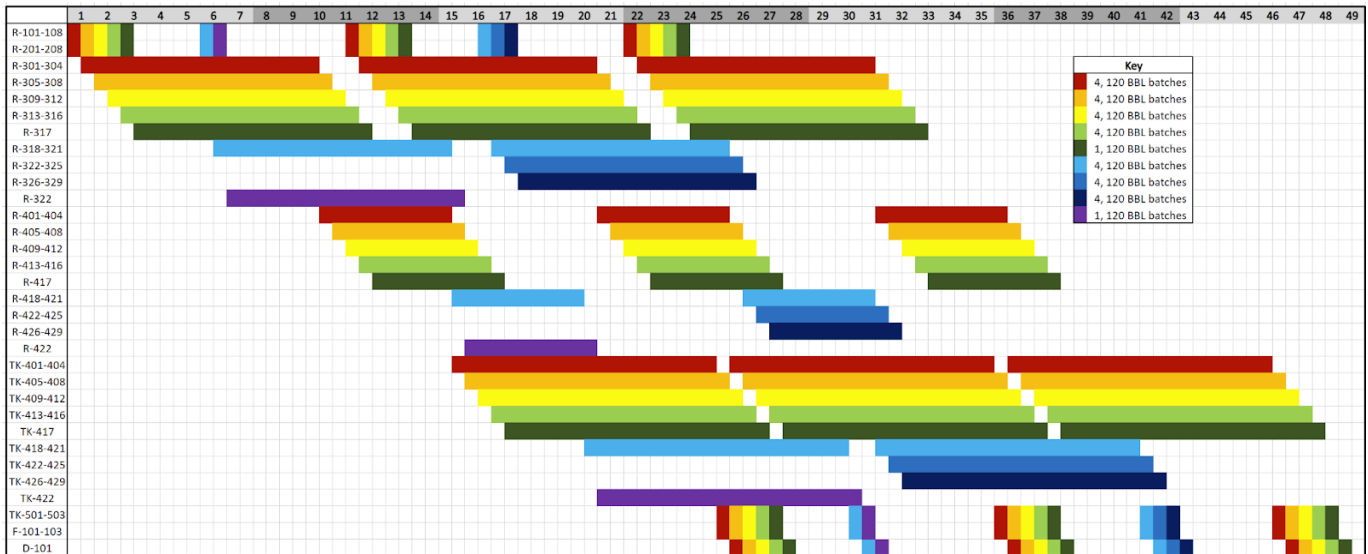
Taking all the individual schedules from the beer process up to this point, we have created an overall batch schedule to complete the 17 batches/week of 120 BBL to accomplish

our target production. In Figure 5.4.6.1, each color represents a collection of batches that are being prepared. This diagram illustrates the time a batch takes in each unit, and the time in between each use of a unit. For example, R-301 stores the first batch (shown in red) for 10 days, is dormant for 2 days, and then is in use for another 10 days for the second batch (also shown in red).

For this schedule to be maintained, we will need the following number of units for each step: 8 mash & lauter tuns, 8 boiler & clarifier tuns, 22 first fermenters, 22 second fermenters, 22 lagering tanks, 3 water tanks, 3 membrane filters, and 1 distillation column.

**Figure 5.4.6.1.**

*Preferment, Fermentation, RO, and Distillation Batch Schedule*



## 5.5 Post Distillation

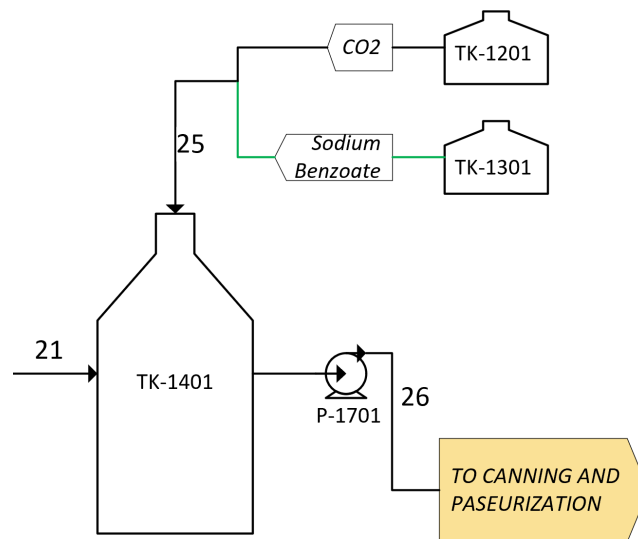
### 5.5.1 Brite Tank

The brite tank, which is 120 BBL in size and purchased from ABS Commercial, will mix together the dealcoholized beer along with carbon dioxide and sodium benzoate. This is in a batch process, with a residence time of 1 day. Carbon dioxide was assumed to be completely lost during the RO process, as the beer was being pumped through the RO device. Therefore, carbon

dioxide is added back in this step to bring the total carbonation to 0.5% carbon dioxide by weight in the final NA beer product. Additionally, sodium benzoate is added to the NA beer in this step. Sodium benzoate is a preservative added to food and beverages to prevent the growth of bacteria, yeast, and mold, and is soluble in water, tasteless, and odorless (Walczak-Nowicka & Herbet, 2022). The FDA currently places a maximum limit of 0.1% sodium benzoate in food and beverages; to err on the side of caution, 0.05% sodium benzoate was added to our NA beer (Code of Federal Regulations, 2024b). A process flow diagram and stream table are shown below:

**Figure 5.5.1.1.**

*Brite Tank PFD*



**Table 5.5.1.1.**

*Brite Tank Stream Table*

Stream Number	21	25	26
Temperature (F)	59	59	59
Pressure (psi)	14.7	14.7	14.7
Total lbs/batch	29,873	160	30,033

<b>Component Flow Rate (lbs/batch)</b>			
Beer	29,873	0	29,873
CO2	0	145	145
Sodium Benzoate	0	15	15

### 5.5.2 Beer Final Product Composition

The final beer product is 0.5% ABV non-alcoholic lager. The mass fraction components of the final beer product are shown in Table 5.5.2.1 below.

**Table 5.5.2.1.**

#### *Beer Final Product Composition*

<b>Component</b>	<b>Mass Fraction</b>
Ethanol	0.0039
Water	0.9513
Beer Proteins	0.0394
Sodium Benzoate	0.0005
CO2	0.0048

### 5.5.3 Canning

The final form of the N.A. beer product is in aluminum 12-ounce cans. 33.4 million cans are required per year and will be produced. To reach this quota, we will purchase a Mic Machinery Cixi canner, capable of canning at a rate of up to 10,000 cans per hour (Alibaba, n.d.-a). Filling and sealing the 33.4 million cans equates to about 649,000 cans a week or about 7,700 cans per hour, which is below the maximum rate with substantial room to account for any fluctuation in demand. The canning process cans from the beverage exiting the brite tank.

#### *5.5.4 Pasteurization*

Following canning, the N.A. beer will be pasteurized in the cans through a mild heat treatment process to inhibit the growth of potential beer spoilage microorganisms and extend the shelf life of the beer (Philliskirk, n.d.). The beer will be tunnel pasteurized in an EQS Tunnel Pasteurizer and held at a temperature of 140 F for 15 minutes (Sheep in Wolf's Clothing Brewery, 2022; Alibaba, n.d.-d). We will purchase 2 of these tunnel pasteurizers; each can run at a maximum rate of 6000 cans per hour, allowing us to comfortably deal with the necessary rate of about 7,800 cans per hour. Afterwards, beer can be stored and shipped at room temperature, though chilling the beer around 40 to 45 F for lagers particularly is also a common choice for beers (Pomranz, 2018).

## **6. Kombucha Design**

### ***6.1 Steeper***

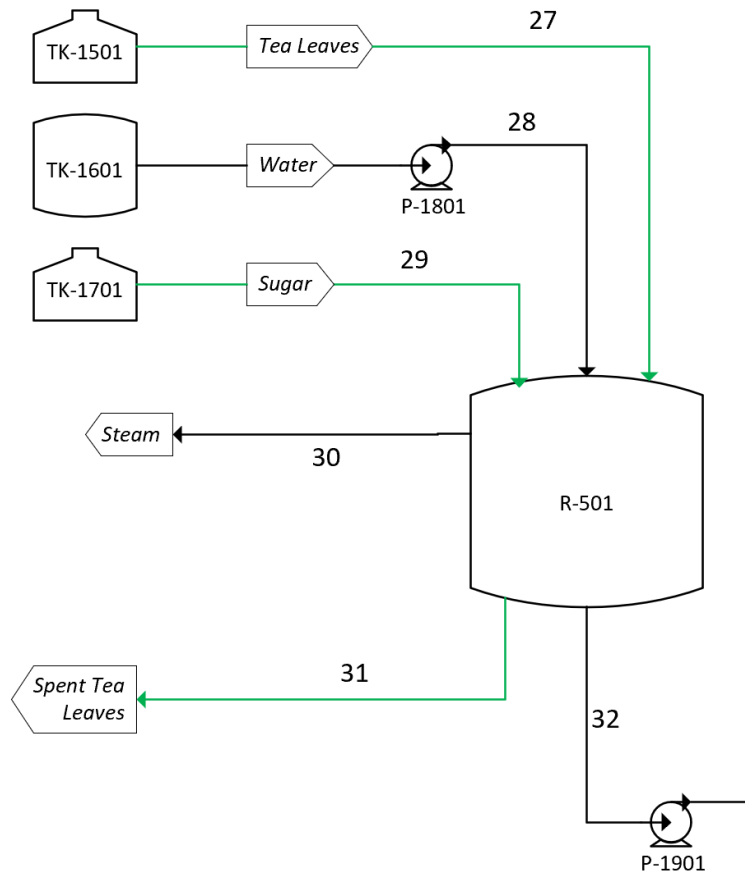
During this initial stage in the kombucha process, 26,336 lbs/batch of water is heated up from room temperature, 72 F, to near boiling temperature at 200 F. Afterwards, 2,011 lbs/batch of sugar is combined with the hot water in the steeping kettle. The water and sugar required was determined from the kombucha recipe from Kickass Kombucha (Bond, 2024). However, an important factor that was considered was that water is added to the kombucha later in the process with the added ethanol from the beer process. Therefore, the amount of water needed to be added for this step was decreased accordingly to account for the added water later. As a result, the tea produced at this step is more concentrated, to allow for a balanced final product at the end. Following this, the solution is mixed and 134 lbs/batch of black tea leaves are added. The mixture is mixed once again and steeped for 30 minutes. After the tea has been steeped, the mixture drains from the bottom of the kettle through a filter, which catches the spent tea leaves that remain. Some water is lost through heating, as well as in the saturated tea leaves, which was taken into account. The tea-infused water and sugar mixture that exits the kettle is sent through a heat exchanger to cool the mixture back to 72 F. After the tea-infused water and sugar mixture is cooled, it is pumped to the fermenter. The time this process step takes is 2 and a half hours total, including time for heating up, steeping for 30 minutes, and then cooling down.

The steeper kettle is a commercial 120 BBL hot/cold liquor tank from ABS. The tank is 19 ft 5 in tall with a diameter of 7 ft 11 in. The hot liquor tank is stainless steel, jacketed, and insulated with 3.2 inches of polyurethane. Steam will be passing through this jacket at 10 psi to heat the tea solution.

The energy requirement of this process is twofold. First, the energy to heat the tea from 72 F to 200 F is needed. Second, the energy to cool the tea from 200 F to 72 F is needed. The energy to heat the tea was calculated as 7.8 MBtu per batch (4,300 MBtu per year). The amount of steam required to heat the tea for a 30 minute duration is 4.4 lbs/s (4,374,915 lbs/yr) of 10 psi steam. The energy needed to cool the tea was found to be 7.2 MBtu per batch (4000 MBtu per year). The amount of coolant required to cool the tea down over a 30 minute timespan is 93 lbs/s (92,889,300 lbs/yr) For future optimizations, these two streams can be run through each other in the heat exchanger to save energy.

**Figure 6.1.1.**

*Steeper PFD*





**Table 6.1.1.***Steeper Stream Table*

<b>Stream Number</b>	<b>27</b>	<b>28</b>	<b>29</b>	<b>30</b>	<b>31</b>	<b>32</b>
Temperature (F)	72	200	72	200	72	72
Total lbs/batch	134	26,336	2,011	1,317	668	26,496
<b>Component Flow Rate (lbs/batch)</b>						
Water	0	26,336	0	1,317	534	0
Tea-Infused Water	0	0	0	0	0	24,485
Tea Leaves	134	0	0	0	134	0
Sugar	0	0	2,011	0	0	2,011

**Table 6.1.2.***Kombucha Energy Table*

<b>Equipment</b>	<b>PFD Label</b>	<b>Annual Energy Usage (MMBtu)</b>	<b>Total Steam Flow Rate (lbs/yr) (10psi)</b>	<b>Total Glycol/Water Flow Rate (lbs/yr)</b>
Steeper	R-501	4,300	4,374,915	-
Pre-Fermentation Heat Exchanger	HE-201	4,000	-	92,889,300

**6.2 Fermentation****6.2.1 Fermentation Conditions**

Kombucha is fermented with a symbiotic culture of bacteria and yeast, known as SCOBY. SCOBY eats the sugar in the tea mixture, and produces ethanol, carbonation, and organic acids such as acetic acids. The fermentation will be done at room temperature with an open lid. The top of the tank will be covered with a breathable, 100% cotton cloth with a tight weave, to allow for aeration of the mixture as well as protecting the kombucha from dust and debris.

The tea-infused water and sugar mixture from the heat exchanger will be in the tank with SCOBY added. Additionally, starter kombucha will be added to the mixture at a volumetric ratio of 1:7 starter kombucha to tea mixture according to the recipe. The starter kombucha is necessary for the fermentation process: starter kombucha introduces the yeast and bacteria into a fresh batch of sweet tea to begin the fermentation and lowers the pH of the mixture (Fermentaholics, n.d.). For the first batch made with 4,022 lbs/batch of starter kombucha, we will purchase the starter kombucha mixture from a provider. However, for all subsequent batches, we will recycle the kombucha post-1st fermentation back into the fermenter for the following batch, which was factored into the material balance.

Finally, at the end, the SCOBY will be fully removed from the tank. In our process, we assume that there is no net production of biomass, and we assume that the sugars are fully converted into acids and proteins in the product solution.

### *6.2.2 Fermentation Tank*

The selected design equipment will be a 145 BBL conical fermentation tank from ABS for the fermentation. This will be used for 10 days plus an hour which overall accounts for fermentation, cleaning, transferring, and any other source of potential time setback. This tank, after accounting for headspace, will be able to hold 120 BBL of kombucha. The tank's dimensions are 22 ft tall with a diameter of 7 ft 5 in.

### *6.2.3 Products*

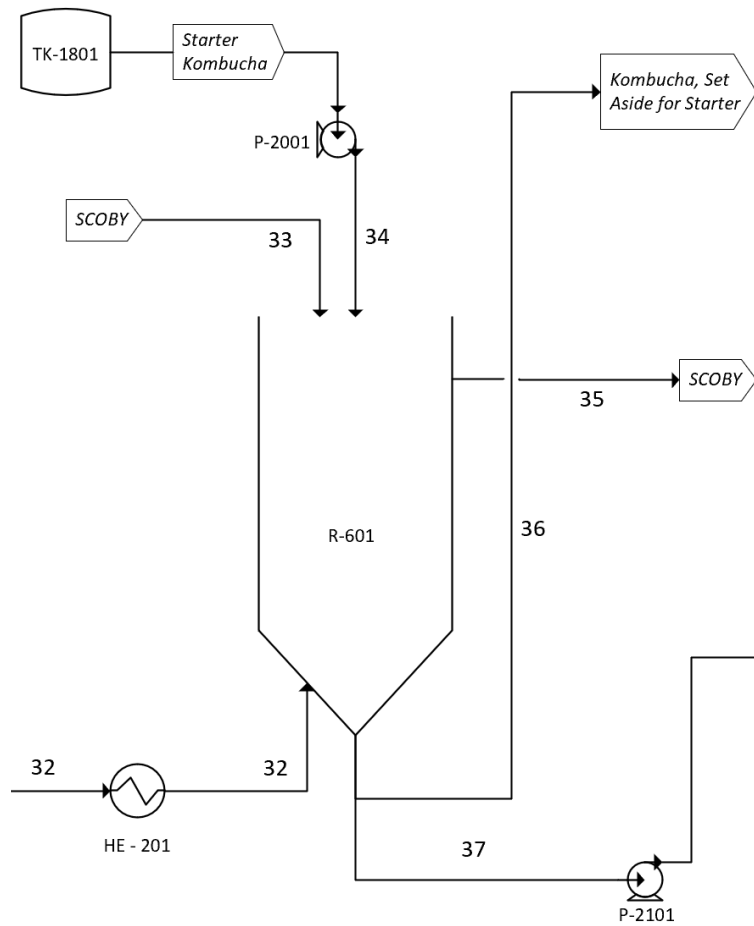
The product exiting the fermenter is composed of tea-infused water, ethanol, carbon dioxide, and organic acids. The kombucha mixture is sent to a mixer.

### 6.2.4 Process Flow Diagram and Stream Table

The process flow diagram for this step is shown below, along with a stream table with the relevant streams.

**Figure 6.2.4.1.**

*Kombucha Fermentation PFD*



**Table 6.2.4.1.***Kombucha Fermentation Stream Table*

<b>Stream Number</b>	<b>32</b>	<b>33</b>	<b>34</b>	<b>35</b>	<b>36</b>	<b>37</b>
Temperature (F)	72	72	72	72	72	72
Total lbs/batch	26,496	0.04	4,022	0.04	4,022	26,496
<b>Component Flow Rate (lbs/batch)</b>						
Tea-Infused Water	24,485	0	3,471	0	3,471	22,865
Ethanol	0	0	4	0	4	28
Carbon Dioxide	0	0	20	0	20	131
Sugar	2,011	0	0	0	0	0
Organic Acids and Proteins	0	0	527	0	527	3,472
SCOBY	0	0.04	0	0.04	0	0

*6.2.5 Scheduling*

The fermentation process takes 10 days and an hour, which incorporates fermentation for 10 days plus an additional hour as a buffer. The kombucha is then sent into the brite tank for 4 days, where it is mixed with carbon dioxide and raspberry juice.

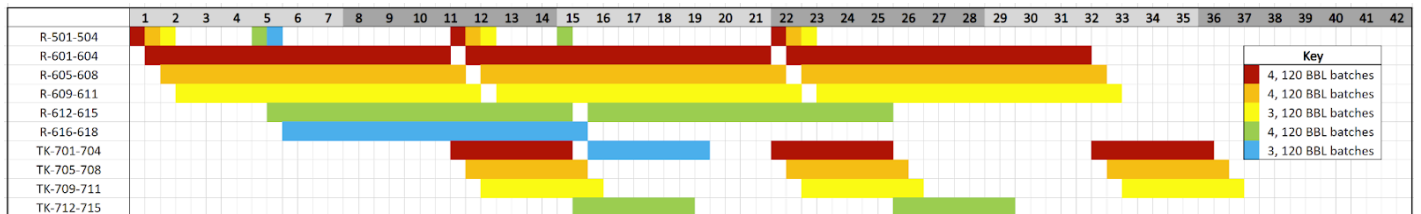
*6.2.6 Overall Scheduling*

Taking all the individual schedules from the kombucha process up to this point, we have created an overall batch schedule to complete the 11 batches/week of 120 BBL to accomplish our target production. In Figure 6.2.6.1, each color represents a collection of batches that are being prepared. This diagram illustrates the time a batch takes in each unit, and the time in between each use of a unit. For example, R-501 stores the first batch (shown in red) for 10 days, is dormant for half a day, and then is in use for another 10 days for the second batch (also shown in red).

For this schedule to be maintained, we will need the following number of units for each step: 4 steepers/kettles, 18 fermenters, and 15 brite/mixing tanks.

**Figure 6.2.6.1.**

*Kombucha Batch Schedule*



### 6.3 Mixer

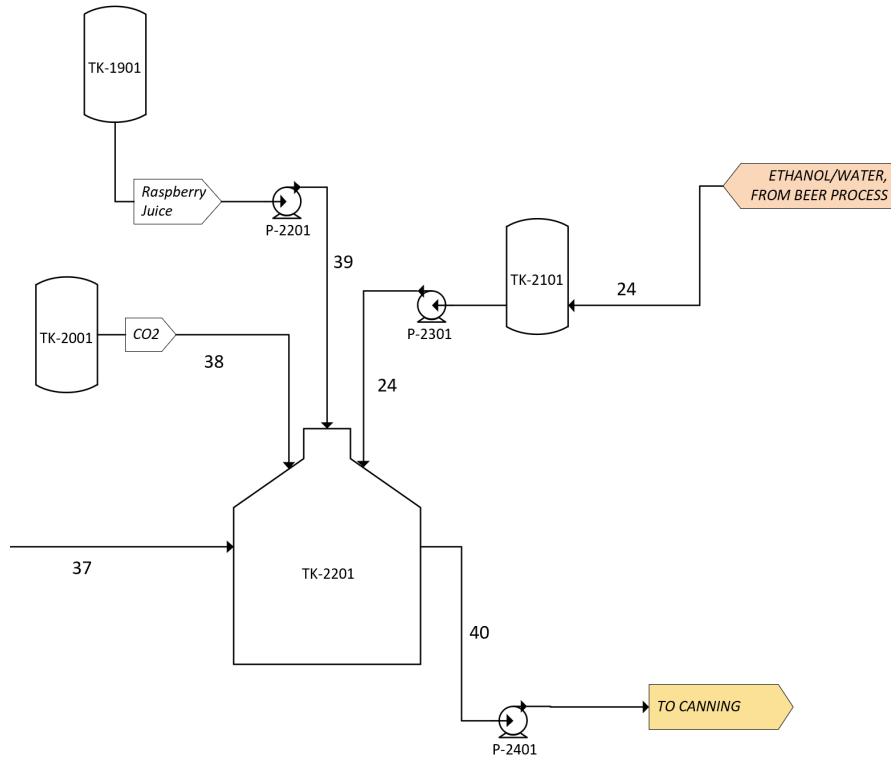
The mixer tank will mix together the kombucha from the first fermentation, the ethanol and water mixture coming from distillation in the beer process, additional carbon dioxide to increase carbonation to the desired final carbonation, and raspberry juice for flavoring. The mixing will be done at room temperature and at standard atmospheric pressure. The carbon dioxide will be purchased from an outside provider.

Additionally, the raspberry juice will be purchased from a provider. Adding the raspberry juice acts as a second fermentation for the kombucha through the added sugars, which allows the flavors to mature.

The mixing tank that will be used is the 120 BBL mixing tank from ABS Commercial. The final product is 5.5% ABV raspberry black tea kombucha. Following the mixing tank, the final kombucha product will be sent to canning. A process flow diagram and a stream table for this mixing step are shown below:

**Figure 6.3.1.**

*Kombucha Mixing PFD*



**Table 6.3.1.**

*Kombucha Mixing Tank Stream Table*

Stream Number	24	37	38	39	40
Temperature (F)	180	72	72	72	72
Total lbs/batch	3,171	26,496	33	1,902	31,601
<b>Component Flow Rate (lbs/batch)</b>					
Water	1,818	0	0	0	0
Tea-Infused Water	0	22,865	0	0	24,684
Ethanol	1,353	28	0	0	1,380
Carbon Dioxide	0	131	33	0	164
Organic Acids and Proteins	0	3,472	0	0	3,472
Raspberry Juice	0	0	0	1,902	1,902

### 6.3 Kombucha Final Product Composition

The final kombucha product is 5.5% ABV alcoholic raspberry kombucha. The mass fraction components of the final kombucha product are shown in Table 6.3.1 below.

**Table 6.3.1.**

*Kombucha Final Product Composition*

Component	Mass Fraction
Tea-Infused Water	0.7811
Ethanol	0.0437
CO2	0.0052
Organic Acids	0.1009
Raspberry Juice	0.0602

### 6.4 Canning

During the canning process, the final kombucha product will be put into 12-ounce aluminum cans. 21.9 million cans will be needed per year to can all of the kombucha product. We will purchase another Mic Machinery Cixi canner, capable of running at a rate of 10,000 cans per hour. Filling and sealing 21.9 million cans of kombucha equates to about 426,000 cans per week, or about 5,100 cans per hour, well below the maximum rate. The kombucha does not go through a pasteurization process after canning. Often, pasteurization is done to kombucha to kill the culture and prevent carbon dioxide and alcohol buildup (Pennsylvania Department of Agriculture, 2017). However, due to our kombucha product being alcoholic and containing live cultures, our kombucha product will not be pasteurized.

## 7. Ancillary Equipment Design

### 7.1 Pump Design

The pumps were designed by taking the product of differential pressure and volumetric flow rate to obtain hydraulic power. The differential pressure was the sum of the actual pressure difference, frictional losses (0.5 atm loss in pipes, 0.5 atm loss in heat exchangers, and 0.5 atm loss for centrifugal pumps), and gravity head. All of the pumps were centrifugal as the pumped fluids were not viscous nor needed to be controlled precisely. Additionally an efficiency of 70% was used for the pumps, and an efficiency of 90% was used for electrical drivers (Appendix III for sample calculation). The actual number of pumps was found by counting the maximum number of pumps needed in a 24 hour timespan. Then, spares were accounted for by making sure there was at least one extra spare for each process step and for process steps with a larger number of required pumps one third of the amount of required pumps was added to be spares. This addition of spares is used to account for maintenance or potentially overlapping batches that may occur in the real world due to setbacks. Pump design information can be found in Table 8.1.1.1.

### 7.2 Heat Exchanger Design

Heat exchangers were designed based upon their necessary area of contact. This equipment, as with most food grade equipment, was designed using Type 316 stainless steel. The area was determined by dividing the heat duty by the overall heat transfer coefficient as well as the logarithmic mean temperature difference (LMTD). Overall heat transfer coefficients were estimated as 850 W/m<sup>2</sup> K for condensers and 285 W/m<sup>2</sup> K for liquid on liquid, as found in Appendix E in *Plant Design and Economics for Chemical Engineers* (Peters et al., 2003). The

LMTD was found using the equation:  $\frac{\Delta T_A - \Delta T_B}{\ln(\Delta T_A) - \ln(\Delta T_B)}$ . The contact areas are tabulated in Table

8.1.2.1.



### ***7.3 Glycol Chiller***

The glycol chiller was designed by finding previously existing auxiliary equipment and using energy efficiency information. In the case of this project, an air cooled glycol chilling system was used with a 35% glycol to 65% water ratio as the fluid to be cooled. An energy efficiency ratio of 10.964 was used to obtain power requirements as this number is comparable for most air cooled chiller units.

### ***7.4 Steam Generator***

In order to provide continuous steam for heating, a steam generator was designed. This generator was designed by using currently existing steam generators in order to determine power output and water requirements.

### ***7.5 Storage Tanks***

Storage tanks will be used extensively throughout both beer and kombucha processes due to the timing differences between process steps and the batch schedule. The volume and number of tanks needed were determined based on the amount required to store one week's worth of batches for both beer and kombucha at a time. In section 8.1.4 of this report, all storage tank contents and their corresponding tank IDs, storage volumes, and number of tanks are detailed in Tables 8.1.4.1 and 8.1.4.2 for beer and kombucha respectively.

### ***7.6 Walk-Behind Forklifts***

To transport the malt, trub, hops, and tea leaves, we will be using walk-behind forklifts. There will be five for the beer portion of the plant, three for the kombucha portion, and two spares.

## 8. Economic Analysis

### 8.1 Capital Costs

#### 8.1.1 Pumps

The capital cost for pumps was estimated using Table 7.2 in *Chemical Engineering Design: Principles, Practice and Economics of Plant and Process Design* (Towler & Sinnott, 2022, pp. 253-255). This uses a correlative equation  $C_e = a + bS^n$  where S is a size parameter which correlates to a design parameter. In the case of pumps, this design parameter is volumetric flow rate. The flow rates for centrifugal pumps typically vary from 1 to 1000 L/s so each pump's size parameter was scaled using this range of flow rates (E. Anderson, 2024b). One exception to this calculation was for the RO pump. This pump operates at a high pressure and is the most critical to the function of the plant. As such, the highest value for S was used in order to provide a conservative estimate that accounts for a pump which needs more accuracy and power. The prices were determined for each pump for a given CEPCI index (532.9). This had to be scaled up to account for inflation where a CEPCI of 800 was used (E. Anderson, 2024a). The capital costs of all pumps were tabulated and summed (Table 8.1.1.1) with the total cost being \$3,159,847.

**Table 8.1.1.1.**

#### *Pump Operating and Capital Cost*

<b>Pump Series Number</b>	<b>Number of Pumps</b>	<b>Volumetric Flow Rate (GPM)</b>	<b>Hydraulic Power (KW)</b>	<b>Time Run (hr/y)</b>	<b>Operating Cost (\$/yr)</b>	<b>Capital Cost</b>
101	2	104.80	929	417	\$86.03	\$24,631
102	2	218.51	1,937	417	\$179.38	\$25,204
103	2	0.03	0	417	\$0.02	\$24,020
201	16	330.06	2,874	834	\$532.13	\$205,891
301	16	324.31	4,506	834	\$834.43	\$205,675
401	16	29.69	221	834	\$40.93	\$193,728

501	2	5.31	55	208	\$2.56	\$24,061
601	12	11.58	81	208	\$3.75	\$144,622
701	12	545.73	5,431	208	\$251.43	\$160,314
801	12	545.73	4,373	208	\$202.46	\$160,314
901	12	545.73	5,573	208	\$258.03	\$160,314
1001	6	56.84	399	10,000	\$885.56	\$73,116
1101	6	68.30	19,870	10,000	\$44,155.58	\$239,993
1201	6	56.74	398	10,000	\$884.09	\$73,114
1301	2	65.67	778	8,760	\$1,515.29	\$24,421
1401	2	63.89	856	8,760	\$1,667.23	\$24,411
1501	2	0.95	9	8,760	\$17.84	\$24,028
1601	12	568.44	5,641	208	\$261.15	\$160,919
1701	12	571.48	4,007	208	\$185.50	\$161,000
1801	12	463.90	4,400	138	\$135.02	\$158,110
1901	12	207.28	2,733	138	\$83.87	\$150,894
2001	12	69.46	694	138	\$21.29	\$146,650
2101	12	207.28	2,070	138	\$63.53	\$150,894
2201	12	24.89	263	138	\$8.06	\$145,123
2301	12	60.06	557	138	\$17.08	\$146,340
2401	12	247.21	1,736	138	\$53.29	\$152,059
<b>Total:</b>	<b>236</b>				<b>\$52,346</b>	<b>\$3,159,847</b>

### 8.1.2 Heat Exchangers

The capital cost for heat exchangers was calculated by using Figure 15.15 in *Plant Design and Economics for Chemical Engineers* (Peters et al., 2003). The cost was estimated using the heat exchange contact area for Type 316 Stainless Steel. Then, the CEPCI index for the year was found (396.9) and cost was scaled to the current year (CEPCI of 800) (Vatavuk, 2002).

The capital costs of all shell and tube heat exchangers were tabulated, as shown in Table 8.1.2.1 below, with the total cost being \$1,259,763.

**Table 8.1.2.1.**

*Heat Exchanger Contact Area and Capital Cost*

<b>ID</b>	<b>Heat Duty (MMBtu/hr)</b>	<b>Heat Exchangers Count</b>	<b>Fluid Contact Area (ft<sup>2</sup>)</b>	<b>Capital Cost (\$)</b>
HE-101	1.06	8	1,962	\$524,061
HE-103	4.15	2	3,115	\$161,250
HE-106	0.83	2	422	\$40,312
HE-102	0.17	3	743	\$90,703
HE-201	0.50	4	3,665	\$443,437
<b>Total:</b>				<b>\$1,259,763</b>

*8.1.3 Miscellaneous Auxiliary Equipment*

The glycol chiller was designed based on the cooling energy required. The heat duties of each heat exchanger (including jacketed reactors) that required a coolant were tabulated and summed. This was then compared to the cooling capacity of a large-scale, air-cooled glycol chiller sold by Advantage Engineering (Advantage Engineering, n.d.). The number of glycol chillers needed to sustain a sufficient enough amount of energy was calculated and rounded up. Then, one extra spare was taken into account (Table 8.1.3.1). This was due to the fact that this process doesn't require a consistent energy flow but instead it fluctuates. The heat duties calculated are all averages but in reality some hours may require more energy than what was calculated. As such, an extra amount of tolerance is needed. This leads to a final estimated capital cost of \$1,526,975 (Table 8.1.3.3).

The steam generator was designed similarly to the glycol chiller. First, the amount of heat required was summed. Then, this heat required was compared to the heating capacity of a large-scale, diesel powered steam generator (Sioux, n.d.). The number of steam generators needed was calculated and a spare was taken into account both for maintenance and leeway due to inconsistent heat duty requirements of a batch process. The estimated pricing of a steam generator was estimated by scaling up the pricing of a smaller scale steam generator (Cole-Parmer, n.d.). Of course, this means that the actual capital is likely lower than what was calculated, but access to pricing of higher capacity machinery was much more difficult to acquire. The final estimated capital cost of the steam generators ended up being \$582,904.

**Table 8.1.3.1.**

*Capital Cost of Glycol Chiller Estimated  
from Required Cooling Capacity*

ID	Heat Duty (MMBtu/hr)
HE-101	1.06
R-301	0.05
TK-801	0.11
HE-106	0.83
HE-201	0.50
HE-104	1.62
Total:	4.16
Glycol Cooling Capacity	1.22
Number of Chillers	5
<b>Total Capital Cost:</b>	<b>\$1,526,975</b>

**Table 8.1.3.2.**

*Capital Cost of Steam Generator Estimated  
from Required Heating Capacity*

ID	Heat Duty (MMBtu/hr)
TK-201	0.23
R-101	0.09
TK-301	0.54
R-201	0.41
HE-102	0.08
R-501	0.46
HE-105	2.04
Total:	3.86
Steam Energy Generation	4
Number of Generators	3
<b>Total Capital Cost:</b>	<b>\$582,904</b>

Table 8.1.3.3 includes the cost of equipment regarding heat transfer and transport between unit ops.

**Table 8.1.3.3.**

*Auxiliary and Miscellaneous Equipment Capital Cost*

Type	Description	Material	Cost/Unit (Averaged)	Number of Units	Total Cost
Auxiliary	Auxiliary Glycol Chiller	Stainless Steel	\$305,395	5	\$1,526,975
	Auxiliary Steam Generator	Stainless Steel	\$194,301	3	\$582,904
	Pumps	Stainless Steel	\$13,390	236	\$3,159,846
	Heat Exchangers	Stainless Steel	\$66,303	15	\$1,259,763
Pasteurization	EQS Tunnel Pasteurizer	Stainless Steel	\$62,000	2	\$124,000
Canning	Mic Machinery Cixi Canner	Stainless Steel	\$8,500	2	\$17,000
Transport	Walk-Behind Forklifts	--	\$8,200	10	\$82,000
<b>Total:</b>					<b>\$6,752,489</b>

*8.1.4 Holding Tanks*

The size of some of the holding tanks in Table 8.1.4.1 (TK-101, TK-401, TK-501, and TK-601) was determined by how much material was needed in a year’s worth of production. The remaining tank sizes and number of units were determined by finding the amount of raw material that was needed for 1 week's worth of production, or 22 batches of 120 BBL, at most, of the final beer product. The cost of beer holding tanks was calculated, resulting in a total cost of \$772,770.

The size of the holding tanks in Table 8.1.4.2 was determined by how much material was needed for 1 week's worth of production, or 18 batches of 120 BBL, at most, of the final kombucha product. The pricing for the tanks can be found in Appendix IV. The cost of the kombucha holding tanks was calculated, resulting in a total cost of \$596,801.

**Table 8.1.4.1.***Beer Holding Tanks Capital Cost*

<b>ID</b>	<b>Description</b>	<b>Size (BBL)</b>	<b>Material</b>	<b>Cost/unit (Averaged)</b>	<b>Number of units</b>	<b>Total cost</b>
TK-101	Grain Silo	<sup>a</sup> 100	Stainless Steel	\$5,430	2	\$10,860
TK-103	Holding Tank - Flaked Rice	35	Stainless Steel	\$2,860	1	\$2,860
TK-201	Hot/Cold Liquor Tank - Strike Water	120	Stainless Steel	\$34,360	6	\$206,160
TK-301	Hot/Cold Liquor Tank - Sparge Water	120	Stainless Steel	\$34,360	15	\$515,400
TK-401	Holding Tank - Hops	60	High-density polyethylene	\$2,510	1	\$2,510
TK-501	Brite Tank - Yeast Nutrient	5	Stainless Steel	\$5,950	1	\$5,950
TK-601	Holding Tank - Clarifier	3	Polyethylene	\$270	1	\$270
TK-701	Brite Tank - Yeast	40	Stainless Steel	\$18,250	1	\$18,250
TK-1201	Holding Tank - CO2	<sup>b</sup> 20	Aluminum	\$138	8	\$1,106
TK-1301	Holding Tank - Sodium Benzoate	<sup>c</sup> 30	Polyethylene	\$79	1	\$79
<b>Total:</b>						<b>\$763,444</b>

Notes:  
a. tons  
b. lbs  
c. gal

**Table 8.1.4.2.***Kombucha Holding Tanks Capital Cost*

<b>ID</b>	<b>Description</b>	<b>Size (BBL)</b>	<b>Material</b>	<b>Cost/unit (Averaged)</b>	<b>Number of units</b>	<b>Total cost</b>
TK-1501	Holding tank - Tea leaves	25	Polyethylene	\$1,255	1	\$1,255
TK-1601	Holding tank - Water	120	Stainless Steel	\$34,360	10	\$343,600
TK-1701	Holding tank - Sugar	90	Stainless Steel	\$34,800	1	\$34,800
TK-1801	Holding tank - Starter	150	Stainless Steel	\$42,600	2	\$85,200
TK-1901	Holding tank - Raspberry juice	150	Stainless Steel	\$42,600	1	\$42,600
TK-2001	Holding tank - CO2	<sup>a</sup> 20	Aluminum	\$138	30	\$4,146
TK-2101	Holding tank - Ethanol	150	Stainless Steel	\$42,600	2	\$85,200
					<b>Total:</b>	<b>\$596,801</b>

Notes:  
a. lbs

*8.1.5 Beer Equipment*

Seen in Table 8.1.5.1, the size and number of units of the grain mill, reactors, and tanks was determined by finding the amount of raw material that was needed for 1 week's worth of production, which is 22 batches of 120 BBL at most. The pricing for the equipment can be found in Appendix IV. The cost of beer equipment was calculated, resulting in a total cost of \$3,719,185.



**Table 8.1.5.1.***Beer Equipment Capital Cost*

Type	ID	Description	Size (BBL)	Material	Cost/unit (Averaged)	Number of units	Total cost
Grain Mill	G-101	MB® Commercial Grain Mill	--	Stainless Steel	\$4,900	2	\$9,800
Reactor	R-101	Mash & Lauter Tun	120	Stainless Steel	\$17,499	8	\$139,992
	R-201	Boiler & Clarifier	120	Stainless Steel	\$34,360	8	\$274,880
	R-301	Primary Fermenter	120	Stainless Steel	\$28,730	30	\$861,900
	R-401	Secondary Fermenter (Brite Tank)	120	Stainless Steel	\$27,576	30	\$827,280
Filter	F-101	RO Membrane Filter	--	Polyamide film - AFC99	\$1,223	204	\$249,401
Column	D-101	12-stage, 26 ft tall Custom Distillation Column	--	Stainless Steel	\$70,692	1	\$70,692
Tank	TK-801	Horizontal Lagering Tank	120	Stainless Steel	\$27,576	30	\$827,280
	TK-901	Brite Tank - Beer + Water Before RO	160	Stainless Steel	\$42,600	3	\$127,800
	TK-1001	Hot/Cold Liquor Holding Tank - Water after RO	120	Stainless Steel	\$34,360	5	\$171,800
	TK-1101	Hot/Cold Liquor Holding Tank - Recycle Water from Distillation	120	Stainless Steel	\$34,360	1	\$34,360
	TK-1401	Brite Tank - NA Beer + Additives	120	Stainless Steel	\$31,000	4	\$124,000
<b>Total:</b>							<b>\$3,719,185</b>

*8.1.6 Kombucha Equipment*

Seen in Table 8.1.5.2, the size and number of units was determined by finding the amount of raw material that was needed for 1 week's worth of production, which is 18 batches of 120

BBL at most. The pricing for the equipment can be found in Appendix IV. The cost of kombucha equipment was calculated, resulting in a total cost of \$1,290,640.

**Table 8.1.6.1.**

*Kombucha Equipment Capital Cost*

Type	ID	Description	Size (BBL)	Material	Cost/unit (Averaged)	Number of units	Total Cost
Reactor	R-501	Hot/Cold Liquor Tank - Tea Steeper	120	Stainless Steel	\$34,360	4	\$137,440
	R-601	Conical Fermentation Tank	145	Stainless Steel	\$31,400	18	\$565,200
Mixing	TK-701	Mixing Tank	120	Stainless Steel	\$31,000	18	\$588,000
<b>Total:</b>							<b>\$1,290,640</b>

*8.1.7 Total Capital Costs*

To determine the total capital costs, we first calculated two costs; the first cost is the Inside Battery Limits investment (ISBL), referring to the already found cost of procurement and installation of process equipment. The equation utilized to estimate ISBL is

$$C = \sum_{i=1}^{i=M} C_{e,i,A} [(1 + f_p) + (f_{er} + f_{el} + f_i + f_c + f_s + f_l)/f_m]$$

where C is the ISBL cost and the remaining variables are defined in Table 8.1.7.1 (Towler & Sinnott, 2022). Notably, the material used is 316 stainless steel instead of carbon steel because the process is food-grade. This ends up being calculated as a cost of \$37,062,010. The second cost is the Outside Battery Limits investment (OSBL), referring to the costs of building an accommodating structure for the plant, including things such as railroads, office rooms, and analytical equipment. The equation for OSBL is  $C_{FC} = C(1 + OS)(1 + D\&E + X)$  where  $C_{FC}$  is the total capital cost, C is the ISBL cost, and the remaining variables are defined in Table 8.1.7.1 (Towler & Sinnott, 2022). The total capital cost ends up being estimated at \$70,047,199 .

Working Capital Cost is the amount of money needed to start a plant running. This cost was estimated using 15% of the Total Capital Cost in Table 8.1.7.1 (Towler & Sinnott, 2022).

The cost estimate came out to be \$10,507,080.

**Table 8.1.7.1**

*Total Capital Cost*

Item	Installation Factors
Equipment Erection ( $f_{er}$ )	0.5
Piping ( $f_p$ )	0.6
Instrumentation and Control ( $f_i$ )	0.3
Electrical ( $f_{el}$ )	0.2
Civil ( $f_c$ )	0.3
Structures and buildings ( $f_s$ )	0.2
Lagging and paint ( $f_l$ )	0.1
Stainless Steel ( $f_m$ )	1.3
<b>Total Purchased Equipment Cost:</b>	<b>\$37,062,010</b>
Offsites (OS)	0.4
Design and Engineering (D&E)	0.25
Contingency (X)	0.1
<b>Total Capital Cost:</b>	<b>\$70,047,199</b>
<b>Working Capital Cost:</b>	<b>\$10,507,080</b>

**8.2 Operating Costs**

*8.2.1 Raw Materials*

The cost of raw materials was calculated on a per year basis. Cost values were determined from a number of selling listings, as cited in Appendix IV in Table A.IV.III. The total raw material cost is \$26,403,066 per year. One particular material of note is the yeast and its

associated cost at \$13.3 million per year, corresponding to over half of the overall total raw materials cost. This associated high cost was subsequently addressed in Section 8.5, Alternative Scenarios for Profitability, to explore options for lowering this cost.

**Table 8.2.1.1.**

*Raw Material Costs*

Process	Raw Material	Cost/Amount (\$/lb)	Amount (lbs/yr)	Total cost (\$/yr)
Beer	Malt	\$0.7200	3,191,300	\$2,297,737
	Strike/Sparging Water	\$0.0008	30,596,570	\$24,756
	Flaked Rice	\$1.3600	851,014	\$1,157,379
	Hops	\$11.9900	15,197	\$182,208
	Yeast Nutrient	\$37.1150	1,270	\$47,131
	Clarifier	\$47.8400	717	\$34,290
	Yeast	\$54.7023	243,923	\$13,343,176
	RO Water	\$0.0008	129,094,157	\$104,453
	CO2	\$0.1900	126,767	\$24,086
	Sodium Benzoate	\$3.6993	13,059	\$48,308
Kombucha	Black Tea Leaves	\$7.5461	73,804	\$556,934
	Water	\$0.0008	14,550,739	\$11,773
	White Sugar	\$0.7336	1,111,096	\$815,100
	SCOBY <sup>1a</sup>	\$39.9600	<sup>1b</sup> 2	\$80
	Starter Kombucha <sup>2a</sup>	\$12.9900	<sup>2b</sup> 4,022	\$52,247
	Raspberry Juice	\$3.0721	1,050,669	\$3,227,789
	CO2	\$0.1900	18,064	\$3,432
Canning & Storage	12-oz Aluminum Cans	<sup>3a</sup> \$0.0700	<sup>3b</sup> 55,275,245	\$3,869,267
	6-can Plastic Rings	<sup>4a</sup> \$0.0654	<sup>4b</sup> 9,212,541	\$602,408
	120" Cotton Cloths	<sup>5a</sup> \$6.6600	<sup>5b</sup> 30	\$200
	48" x 40" Pallets	<sup>6a</sup> \$4.0000	<sup>6b</sup> \$46,063	\$184,251

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**Total:           \$26,403,066**

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Notes:

1a & 2a. First batch only

1b & 2b. lbs/batch

3a. \$/can

3b. cans/yr

4a. \$/ring

4b. rings/yr

5a. \$/cloth

5b. cloths/yr

6a. \$/pallet

6b. pallets/yr

### *8.2.2 Utilities*

Utility costs include the costs associated with treating organic waste as well as suspended solids, diesel, CIP treatment and associated water costs, steam costs throughout the process, and electricity costs to operate the pumps and glycol chiller.

The waste disposal cost was calculated using the city of Waukesha’s waste disposal charge and fee schedule (City of Waukesha, 2024). The two relevant charges are the price per pound of Total Suspended Solids (TSS) and Biochemical Oxygen Demand (BOD). Each of these are present in all liquid wastewater streams. A total amount of TSS and BOD was calculated based on concentration estimates provided by Kennewick Economic Development’s Craft Brewery Wastewater Program (Kennewick Washington, n.d.).

The price of diesel and water for steam was found using fuel and water usage information provided in the specification sheet for the sample steam generator which capital costs were based off of (Sioux, n.d.). Once the flow rate was determined, the pricing was calculated using standard wholesale prices (U.S. Energy Information Administration, 2024).

The utility cost of the glycol chiller was found by summing the total heat duty required for cooling. Then, the Energy Efficiency Rating (EER) was estimated to be 10.96 from information about air-cooled chillers provided by the Federal Energy Management Program

(Federal Energy Management Program, n.d.). The EER is the ratio of energy output to energy input which allows for an estimation of utility electrical cost.

The utility cost (electricity) for pumps was determined using hydraulic power. The amount of hydraulic power was multiplied by the time each pump and the cost per kWh to find the operating cost of each pump.

The last cost to be estimated is CIP which is crucial in food plants. The process of CIP is two steps. First, a caustic and water mixture is run through all equipment. Then, the equipment is rinsed with just water. The amount of water necessary was determined from prior literature with one suggestion being 3 gallons of water per 1 gallon of tank (Ss Brewtech, 2021). To note, this estimate provided in reference to smaller sized equipment. It is likely that less water per tank space is necessary for larger-sized equipment. Once the amount of water was estimated, the amount of caustic per water was found using caustic product details (WebstaurantStore, n.d.). The product page also had the price of caustic (at wholesale price) which was factored in to determine the cost.

In the end, the total utility costs are \$2,925,090 per year (Table 8.2.2.1).

**Table 8.2.2.1.**

*Utility Costs*

<b>Utility</b>	<b>Cost/Amount (\$/lb) or (\$/kWh)</b>	<b>Amount (thousand lbs/yr) or (thousand kWh)</b>	<b>Total cost (\$/yr)</b>
Waste Disposal (BOD)	\$1.4800	35	\$52,260
Waste Disposal (TSS)	\$0.7100	5.6	\$3,950
Diesel	\$0.3915	1,866	\$730,584
Caustic (CIP)	\$4.3290	99	\$428,827
Water (CIP)	\$0.0008	52,810	\$42,730
Water (Steam)	\$0.0008	35,026	\$28,652

Electricity (Pumps)	\$0.1400	366	\$51,298
Electricity (Glycol Chiller)	\$0.1400	11,334	\$1,586,788
		<b>Total:</b>	<b>\$2,925,090</b>

### 8.2.3 Labor

To determine the size of the labor force required, we used Equation 8.2.3.1. This equation, based on data from chemical plants and refineries, accounts for particulate and non-particulate processing steps appropriately (Lee, n.d.). Following the variables in the equation, we have 2 particulate processing steps (milling) and 172 non-particulate processing steps (every other step in our plant). This equates to 14 operators; we will have 3 more to account for workers during the lower-capacity night shift. In total, two managers, two engineers, seventeen operators, and four maintenance workers result in a workforce of 25 people. After factoring into account salary, benefits, and bonuses, the projected total labor cost is \$1,938,000 per year.

$$\text{(Equation 8.3.2.1) } N_{OL} = (6.29 + 31.7P^2 + 0.23N_{np})^{0.5}$$

$N_{OL}$ : number of operators per shift

P: particulate processing steps

$N_{np}$ : non-particulate processing steps

**Table 8.2.3.1.**

*Labor Costs*

<b>Employees</b>	<b>Salary (\$/yr)</b>	<b>Medical Benefits <sup>1</sup></b>	<b>Retirement Benefits</b>	<b>Bonuses</b>	<b>Number of employees</b>	<b>Total Cost</b>
Managers	\$120,000	\$8,000	\$9,600	\$5,000	2	\$285,200
Engineers	\$70,000	\$8,000	\$9,600	\$5,000	2	\$185,200
Operators	\$45,000	\$8,000	\$9,600	\$5,000	17	\$1,149,200
Maintenance	\$57,000	\$8,000	\$9,600	\$5,000	4	\$318,400
<b>Total:</b>					<b>25</b>	<b>\$1,938,000</b>

Notes:

1. Medical Benefits: single coverage medical insurance

*8.2.4 Miscellaneous*

A few miscellaneous costs were also necessary to consider. For instance, to account for fouling of the membrane used in the RO system, the cost for replacements every three years was incorporated. Other miscellaneous costs included insurance costs, the cost for our land in Waukesha (LandWatch, n.d.) and the associated property tax of 1.40% in Waukesha County (SmartAsset, n.d.), licensing fees to operate and sell liquor and licensing the beer and kombucha recipes that we based our recipes on, a 1-inch water meter sewage connection to our plant, marketing costs to advertise our products, and general and administrative costs, which was estimated as 65% of our total labor cost according to Towler and Sinnott. The total for miscellaneous costs is \$6,930,822 per year.



**Table 8.2.4.1.**

*Miscellaneous Costs*

Miscellaneous	Cost (\$/yr)
Membrane Fouling (avg 3 years)	\$83,134
Insurance	\$5,371,772
Land and Property Tax	\$167,209
Licensing Fees	\$2,078
1" Water Meter Sewage Connection	\$6,000
Marketing	\$100,000
General and Administrative	\$1,259,700
<b>Total:</b>	<b>\$6,989,893</b>

**8.3 Projected Revenues**

Projected revenue was determined based on wholesale prices for 6-packs of each beverage. The wholesale price for NA beer was priced based upon recommendation from Rob Mullin, production manager at Three Notch'd Brewing Company in Charlottesville, Virginia, and the wholesale price for alcoholic kombucha was priced based on prices for similar products currently in the market. Altogether, the projected revenue for both products totals \$56,210,406 per year.

**Table 8.3.1.**

*Projected Revenues from NA Beer and Hard Kombucha*

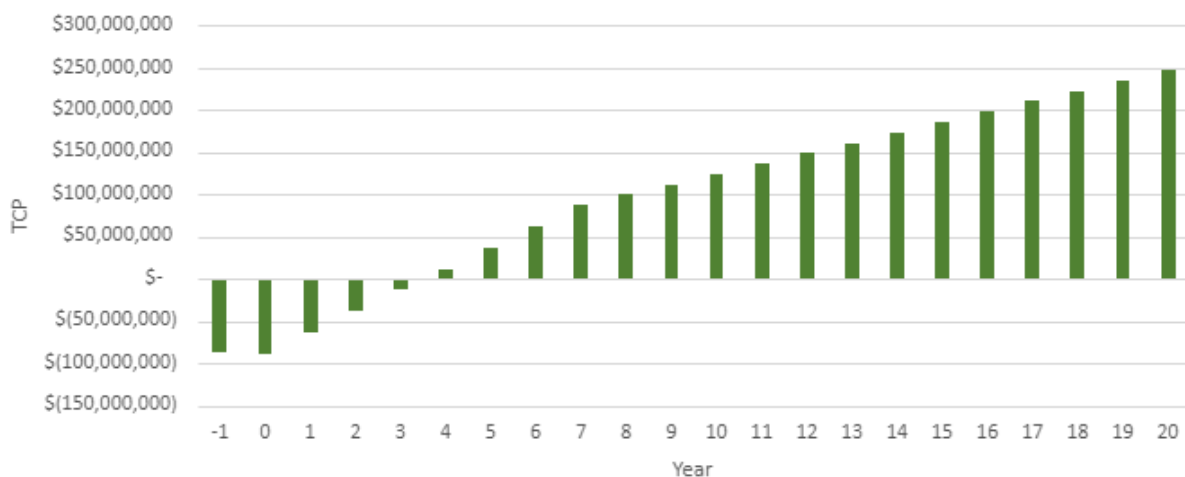
Type	Number of 6-packs/yr	Wholesale Price (\$/pack)	Revenue (\$/yr)
NA Beer	5,553,950	\$6.5625	\$36,483,234
Hard Kombucha	3,653,180	\$5.4000	\$19,727,172
		<b>Total :</b>	<b>\$56,210,406</b>

### 8.4 Cash Flow and Return on Investment (ROI) Analysis

The Total Cash Position, seen in Figure 8.4.1, illustrates our economic situation in a cumulative, yearly sense. The chart shows that we are in the negatives for the first few years. However, we do start making money in an estimated linear fashion as soon as we open (second half of Year 0), climbing out of the negatives by our fourth year and continuously climbing up. We expect to reach a little under \$250,000,000 in our net cash position by the end of year 20. The startup process which was simulated is that of 1.5 years of construction and 0.5 years running at half capacity. The process is run at full capacity starting at year 1. A 7 year straight line depreciation model was utilized to dampen the impact of taxation for the early stages of the facility's lifespan. Taxation was found using not only using standard tax rates based on our location in Wisconsin but also both federal and state liquor tax. Federal liquor tax was \$3.5 per barrel for the first 60,000 barrels (Beer Institute, n.d.) while state tax was \$2 per barrel except for the first 50,000 barrels which was only \$1 per barrel (State of Wisconsin Department of Revenue, 2023).

**Figure 8.4.1**

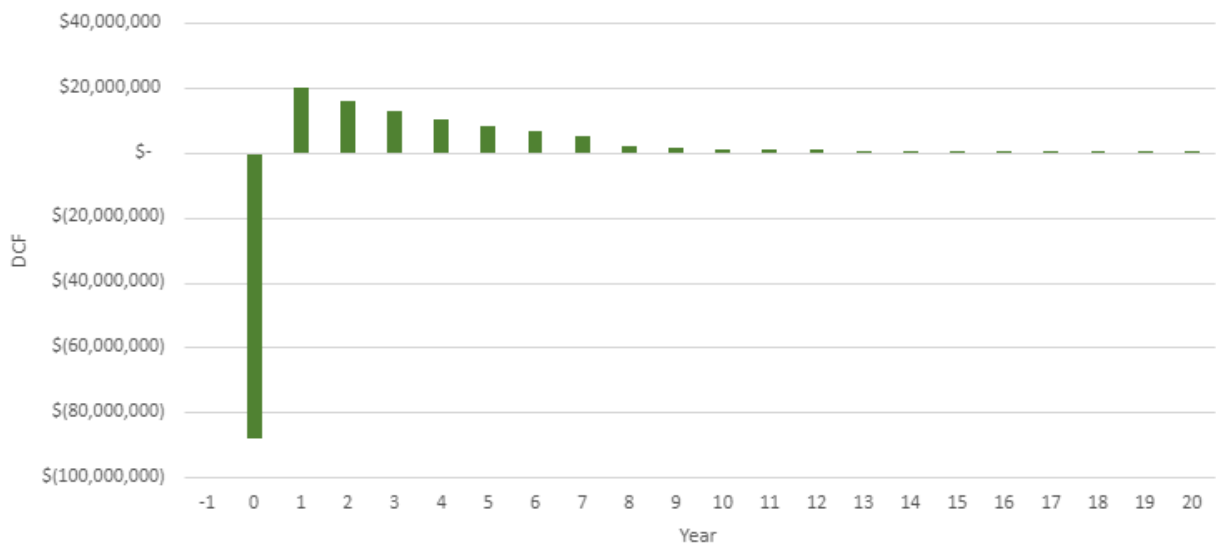
*Total Cash Flow Position*



The Discounted Cash Flow, seen in Figure 8.4.2, takes into account the time value of money to help value this potential investment. This is done by finding the interest rate that gives a net present value of zero (Towler & Sinnott, 2022). This interest rate (internal rate of return) was found to be 25.3%.

**Figure 8.4.2**

*Discounted Cash Flow at 25.3% Interest Rate*



The major decision-maker in if this process is a go or no-go is the internal rate of return (IRR). Reasonable IRRs can range from 10% to 40% depending on the technology (E. Anderson, 2024c). In the case of this process, NA beer is a relatively safe market and represents around 2/3 of our revenue. Meanwhile, hard kombucha is a rapidly growing product with its downside being its market size and novelty. Additionally, the process of extracting ethanol from beer and injecting it into another product is quite innovative. Some final considerations are location and potential political conflict. Wisconsin is a craft brewing haven, especially in Milwaukee and its surrounding area (Vinepair, 2022), which adds a layer of safety to investment. The most likely negative political decision that could be made in the future is a change to liquor tax or maybe

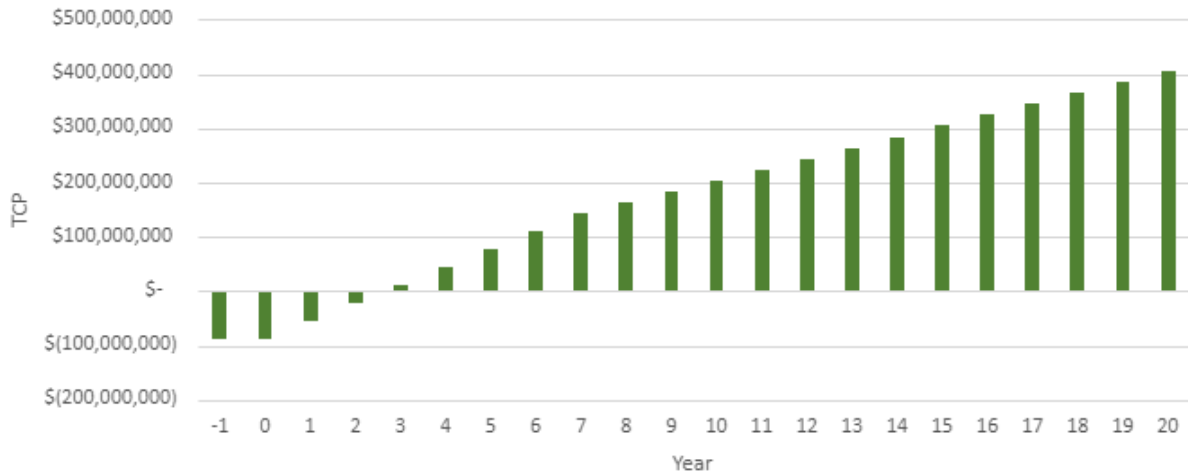
wastewater disposal. These are smaller issues as changes are not likely to significantly affect cash flow. A reasonable IRR that could be used is 20% for these mentioned reasons. Since the calculated IRR is 25%, a go decision is recommended (additionally, the alternative scenarios add even more motive to investment).

### ***8.5 Alternative Scenarios for Profitability***

Although already profitable, a few alternate scenarios were proposed to increase profits further. First, recycling yeast was considered. This is an extremely common practice, especially among larger-scale breweries. Breweries may reuse yeast for months (Brew Your Own, n.d.). However, an estimate of 6 batches per reuse was used. Currently, yeast accounts for just over 50% of raw material costs (\$13,343,176 a year). This number can be cut down to \$2,223,862 a year or 14% of raw material costs if the process of yeast recycling was implemented. The process of recycling yeast is relatively simple. Most of the bottom fermenting yeast would settle to the bottom of the fermenter. Then, the yeast would be cropped from the bottom of the fermenter and filtered. The filtered yeast would be separated via some separation process such as a disk centrifugation. Doing so would increase both the capital and utility costs. The capital cost would be that of a filter, centrifuge, and yeast storage tank. The utility cost would be that of pumping the yeast and the energy cost of centrifugation. For the purpose of rough estimation, utility cost was assumed to be negligible, while the capital cost was the estimated price of food-grade centrifuges, tanks, and pumps to meet capacity (\$50,000) (Alibaba, n.d.-b). The total cash position (Figure 8.5.1) and discounted cash flow (Figure 8.5.2) can be seen below. Notably, the total cash position goes from \$250,000,000 to \$400,000,000 by the end of year 20 while the IRR increases from 25.3% to 35.7%.

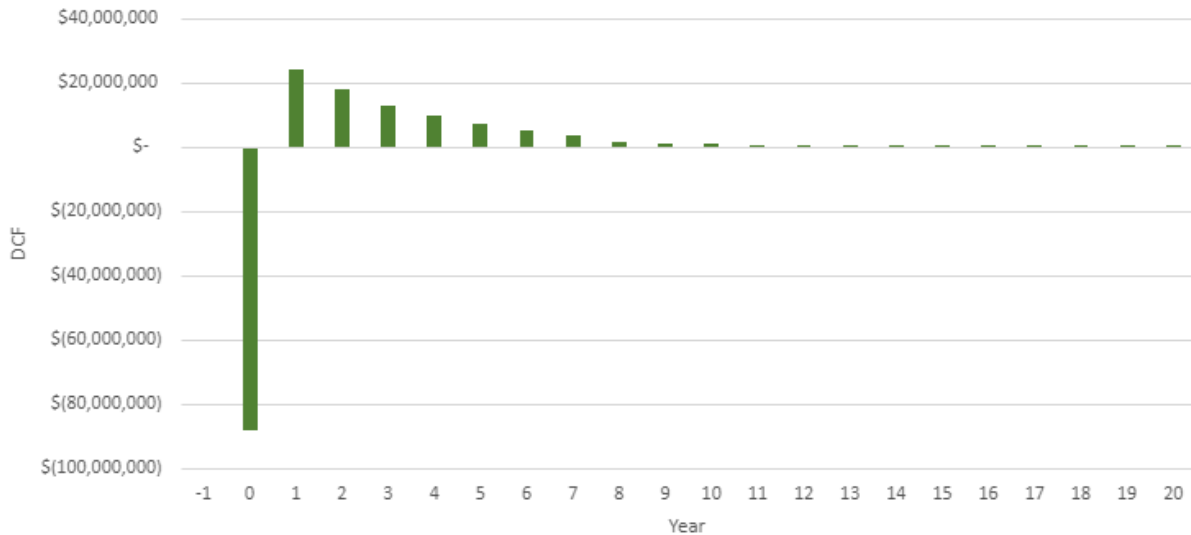
**Figure 8.5.1**

*Total Cash Flow Position when Reusing Yeast*



**Figure 8.5.2**

*Discounted Cash Flow at 35.7% Interest Rate when Reusing Yeast*



Another scenario is the addition of dryers. The spent grain in the pre fermentation stage is currently being sent to waste. However, the grains could be dried and then sold as brewer's spent grain. This would have a two-fold effect. The grains will be sold as feed to make additional profit

and the waste disposal costs will decrease. The estimated revenue would be around \$16,000 using standard wholesale pricing (Agricultural Electronic Bulletin Board, 2024). Meanwhile, the wastewater utilities bill would be 25% smaller, going from \$56,210 to \$42,157 a year. Additionally, the dryer would require an operating cost which could potentially offset the benefit it could bring (this operating cost was not estimated because, as will be seen shortly, the economic benefit of this addition is negligible compared to the extraneous benefits such as community building). The only major capital cost would be that of a grain dryer at approximately \$11,000 (Alibaba, n.d.-c). When it comes to the total cash flow, there is a barely noticeable difference with there being around \$400,000 extra in total cash position by the end of 20 years. The IRR remains almost the exact same (25.3%). However, this implementation would have the added benefits of increasing sustainability and increasing local community interaction.

The third scenario involves trub and spent yeast repurposing. In this scenario, the dead yeast, spent yeast, and trub would be pumped to a wastewater holding tank. The solids would be allowed to settle and the wastewater would be drained from the top of the tank to reduce wastewater fees from BOD and TSS. Once the tank is filled enough, the solids would be transferred to an anaerobic digester. An anaerobic digester is a unit operation that involves living organisms breaking down organic matter in anaerobic conditions. These organisms then create a gas byproduct, such as methane, which can then be burned for energy (U.S. Environmental Protection Agency, 2024). Implementation would cut waste water costs by 75% (from \$56,210 to \$14,052). Additionally, there would be revenue generated from the sale of natural gas. The only expenses would be a wastewater holding tank and transport costs to the digester. This scenario is a lot more difficult to estimate, so it is only brought up here to suggest another cost reduction solution without economic analysis.

The final scenario is increasing the wholesale price of hard kombucha. When selecting wholesale prices, the wholesale price of kombucha (and not hard kombucha) was used. This was done because information on hard kombucha wholesale pricing was extremely difficult to obtain. In this scenario a wholesale estimate was calculated by finding typical retail prices of NA beer (Brilliant Drinker, n.d.) and hard kombucha (Instacart, n.d.). Next, the cost ratio between the price of hard kombucha and NA beer was calculated. Lastly, this ratio was multiplied by the wholesale price of NA beer. This would move the wholesale price of hard kombucha from 5.4 \$/pk to 7.1 \$/pk and bump the revenue up an extra \$6,194,709. The total cash position and discounted cash flow was plotted in Figure 8.5.3 and Figure 8.5.4. The total cash position goes from \$250,000,000 to \$340,000,000 by the end of year 20 while the IRR increases from 25.3% to 31.8%.

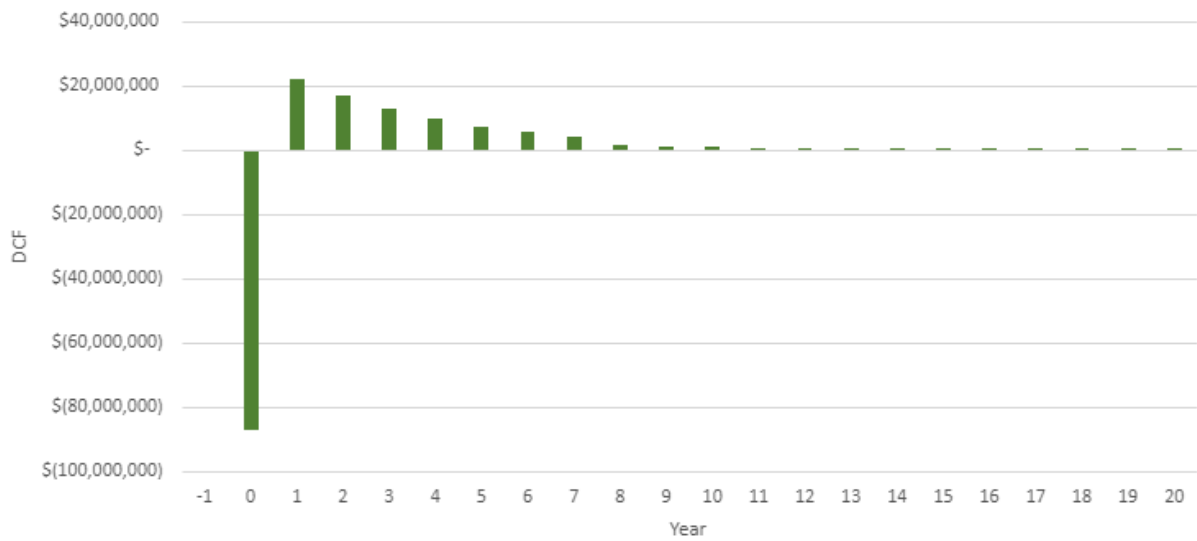
**Figure 8.5.3**

*Total Cash Flow Position when Adjusting Pricing of Hard Kombucha*



**Figure 8.5.4**

*Discounted Cash Flow at 31.8% Interest Rate when Adjusting Pricing of Hard Kombucha*





## 9. Safety, Environmental, and Societal Considerations

### 9.1 Safety Considerations

#### 9.1.1 Chemical Compatibility

Chemical reactivity matrices for the beer and the kombucha were created using the AIChE Chemical Reactivity Worksheet software. The chemical reactivity chart for beer is shown in Figure 9.1.1.1 below:

**Figure 9.1.1.1.**

*Beer Chemical Compatibility Chart*

NFPA				Beer Compatibility Chart	BENZOIC ACID	CARBON DIOXIDE	ETHANOL	WATER
Health	Flammability	Instability	Special					
1	1	0		BENZOIC ACID				
				CARBON DIOXIDE	Y			
2	3	0		ETHANOL	N	Y		
				WATER	Y	Y	Y	

As a note, benzoic acid was used instead of sodium benzoate, since sodium benzoate is the sodium salt of benzoic acid and sodium benzoate was not an available option in the software.

The chemical combination of ethanol and benzoic acid presents a few compatibility issues. Namely, the resulting combination may be flammable, may cause pressurization, releases heat in an exothermic reaction at ambient temperatures, and may be explosive. As a result, multiple safety precautions will be needed to be taken. One main precaution implemented is the

limitation of the amount of sodium benzoate in the beer beverage: while the FDA places a maximum limit of sodium benzoate preservative in food and beverages at 0.1% (Code of Federal Regulations, 2024b), the amount of sodium benzoate in the final beer product is at 0.05%. This precaution allows for the beer to be shelf-stable, while remaining well within the FDA limit and minimizing the potential for unwanted chemical reactivity with the ethanol in the beer. Another precaution implemented is the minimal amounts of ethanol present in the beer itself, due to the nature of non-alcoholic beer. Together, these precautions help minimize the potential safety concerns that arise from the chemical interactions between ethanol and benzoic acid.

The chemical reactivity chart for kombucha is shown in Figure 9.1.1.2 below:

**Figure 9.1.1.2.**

*Kombucha Chemical Compatibility Chart*

NFPA				Kombucha Compatibility Chart	ACETIC ACID, SOLUTION, MORE THAN 10% BUT NOT MORE THAN 80% ACID	CARBON DIOXIDE	ETHANOL	SUCROSE	WATER
Health	Flammability	Instability	Special						
				ACETIC ACID, SOLUTION, MORE THAN 10% BUT NOT MORE					
				CARBON DIOXIDE	Y				
2	3	0		ETHANOL	N	Y			
				SUCROSE	N	Y	Y		
				WATER	Y	Y	Y	Y	

The chemical combination of ethanol and acetic acid presents several compatibility issues. The reaction products may be flammable, the reaction may cause pressurization, the reaction is exothermic, and the reaction may be intense or explosive. This compatibility issue will be combated in several ways to ensure maximum safety: first, the acetic acid present is formed as a result of the kombucha fermentation process, and thus the amount produced is very

small. Additionally, the mixing vessel once the ethanol is added will be periodically vented to the atmosphere, ensuring that there is no buildup of pressure over long periods of time.

Lastly, the chemical combination of sucrose and acetic acid presents the same compatibility issues of potential flammation, pressurization, release of heat, and explosion. Measures that will be taken to circumvent these issues include minimal amounts of acetic acid in the mixture, adding the raspberry juice slowly into the mixing vessel, and venting the mixing vessel periodically to prevent pressure buildup.

### 9.1.2 CIP Compatibility

The chemical reactivity chart for the chemical used in CIP procedures, sodium hydroxide, compared against the components in beer and kombucha, is shown in Figure 9.1.2.1 below:

**Figure 9.1.2.1.**

*CIP Compatibility Chart*

NFPA			CIP Compatibility Chart	ACETIC ACID, SOLUTION, MORE THAN 10% BUT NOT MORE THAN 80%-ACID	BENZOIC ACID	CARBON DIOXIDE	ETHANOL	SODIUM HYDROXIDE, SOLID	SUCROSE	WATER
Health	Flammability	Instability								
			ACETIC ACID, SOLUTION, MORE THAN 10% BUT NOT MORE THAN 80%-ACID							
1	1	0	BENZOIC ACID	Y						
			CARBON DIOXIDE	Y	Y					
2	3	0	ETHANOL	N	N	Y				
3	0	1	SODIUM HYDROXIDE, SOLID	N	N	Y	N			
			SUCROSE	N	N	Y	Y	N		
			WATER	Y	Y	Y	Y	C	Y	

Sodium hydroxide presents incompatibilities with acetic acid, benzoic acid, and ethanol. With acetic acid and benzoic acid, the reaction product may be corrosive, flammable, and toxic, with the reaction causing pressurization. With ethanol, the reaction product may be flammable, the reaction may release heat, and the reaction may cause pressurization. Sodium hydroxide, also

known as caustic soda, is an alkali that is used in solution as a detergent during CIP wash cycles. Therefore, due to the potential hazards associated with sodium hydroxide and the components in the beer and kombucha, preparation of the sodium hydroxide cleaning solution will be done carefully to monitor the concentration to ensure it is not too high — typically, a concentration of 0.5-2.0% is used (Central States Industrial, 2022). An additional safety measure will be ventilating the machinery, such as the fermentors, often to prevent any buildup in pressure.

### *9.1.3 Equipment & Process Hazards*

In addition to chemical hazards, this process presents some equipment and process hazards. Although all of the components used are not corrosive, corrosion may occur over long periods of time. While all equipment is made of food-grade, corrosion-resistant stainless steel, regular inspection should be performed. Any cracks, leaks, machinery failure, and fouling, should they occur, should be immediately inspected.

In the event of fermentor, boiler, or mixing tank failure, remote shut-off systems will be used to prevent loss of containment. Additional safety measures including relief valves and flares can be used to prevent catastrophic failure.

Storage tanks are used extensively throughout the process. The storage tank holding milled grain presents the safety concern of fires and explosions from grain dust accumulation. The storage tanks holding fermented products may corrode over time and may experience buildup of pressure if not stored properly, and thus the environment must be controlled and the tanks inspected periodically.

Pumps can experience mechanical degradation over time due to cavitation and corrosion, and can lead to incorrect flow of products in the process, disrupting the whole production. The pressure can also build, and lead to containment failure through cyclic loading.

Heat exchangers can experience mechanical failure, as well as buildup of material within the tubes in a shell-and-tube configuration. Regular maintenance must be performed, including cleaning the inside of the tubes, to ensure the heat exchanger is performing at maximum effectiveness.

The distillation column separating ethanol and water can experience multiple failures. Pressure changes and excessive vibration can damage internal trays, and tray plugging can result in column damage. As a result, the column must be highly regulated and equipped with safeguards in the case an emergency shut down is needed.

Slips while on the manufacturing floor may occur. Care must be taken to wear the proper shoes, and avoid wet spots. Additionally, the machinery can be tall, which may necessitate the use of ladders. In this case, ladder safety should be reiterated to employees and practiced.

Our process involves a particulate step – grain milling – which comes with many safety concerns, most notably suffocation and grain dust explosions (Occupational Safety and Health Administration, n.d.). Suffocation occurs when a worker walks over the grain, which may start acting like quicksand, trapping and burying the worker. Grain dust explosions are also deadly, with the added likelihood of property damage. According to OSHA, “grain dust is highly combustible and can burn or explode if enough becomes airborne or accumulates on a surface and finds an ignition source (such as hot bearing, overheated motor, misaligned conveyor belt, welding, cutting, and brazing).”

Incorporating transportation machines like walk-behinds and forklifts also comes with another layer of danger that must be accounted for appropriately. There are a couple practices that should be ingrained in all operators’ heads while in the plant, such as having horns on the walk-behinds that must be used at a certain interval and at every turn and walking operators

looking both ways before crossing a walk-behind pathway (Stop Painting, 2020). Practices like these not only significantly reduce accidents, but contribute to a strong safety culture.

To minimize process safety incidents from occurring, a strong safety culture will need to be established. Appropriate personal protective equipment (PPE) will need to be worn, such as steel-toed shoes and hair protection to abide by food safety regulations. Additionally, safety practices must be well documented and operational procedures must be accessible and followed. Safety training must be administered to new employees, with regular trainings incorporated for all employees to maintain a strong safety culture. In the case of an event, evacuation procedures must be planned in advance and communicated, so that all employees and operators will know what measures to take. Integration of vigilant near miss reporting is important to everyone's safety, ideally reducing the chance that no larger, more damaging events happen in the future. In all, every employee — operators, contractors, and management — are responsible for creating and maintaining a safe work environment.

## ***9.2 Environmental Considerations***

### ***9.2.1 Water Pollution***

Waste water from breweries has three main concerns that must be addressed before they can be sent to public wastewater treatment facilities (WWTFs). Firstly, the total suspended solids (TSS) is relatively high due to spent yeast, grains, and trub in the water (New Hampshire Department of Environmental Services, 2020). It must be brought down to the acceptable local level by either our facility or a third party before it can be sent to the WWTF, otherwise buildup and blockage is likely. The second concern is biochemical oxygen demand (BOD), of which beer and beer waste has a high concentration. This is something that we can pay the WWTF to take care of for us. The final concern is the pH of the wastewater (Apex Publishers, n.d.). Generally,

wastewater needs to be between 5.0 and 12.5; so if the stream is too acidic, an affordable solution used by many is a 50/50 NaOH/water solution added manually (Brewery Wastewater Design, 2016).

For kombucha waste, TSS is not a concern, but the BOD and pH are, due to the high microbial activity and acidity (You Brew Kombucha, n.d.). Identical methods will be used to make sure that these properties are in line with the local WWTF's guidelines.

### *9.2.2 Air Pollution*

When considering sources of air pollution, heat exchangers and the compounds they emit are the most significant pollutants. Since natural gas is being used to power the heat exchangers, nitrogen oxides and carbon dioxide take up the vast majority of the air pollution that a brewery produces (New Hampshire Department of Environmental Services, 2019). There is also a notable amount of carbon dioxide produced during fermentation that is released into the environment. Although it would be ideal to reduce the amount of air pollutants throughout the entire facility, our operations are not currently large enough to incentivize an approach to reduce, capture, or reuse those pollutants.

### *9.2.3 Spent Grains and Tea Leaves*

According to the New Hampshire Department of Environmental Services, spent grains are the largest source of waste for most breweries (2019). Traditionally, spent grains at this scale are sent to landfills. However, there is a growing movement to create renewable and community-focused efforts to reduce waste, such as composting it or sending it to local farmers as animal feed supplement (Morikawa & Saigusa, 2008). There are not currently any widespread uses for spent tea leaves, but research is going into use in fertilizers and soil supplements.

### ***9.3 Societal Considerations***

#### ***9.3.1 Public American Health***

When selling alcoholic products, it is important to recognize the characteristics of the consumers. There are tens of millions of Americans, including hundreds of thousands of teenagers, who deal with alcoholism (National Institute of Alcohol Abuse and Alcoholism, 2023). Underage drinking is especially dangerous; underage drinkers are more likely to develop lifelong illnesses and an alcohol dependence as an adult, compared to those who don't drink (Bonnie, 2004). Additionally, over 170,000 people die each year from alcohol-related causes, both indirectly and directly. About two-thirds of these deaths come from chronic conditions caused or exacerbated by alcohol, including heart disease, liver disease, and cancer. The other one-third comes from single-occasion incidents, like vehicle crashes and overdoses (Centers for Disease Control and Prevention, 2024). This is not only an individual issue, but a societal, systemic issue that we must recognize when we produce and market alcoholic products.

#### ***9.3.2 Marketing Towards Underaged Drinkers***

Many drugs are marketed towards underaged people through a variety of methods (Jackson et al., 2018). With a traditionally non-alcoholic and family-friendly drink like kombucha now containing alcohol, the marketing and packaging for this product may influence people who cannot drink to try consuming it, possibly leading to health issues later in life as mentioned in Section 9.3.1. With regards to non-alcoholic beer, there might be an unexpected consequence. By creating a drink that traditionally is not meant for underage consumption, and creating a situation where it is arguably okay for said underage consumption, this may create an undesired gateway to more alcoholic drinkers and in turn adverse health effects described in



Section 10.3.1. To combat this possible alcoholic pipeline, we would like to prevent underage people from buying our beer in the store.

## **10. Conclusions & Recommendations**

Our final design creates a novel process that combines beer production, reverse osmosis, distillation, and kombucha production. We produce annually about 101,000 barrels of beer and 66,000 barrels of kombucha, or 33.4 million 12 oz cans of non-alcoholic beer and 21.9 million 12 oz cans of hard kombucha.

We recommend undergoing construction and operation of this plant. Our process has an IRR of 25.3%, with our alternate scenarios determining that feasible adjustments can be made to increase it to 35.7%. Considering that there are very low safety, environmental, and social concerns, combined with the chance to become a major name in these relatively young yet rapidly growing and robust markets, this IRR is incredibly appealing.

The next steps to solidify the success of this project is to set up a robust testing process that ensures a high standard in taste and overall quality. It would also be worth looking into methods of decreasing our pollution; this may lead to a healthier local environment along with lower annual costs.

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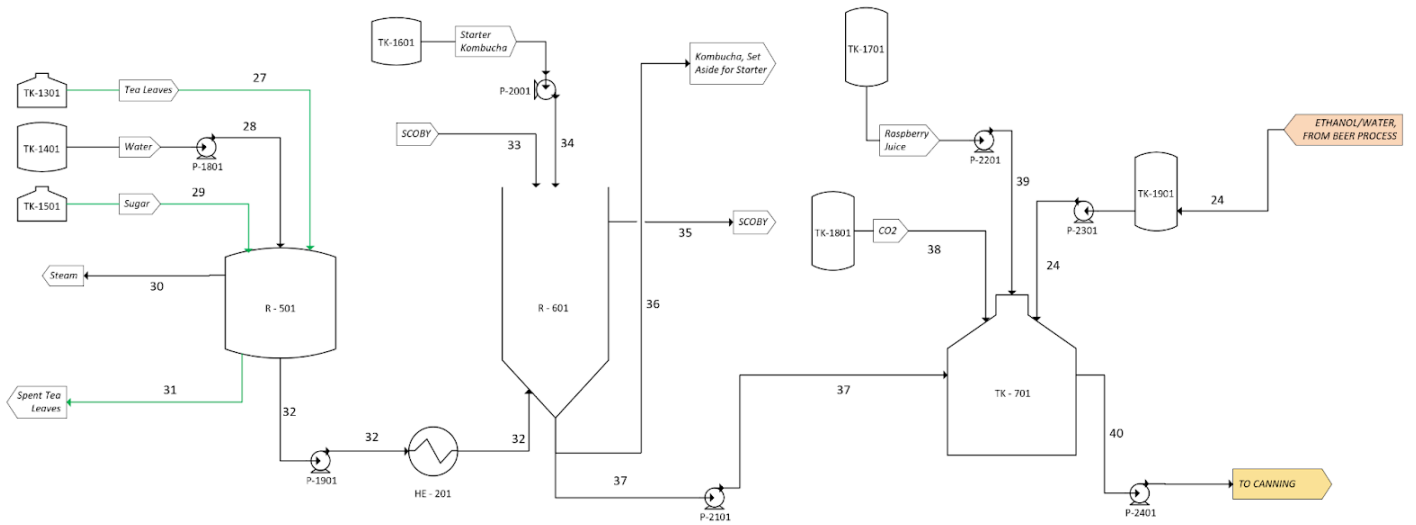
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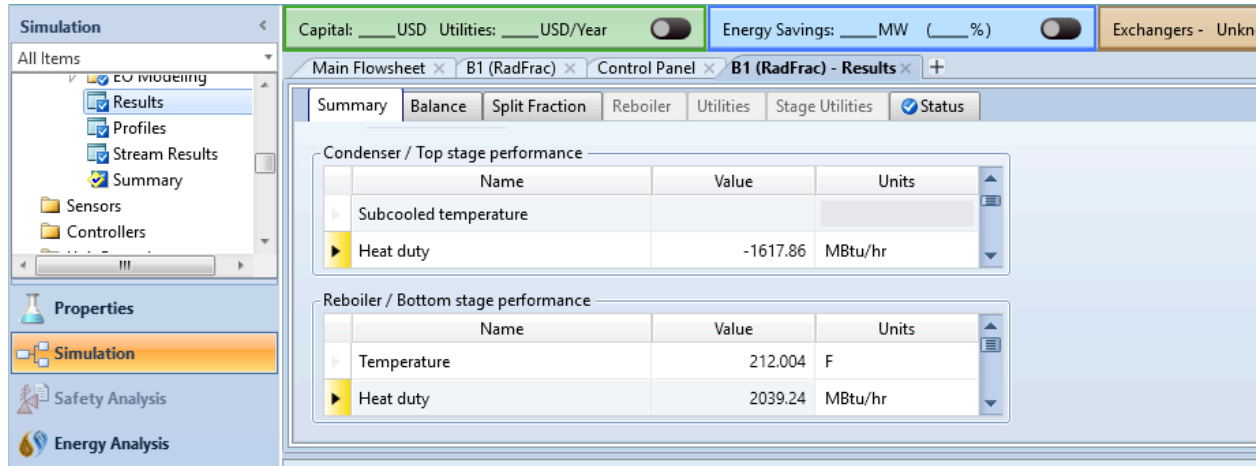
Figure A2.

Kombucha PFD



## Appendix II: Aspen

### Heat duties for condenser and reboiler:



### Cost information for distillation column:

The distillation simulation has this information under Energy Analysis > Costing. Used the capital cost equation to calculate the capital cost for the distillation column.

Rate of return (ROR) [%]:

Operating life of plant (PL) [yr.]:

Operational hours per year:

Capital cost annualization factor =  $[(ROR/100) \cdot (1 + ROR/100)^{PL}] / [(1 + ROR/100)^{PL} - 1]$  :

Heat exchanger costing

Capital cost =  $+ 800 \left( \frac{\text{Area}}{N_s} \right)^{0.8} N_s$

### Appendix III: Sample Calculations

#### Hydraulic Power Calculations:

Scenario: Centrifugal pump required to flow 1 m<sup>3</sup>/s of water at pressure difference of 506625 Pa up 10 meters.

$$P_{h,a} = P_h / \eta_p / \eta_{ed} ; P_h = P_{tot} * Q ; P_{tot} = P_f + P_g ; P_f = \Delta P + P_{pipe} + P_{HE} + P_{CV} ; P_g = \rho gh$$

$P_{h,a}$  = Hydraulic power (efficiency adjusted)

$P_h$  = Hydraulic power

$\eta_p$  = Pump efficiency

$\eta_{ed}$  = Electrical driver efficiency

$P_{tot}$  = Total differential pressure

$Q$  = Volumetric flow rate

$P_f$  = Total frictional loss

$P_g$  = Gravity head

$\Delta P$  = Actual pressure difference

$P_{pipe}$  = Pipe loss

$P_{HE}$  = Heat exchanger loss

$P_{CV}$  = CV loss

$\rho$  = Density

$g$  = Gravity

$h$  = Height

$$P_f = 506625 \text{ Pa} + 50662.5 \text{ Pa} + 0 + 50662.5 \text{ Pa} = 607950 \text{ Pa}$$

$$P_g = 1000 \text{ kg/m}^3 * 9.81 \text{ m/s}^2 * 10 \text{ m} = 98100 \text{ Pa}$$

$$P_{tot} = 607950 \text{ Pa} + 98100 \text{ Pa} = 706050 \text{ Pa}$$

$$P_h = 706050 \text{ Pa} * 1 \text{ m}^3/\text{s} = 706050 \text{ W}$$

$$P_{h,a} = 706050 / 0.7 / 0.9 = 1120714.286 \text{ W}$$

## Appendix IV: References for Equipment and Raw Material Cost

### *Equipment (Holding Tanks, Beer & Kombucha Equipment)*

**Table A.IV.I.**

#### *Beer Equipment Sources*

<b>ID</b>	<b>Description</b>	<b>Source</b>
TK-101	Grain Silo	<a href="#">Uline</a>
TK-103	Holding Tank - Flaked Rice	<a href="#">Uline</a>
TK-201	Hot/Cold Liquor Tank - Strike Water	<a href="#">Craft Kettle</a>
TK-301	Hot/Cold Liquor Tank - Sparge Water	<a href="#">Craft Kettle</a>
TK-401	Holding Tank - Hops	<a href="#">Union Jack Tools</a>
TK-501	Brite Tank - Yeast Nutrient	<a href="#">MoreBeer</a>
TK-601	Holding Tank - Clarifier	<a href="#">Uline</a>
TK-701	Brite Tank - Yeast	<a href="#">MoreBeer</a>
TK-1201	Holding Tank - CO2	<a href="#">Cylinder</a>
TK-1301	Holding Tank - Sodium Benzoate	<a href="#">USPlastic</a>
G-101	MB Commercial Grain Mill	<a href="#">MoreBeer</a>
R-101	Mash & Lauter Tun	<a href="#">MoreBeer</a>
R-201	Boiler & Clarifier	<a href="#">Craft Kettle</a>
R-301	Primary Fermenter	<a href="#">Conical Fermenter</a>
R-401	Secondary Fermenter (Brite Tank)	<a href="#">Conical Fermenter</a>
F-101	RO Membrane Filter	<a href="#">Alibaba</a>
D-101	12-stage, 26 ft tall Custom Distillation Column	<a href="#">Appendix II</a>
TK-801	Horizontal Lagering Tank	<a href="#">Craft Kettle</a>
TK-901	Brite Tank - Beer + Water Before RO	<a href="#">Craft Kettle</a>
TK-1001	Hot/Cold Liquor Holding Tank - Water after RO	<a href="#">Craft Kettle</a>
TK-1101	Hold/Cold Liquor Holding Tank - Recycle Water from Distillation	<a href="#">Craft Kettle</a>
TK-1401	Brite Tank - NA Beer + Additives	<a href="#">Craft Kettle</a>

**Table A.IV.II.**

*Kombucha Equipment Sources*

<b>ID</b>	<b>Description</b>	<b>Source</b>
TK-1501	Holding Tank - Tea Leaves	<a href="#">Union Jack Tools</a>
TK-1601	Holding Tank - Water	<a href="#">Craft Kettle</a>
TK-1701	Holding Tank - Sugar	<a href="#">Uline</a>
TK-1801	Holding Tank - Starter	<a href="#">Supply House</a>
TK-1901	Holding Tank - Raspberry Juice	<a href="#">Supply House</a>
TK-2001	Holding Tank - CO2	<a href="#">Cylinder</a>
TK-2101	Holding Tank - Ethanol	<a href="#">Supply House</a>
R-501	Hot/Cold Liquor Tank - Tea Steeper	<a href="#">Craft Kettle</a>
R-601	Conical Fermentation Tank	<a href="#">Craft Kettle</a>
TK-701	Mixing Tank	<a href="#">Craft Kettle</a>

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*Raw Materials*

**Table A.IV.III.**

*Raw Materials Sources*

<b>Process</b>	<b>Raw Material</b>	<b>Source</b>
Beer	Malt	<a href="#">HowdyBrewer</a>
	Strike/Sparging Water	<a href="#">Waukesha Water</a> Page 4
	Flaked Rice	<a href="#">Ritebrew</a>
	Hops	<a href="#">Hop Alliance</a>
	Yeast Nutrient	<a href="#">Yeast Man</a>
	Clarifier	<a href="#">Fermentaholics</a>
	Yeast	<a href="#">The Yeast Bay</a>
	RO Water	<a href="#">Waukesha Water</a> Page 4
	CO2	<a href="#">Fizzy With The Rizzy Paper</a> Table 10
	Sodium Benzoate	<a href="#">Chem Central</a>
Kombucha	Black Tea Leaves	<a href="#">Restaurant Supply Drop</a>
	Water	<a href="#">Waukesha Water</a> Page 4
	White Sugar	<a href="#">WebstaurantStore</a>
	SCOBY	<a href="#">Kombucha Company</a>
	Starter Kombucha	<a href="#">Kombucha Company</a>
	Raspberry Juice	<a href="#">Old Orchard</a>
	CO2	<a href="#">Fizzy With The Rizzy Paper</a> Table 10
Canning & Storage	12-oz Aluminum Cans	<a href="#">Saxco</a>
	6-can Plastic Rings	<a href="#">Amazon</a>
	120" Cotton Cloths	<a href="#">Amazon</a>
	48" x 40" Pallets	<a href="#">eBay</a>

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