HIGH EFFICIENCY BREWERY-DISTILLERY HYBRID

By

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Abstract:

The brewery/distillery hybrid uses a High Efficiency Brewing System (HEBS) to maximize yield of fermentable sugar. In comparison to a typical 30 BBL system, HEBS cuts down on production time and raw material demand. Additionally, HEBS allows for a 20% increase in mash efficiency and uses 57% less water to produce an equivalent amount of wort. The hybrid also utilizes a unique tray distillation column that can produce a higher purity of ethanol using less energy, and requiring less labor compared to traditional copper stills. In total, the hybrid process equipment demands 304,080 kWh per year. Major energy savings come from HEBS low energy requirements and tank insulation. Development of the hybrid would require a capital investment of $3.8 million. After a year of sales, the net present value is projected to be $2.4 million, and after 15 years of alcohol sales the cumulative present value is expected to reach $19.9 million assuming all alcohol is sold. Brewery/distillery calculations assume glucose is the only fermentable sugar in the production of ethanol and that there are no competing side reactions, which could potentially affect alcohol yields. All calculations and projections are theoretical and require direct system comparison for proper validation.

University of Arizona Department of Chemical Engineering

Final Project ChEE 443

High Efficiency Brewery-Distillery Hybrid

Submitted by

Team 8 (High Efficiency Brewery-distillery Hybrid)

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By signing this document, we certify that we have participated in the project, read the report and are familiar with all of the information within.

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- Utility tables
- Fermentation tanks
- Brite tanks
- Glycol unit
- Oxygen tank
- Capital and operating costs
- Economic analysis
- Nomenclature
- Energy balance
- Equation Sheet

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- Mass balance
- Equipment tables
- Stream tables
- Rationale for process choice
- Hazardous chemicals
- Environmental impacts & impact statement
- Sources of error in assumptions
- Recommendations
- Equation Sheet

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- Summary
- Introduction & background
- Overall process description
- BFD
- PFD
- Distillation column & Aspen
- bottling/ barreling/ canning/ packaging
- RO Unit

- Safety factors
- Personal protective equipment
- Safety risks and equipment
- Process design accuracy
- Equation Sheet

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- HEBS
    - Mill
    - Screw Auger
    - Mash Tun
    - Hot Liquor Tank
    - Mash Filter
    - Whirlpool
    - Hopper
- Pumps
- Overall edit & formatting
- Equation Sheet

DO NOT REGRADE CALCULATIONS

EXECUTIVE SUMMARY

The craft brewery market has been expanding since the late 1990s and the craft distillery market has hit a recent boom with over 4,200 craft distilleries in the United States (Kell, 2016). The premise of this project is to design a brewery-distillery hybrid that produces 10,000 BBL of beer per year and 3,000 cases of whiskey. The plant is designed so both beer and whisky production share the same pieces of equipment in order to decrease energy duties and water demands.

The brewery/distillery hybrid uses a High Efficiency Brewing System (HEBS) developed by IDD to maximize yield of fermentable sugar. In comparison to a typical 30 BBL system, HEBS cuts down on production time and raw materials demand. Additionally, the HEBS allows for a 20% increase in mash efficiency and uses 57% less water to produce an equivalent amount of wort. The HEBS uses a mash filter unit (TK-105) unique to the brewing industry. The unit uses compressed air and water chambers to separate solid waste from fermentable wort. The wort enters a fermentation vessel (TK-112:TK-119), to convert sugars to alcohol for a 14-day batch period.

Once the fermentation is complete, beer is either transported into a brite tank (TK-110) to be carbonated and later packaged (Z-101) as a 7% ABV beer, or the process continues to a tray distillation column (T-101) to produce a 60% ABV whiskey that will age for one year. The unique tray distillation column can produce a higher purity of ethanol using less energy compared to a traditional copper still. For an inlet wash of 10% ABV, the 10-tray distillation column is able to produce an 80% ABV spirit with 17% recovery, while the traditional pot still produces a spirit of 67% ABV with 13% recovery.

The total energy demand for process equipment is 304,080 kWh per year. Insulation of all tanks and water lines creates negligible heat loss for each piece of equipment resulting in significant energy savings. The HEBS uses nearly half the energy in comparison to a traditional 30 BBL brewery (HEBS).

The brewery/distillery generates profit within a year of startup. The brewery/distillery requires a capital investment of $3,845,432 (table 5.2). After a year of beer sales alone, the net present value (NPV) is projected to be $2.4 million, and after 15 years of alcohol sales the cumulative present value (cum PV) is projected to reach $19.9 million (Table 6.1). It is assumed that all alcohol produced will be sold.

Brewery/Distillery calculations assume that glucose is the only fermentable sugar in the production of ethanol and that there are no competing side reactions. This assumption could potentially alter final alcohol yields. Another major assumption is that the fermentation period takes a total of 14 days which if incorrect could alter the total number of necessary fermentation vessels.

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SECTION 1 INTRODUCTION

1.1 Overall Goal

This plant is a dual production facility for whiskey and beer. The hybrid brewery-distillery process utilizes multiple pieces of equipment for both processes in order to cut down on equipment demands and raw materials. Production requirements that this plant will need to output on a yearly basis are 10,000 barrels (1,173,477 liters) of wheat beer and 3,000 cases (27,360 liters) of whiskey. At the end of the brewing and distilling processes, the beer will have a final canned alcohol by volume purity of 7% ABV and the whiskey will have a final purity of 60% ABV. The brewing-distilling process produces wastes including excess CO_2, water, spent grains out of the mash tun, and solids settled in the fermentation tanks. This plant recycles water from the frontline brewing process through a Reverse Osmosis unit to be reused in a water conservation cycle. Due to economic infeasibility of reusing CO_2 in the process, excess CO_2 from the fermentation process that is not captured within the fermentation vessels is collected and disposed of offsite. After the mash filtration unit squeezes out all usable wort for fermenting, the solid wastes, called spent grains, are donated to local farmers in the Tucson, AZ as livestock feed (Edward). The solids that settle to the bottom of the fermentation tanks are disposed of offsite. This hybrid allows for an increase in the combined output of beer and whiskey while maximizing efficiency.

1.2 Market Information

The American craft alcohol market has been steadily increasing since the 1990's, especially in the craft beer market; the spirits industry now commands 35.9% of the total alcohol market vs. 47% for beer and 17.1% for wine with a total of 1,315 craft distillers and over 4,200 craft breweries in the United States (Kell, 2016). The total volume of craft spirits could increase from 4.9 million cases in 2015 to as much as 25.6 million cases by 2020 assuming the industry will achieve similar market share and trends as the craft brewing market experienced in the earlier 2000s (Kell, 2016). The trends reported reflect the American people's preference of hometown craft style versus large market suppliers. For the 2017 fiscal year in the state of Arizona, the Arizona Department of Liquor Licenses and Control reported 110 total microbreweries (Arizona Department of Liquor Licenses). With this information, it can be inferred that the craft market is expanding, and consumers are asking for more unique alcohol tastes and styles. This innovative process design has the opportunity to become a precedent in the liquor and beer industries.

1.3 Project Premises and Assumptions

The project premises of the craft brewery-distillery, provided by the team sponsor Scott Bemis, are to produce 10,000 barrels of beer and 3,000 cases of whiskey annually utilizing a 200 gallon (~757 liters) batch still. The inlet malt requirements are 146 kg per batch for beer and 2,775 kg (table 2.4.1.1) per batch for whiskey production in ambient temperature and pressure. Over the course of one year, 56 distillation batches and 547 batches of brewing are necessary to meet production requirements. This process also requires the use of novel filtration techniques included in the High Efficiency Brewing System (HEBS), which produces nearly 100% yield of spent grains to fermentable sugars. This unit has a high purchase cost, but saves 57% on water compared to a typical 30 BBL brewery per batch (“HEBS”, 2018). The distillery uses a distillation column (T-101) designed to remove volatiles, wastes, and products in a single column straying away from the traditional single still or double single-still series distillation. Process design was based off a 60% ABV whiskey and a 7% ABV beer as final products.

The fermentation process lasts a total of two weeks; the first five to six days allow the sugars to convert to alcohol, then the beer gets crashed for one day by way of a sudden cold temperature contact controlled by the glycol system. Following the cold crash are four days of conditioning for maturation of beer (Greene). The whiskey distillation is a 24 hour batch process directly from the fermentation vessels (TK-117-TK-119).

The location of Tucson, Arizona has ideal operating temperatures for whiskey production, especially aging, due to the hot and dry climate allowing quick diffusion of whiskey into and out of the aging barrels; this will speed up the aging process (Brumder).

The pieces of equipment that interact directly with the product will be cleaned regularly. The HEBS units will be cleaned every other day, and the fermentation tanks (TK-112-TK-119) will be cleaned after every batch, which is every 14 days (Edward).

SECTION 2 OVERALL PROCESS DESCRIPTION, RATIONAL, and OPTIMIZATION

2.1 Overall Process Description

The following is a description of the process referring to the Process Flow Diagram (PFD) (figure 2.1.4).

The overall process of the brewery-distillery can be categorized into three components. The first component is the frontline wort preparation process that then separates into the final two components, beer production and whiskey production. The frontline process consists of two malts entering the plant, one malt for whiskey and a different malt for beer as described in the Introduction. The malt is sent to the Mill (M-101) to be ground, then to the hopper (TK-106), by way of screw auger (P-101) lines, to be held until enough malt is ground for the process. The fresh malt enters the HEBS, which consists of the hot liquor tank (TK-101), mash tun (TK-102), mash filter (TK-105), kettle tank (TK-103), and whirlpool (TK-104). The hot liquor tank (TK-101) heats up water from the reverse osmosis unit (F-101) to be used in the HEBS. First, the mash travels to the mash tun (TK-102) where it is mixed with water in Stream 10 from the hot liquor tank (TK-101) at a temperature of 93.3°C in order extract fermentable sugars. From the mash tun, the mash is sent to the mash filter (TK-102), which squeezes the mash via compressed air chambers separating the organic solids from the liquid wort. This system automatically rinses itself and easily breaks down for manual cleaning and spent grain removal. The wort then enters the kettle tank (TK-103) where it is heated again to a temperature of 79°C to mix in hops. The final step of the HEBS is the whirlpool. The whirlpool (TK-104) is a mixing tank activated by a tangential pump to stir the wort for five minutes, followed by 15 minutes of resting to ensure the wort is perfectly mixed. Solid wastes produced by the whirlpool and mash tun are disposed of offsite.

After the frontline process is completed, the wort travels through a double pass heat exchanger (E-101) that contains wort, processed water from the reverse osmosis recycle loop, and cool glycol in order to cool wort and raise the temperature going to the hot liquor tank (TK-101). In stream 17 the wort is injected with oxygen (TK-107) then travels on to either the brewery or the distillery, which both begin at the fermentation process. Yeast is added to the fermentation tanks for the brewery (TK-112-TK-116) to initialize the fermentation reaction. The fermentation tanks are equipped with a glycol cooling jacket from the centered glycol unit (V-102) in order to control the temperature of the beer. Beer sits in the tanks for about two weeks in total, producing wastes of carbon dioxide and residual organics. The brewery process continues after fermentation to the brite tank (TK-110-TK-111) where the beer is carbonated and stored until it goes to the canner (Z-101) to be packaged and distributed offsite.

In the distillery after the frontline component and the fermentation process (TK-117-TK119), the wash (beer) travels to the ethanol tower (T-101). This tower/distillation column strays from tradition by separating the low wines (wastes), hearts (products), and tails (volatiles) in a single run. The tops go through the condenser (E-102) and collect in the reflux drum (V-101). The majority of the pure ethanol continues to the whiskey dilution tank (TK-109) and the remainder is pumped back as reflux into the distillation column. The bottoms are removed and remaining volatiles reenter the column for further separation. This distillation column is designed to cut down on batch time and increase yield. The spirits from the distillation column are then diluted (TK-109) with pure water from the reverse osmosis unit (F-101) in order to become a product that is of legal alcohol concentration. The whiskey continues on to be put into storage barrels (B-101) for up to a year in order age the whiskey. The whiskey process is completed by being bottled (Z-102) for distribution.

2.1.1 Block Flow Diagram

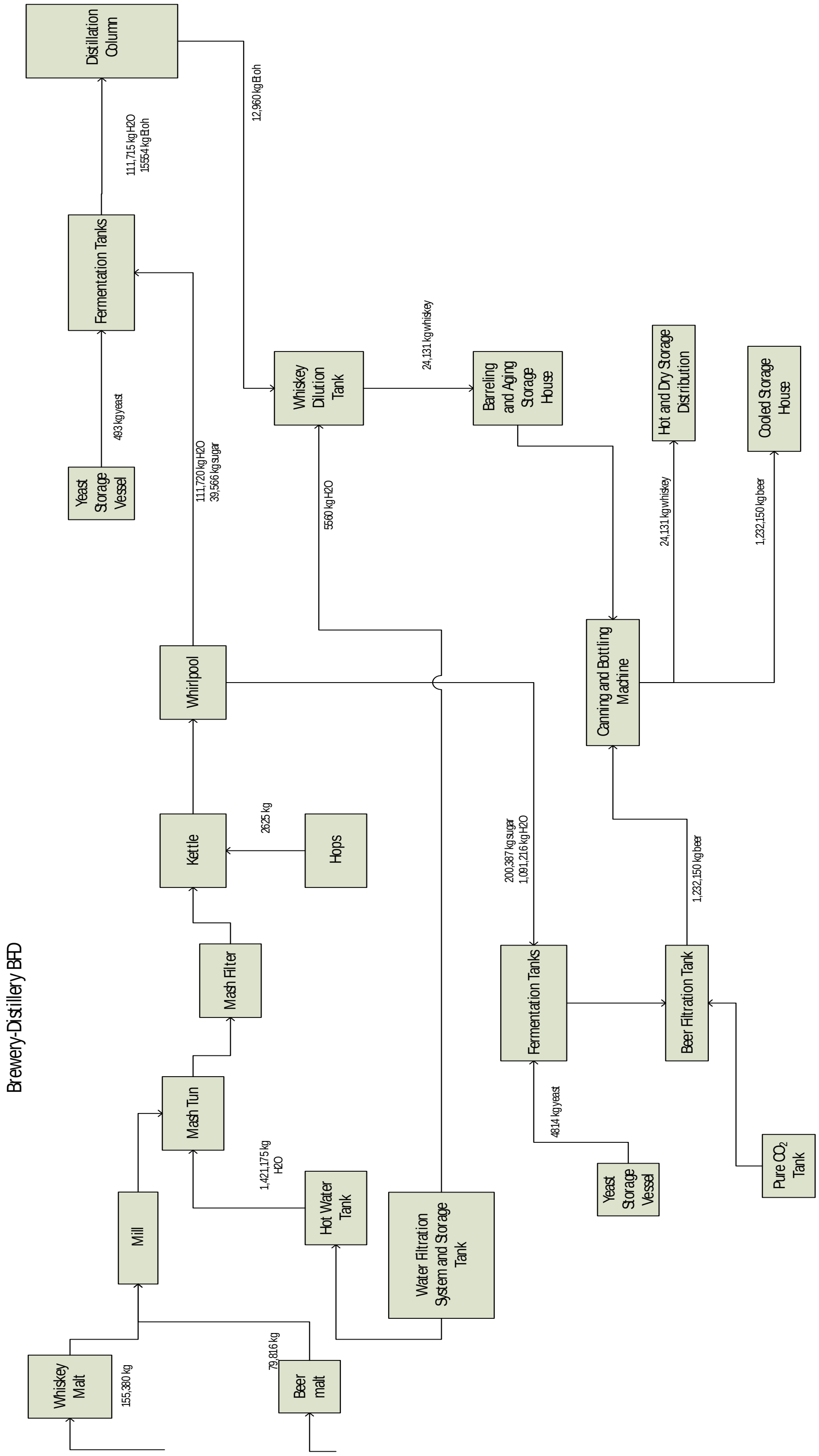


Figure. 2.1.1 Quantitative Block Flow Diagram

2.1.2 Process Flow Diagram

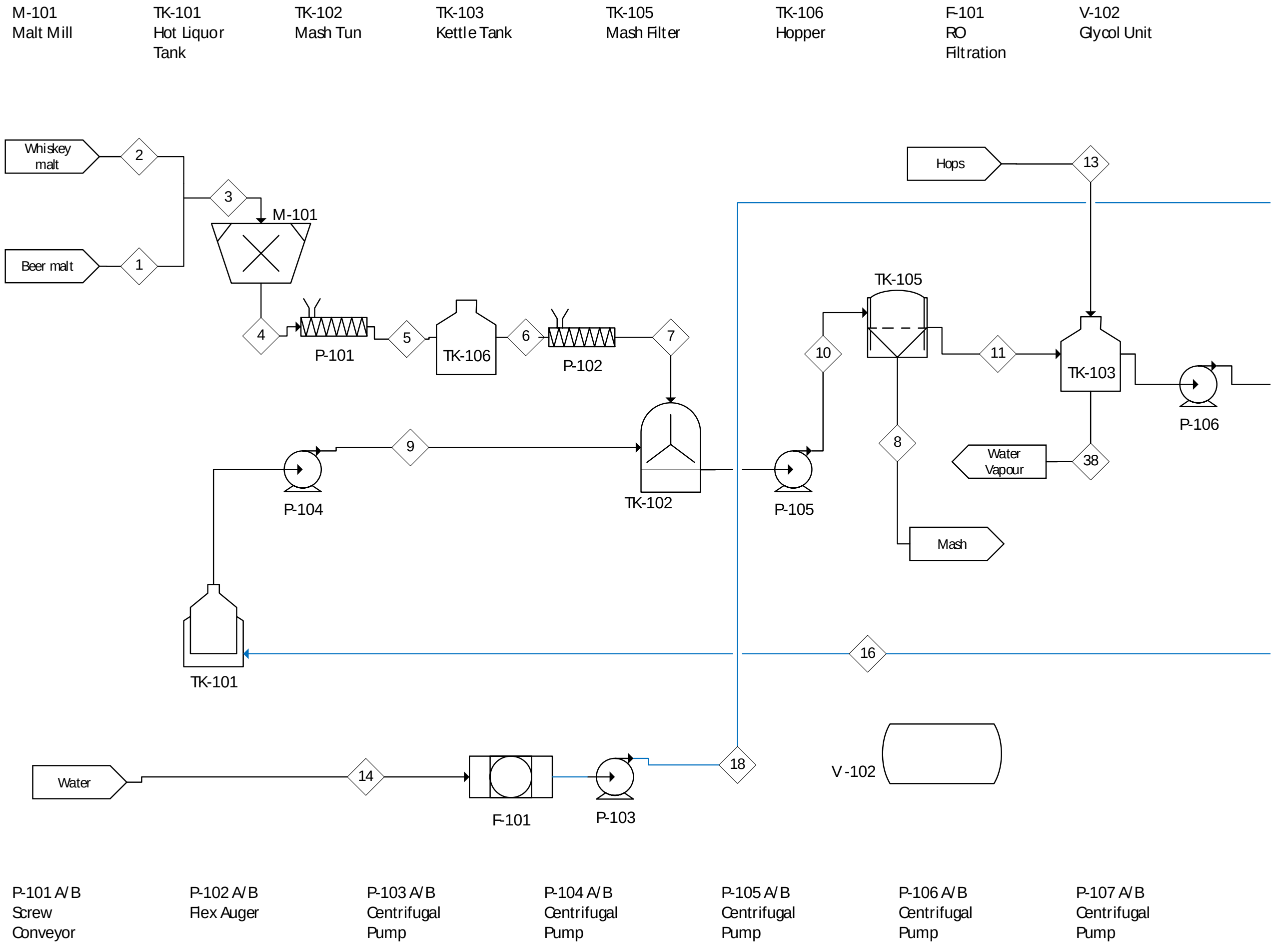
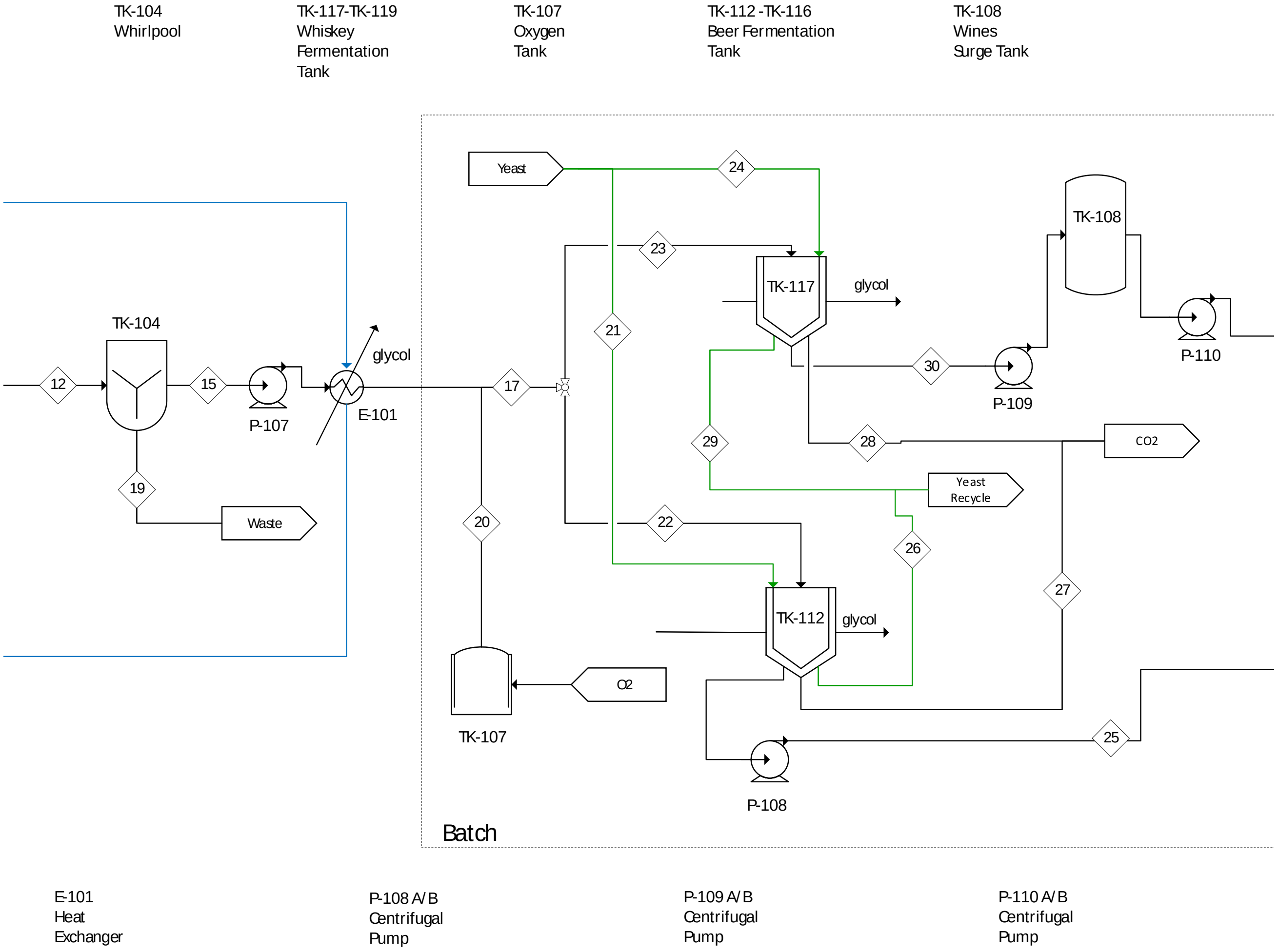


Figure 2.4.2.1 Process Flow Diagram part 1



2.4.2.2 Process Flow Diagram part 2

TK-109
Whiskey
Dilution Tank

T-101
Ethanol
Tower

E-103
Ethanol
Reboiler

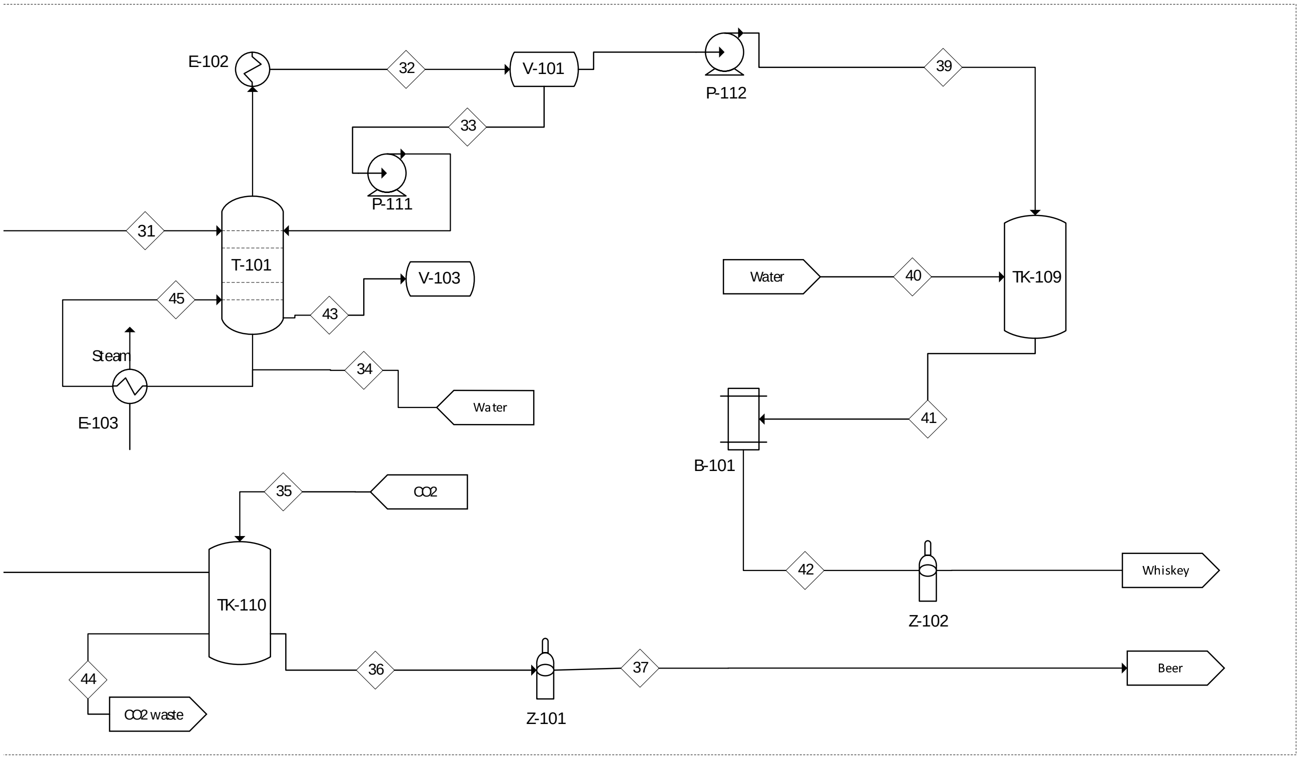
V-101
Reflux
Drum

V-103
Bottoms
Drum

E-102
Condenser

B-101
Barrel Whiskey
Storage

TK-110-TK-111
Brite Tank



P-111 A/B
Centrifugal
Pump

P-112 A/B
Centrifugal
Pump

Z-101
Canner

Z-102
Whiskey
Packaging

Signature

Date

2.4.2.3 Process Flow Diagram part 3

2.1.3 Equipment Tables

Heat Exchangers	E-101	E-102	E-103
Type	Plate and Frame	Plate and Frame	Plate and Frame
Area	930 cm^2		
Duty	-	-2735 Cal/s	3350 Cal/S
Temperature ºC	20 - 77	79 - 98	26
Pressure (atm)	1 atm	1atm	1atm
Phase	liquid	liquid-vapor	liquid-vapor
MOC	304 Stainless Steel	304 Stainless Steel	304 Stainless Steel

Vessels/Towers/Reactors	T-101	TK - 101	TK-102	TK-103	TK-104	TK-105
Temperature ºC	70	93.3	79	79	60	60
Pressure (atm)	1	1	1	1	1	1
Orientation	Vertical	Vertical	Vertical	Vertical	Vertical	Vertical
MOC	Copper	304 Stainless Steel	304 Stainless Steel	304 Stainless Steel	304 Stainless Steel	304 Stainless Steel
Size						
Height/Length	4 m	3.5 m	3.7 m	3.5 m	2.7 m	1.8 m / 4.0 m
Diameter	0.15 - 0.20 m	1.7 m	1.7 m	1.7 m	1.7 m	1.2 m
Internals	2351 kg/ day	152.4 cm ID	152.4 cm ID , 17 BBL	152.4 cm ID, 3400 L	152.4 cm ID	851.7 liters

Vessels/Towers/Reactors	TK-106	TK-107	TK-108	TK-109	TK-110-TK-111
Temperature ºC	25	25	24	24	25
Pressure (atm)	1	4	1	1	1
Orientation	Vertical	Vertical	Vertical	Vertical	Vertical
MOC	304 Stainless Steel	304 Stainless Steel	304 Stainless Steel	304 Stainless Steel	304 Stainless Steel
Size					
Height/Length	3.0 m	129.5 cm	-	-	2.7 m working
Diameter	1.4 m	22.9 cm	-	-	2.25 m OD, 2.1 ID
Internals	907 kg	7.08 m^3	2006 liters	567.8 liters	PU insulation and Dimple Jacket

Vessels/Towers/Reactors	TK -112 - TK-116	TK-117 - TK-119	V-101	V-103
Temperature ºC	1	1-26	79.4	98.5
Pressure (atm)	1	1	1	1
Orientation	Vertical	Vertical	Horizontal	Horizontal
MOC	304 Stainless Steel	304 Stainless Steel	304 Stainless Steel	304 Stainless Steel
Size				
Height/Length	2.7 m working (conical)	1.5m working (conical)	-	-
Diameter	2.25 m OD, 2.1 ID	1.3 m OD, 1.4 ID	-	-
Internals	PU insulation and Dimple Jacket	PU insulation and Dimple Jacket	1 (m^3)	5 (m^3)

Flex Auger	P-101 (A/B)	P-102 (A/B)
Type	screw auger	screw auger
Flow Rate (kg/min)	1500	1500
Max particle Size (mm^2)	52	52
Power (W)	746	746

Pumps	P-103 (A/B)	P-104 (A/B)	P-105 (A/B)	P-106 (A/B)	P-107 (A/B)
Type	centrifugal	diaphragm	centrifugal	centrifugal	centrifugal
Max Flow Rate (L/min)	567	400	567	567	567
Max Head (m)	23	25	23	23	23
Power (W)	1491	1491	1491	1491	1491

Pumps	P-108 (A/B)	P-109 (A/B)	P-110 (A/B)	P-111 (A/B)	P-112 (A/B)
Type	centrifugal	centrifugal	centrifugal	centrifugal	centrifugal
Max Flow Rate (L/min)	567	567	567	284	284
Max Head (m)	23	23	23	15	15
Power (W)	1491	1491	1491	746	746

Mill	M-101
Height (m)	0.91
Area (m^2)	0.6
Rate (kg/hr)	907

Filtration	F-101
Rate	28.4 LPM
Membrane	Reverse Osmosis 10.16 cm membranes
Size	376 cm length

Barreling	B-101
Size	200 liters
Amount	137

Beer Packaging/Whiskey Packaging	Z-101
Amount of cans	59,400
Rate of packaging	35 cans / min
Materials	Aluminum

Bottles	36,000
Glycol Chiller	**V-102**
HP	9
Cooling Capacity (BTU/Hr)	80635
Size (in^3)	72x46x78
Tank Size	20 gallons

Table 2.1.3 Equipment Table

2.1.4 Stream Tables

For Beer:

Stream number	**1,3**	**4**	**6**
Description	Beer Malt to Mill	Mill to Screw Conveyor	Screw Conveyor to Hopper
Temp(°F)	75	75	75
Pressure(atm)	1	1	1
Vapor Fraction	0	0	0
two-row malt (kg)	230.4	230.4	230.4
wheat malt (kg)	307.2	307.2	307.2
munich malt (kg)	46.1	46.1	46.1
water (kg)	0.0	0.0	0.0
EtOH (kg)	0.0	0.0	0.0
Sugar (kg)	0.0	0.0	0.0
Hops (kg)	0.0	0.0	0.0
C02 (kg)	0.0	0.0	0.0
Yeast (kg)	0.0	0.0	0.0
Oxygen (kg)	0.0	0.0	0.0

7	**10**	**14**	**18**
Hopper to Screw Conveyor	Hopper to Mash Tun	Process Water to RO system	RO Water to Glycol Heat ex
75	75	75	75
1	1	1	1
0	0	0	0
230.4	230.4	0.0	0.0
307.2	307.2	0.0	0.0

46.1	46.1	0.0	0.0
0.0	0.0	2393.9	1994.9
0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0

16	**9**	**10**	**8**
Glycol Heat ex to Hot Liquor Tank	Hot Liqour To Mash Tun	Mash Tun to Mash Filter	Mash Filter to Waste
75	176	176	176
1	1	1	1
0	0	0	0
0.0	0.0	230.4	0.0
0.0	0.0	307.2	0.0
0.0	0.0	46.1	0.0
2393.9	2393.9	2393.9	0.0
0.0	0.0	0.0	0.0
0.0	0.0	366.3	0.0
0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0

11	**13**	**38**	**12**	**19**
Mash Filter to Boiler	Hops to Boiler	Water Vapor Outgas	Boiler to Whirlpool	Whirlpool to Waste
176	75	212	212	78
1	1	1	1	1
0	0	1	0	0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0
2393.9	0.0	399.0	1994.9	0.0
0.0	0.0	0.0	0.0	0.0
366.3	0.0	0.0	366.3	0.0
0.0	9.6	0.0	9.6	9.6
0.0	0.0	0.0	0.0	0.0

0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0

15	**20**	**17,22**	**21**
Whirlpool to Glycol Heat Ex	O2 to Wort Stream	Oxygenated Wort to Ferment. Reactor	Yeast to Ferment. Reactor
78	75	75	75
1	1	1	1
0	1	0	0
0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0
1994.9	0.0	1994.9	0.0
0.0	0.0	0.0	0.0
366.3	0.0	366.3	0.0
0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0
0.0	0.0	0.0	8.8
0.0	0.0000393	0.0	0.0

26	**27**	**25**	**35**
Fermentation to Yeast Recycle	CO2 to outgas	Ferment. Reactor To Brite Tank	CO2 into Brite Tank
34	70	34	34
1	1	1	2
0	1	0	1
0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0
0.0	0.0	1994.9	0.0
0.0	0.0	118.5	0.0
0.0	0.0	78.9	0.0
0.0	0.0	0.0	0.0
0.0	113.2	0.0	19.9
8.8	0.0	0.0	0.0
0.0	0.0	0.0	0.0

44	**36**	**37**

CO2 Off-gassing from Brite Tank	Brite Tank To Beer Packaging	Beer Packaging to Distribution
34	34	60
2	2	1
1	0	0
0.0	0.0	0.0
0.0	0.0	0.0
0.0	0.0	0.0
0.0	1994.9	1994.9
0.0	118.5	118.5
0.0	78.9	78.9
0.0	0.0	0.0
0.1	19.8	19.8
0.0	0.0	0.0
0.0	0.0	0.0

Table 2.1.4.1 Beer Stream Tables

For liquor:

Stream number	**2,3**	**4**	**5**	**6**
Description	Malt to Mill	Mill to Screw Conveyor	Screw Conveyor to Hopper	Hopper to Screw Conveyor
T (°F)	75	75	75	75
P(atm)	1	1	1	1
Vapor Fraction	0	0	0	0
wheat malt (kg)	1258.6	1258.6	1258.6	1258.6
water (kg)	0.0	0.0	0.0	0.0
EtOH (kg)	0.0	0.0	0.0	0.0
Sugar (kg)	0.0	0.0	0.0	0.0
C02 (kg)	0.0	0.0	0.0	0.0
Yeast (kg)	0.0	0.0	0.0	0.0
Oxygen (kg)	0.0	0.0	0.0	0.0

7	**14**	**18**	**16**	**9**	**10**
Screw Conveyor to Mash tun	Process Water to RO system	RO Water to Glycol Heat ex	Glycol Heat ex to Hot Liquor Tank	Hot Liquor to Mash Tun	Mash Tun to Mash filter
75	75	75	75	176	176
1	1	1	1	1	1
0	0	0	0	0	0
1258.6	0.0	0.0	0.0	0.0	1258.6
0.0	1994.9	1994.9	1994.9	1994.9	1994.9
0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	719.7
0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0

8	**15**	**20**	**17,23**	**24**	**28**
Mash Tun to Waste	Mash Filter to glycol Heat ex	O2 to Liquor Stream	Oxygenated Fermentation Broth to Whisky Ferm. Reactor	Yeast to Ferment. Reactor	CO2 to Outgas
176	176	75	75	75	70
1	1	1	1	1	1
0	0	1	0	0	1
1258.6	0.0	0.0	0.0	0.0	0.0
0.0	1994.9	0.0	1994.9	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0
0.0	719.7	0.0	719.7	0.0	0.0
0.0	0.0	0.0	0.0	0.0	265.3
0.0	0.0	0.0	0.0	8.8	0.0
0.0	0.0	0.000393	0.0	0.0	0.0

29	**30**	**31**	**34**	**39**	**40**
Ferment. Reactor to Yeast Recycle	Ferment. Reactor to Wines Surge Tank	Surges Tank to Distl.	Distl. To Wastes (bottoms)	Distl. To Dilution Tank	Cold liquor to Dilution Tank
34	34	75	208	174	75
1	1	1	1	1	1
0	0	0	0	0	0

0.0	0.0	0.0	0.0	0.0	0.0
0.0	1994.9	1994.9	1898.8	96.2	99.3
0.0	277.8	277.8	46.3	231.4	0.0
0.0	78.9	78.9	74.9	3.9	0.0
0.0	0.0	0.0	0.0	0.0	0.0
8.8	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0

41	**42**
Dilution Tank to Barrel Storage	Barrel Storage to Bottling
75	75
1	1
0	0
0.0	0.0
195.5	195.5
231.4	231.4
3.9	3.9
0.0	0.0
0.0	0.0
0.0	0.0

Table 2.1.4.1 Liquor Stream Tables

2.1.5 Utility Tables

Values for convection and total duty were calculated using equations 1-1 to 11-7. These equations were obtained from the ‘Thermal Process Engineer for Brewers’ presentation (Scheer).

Equipment	Cooling (kWh)	Convection (kWh)	Total Duty (kWh)
Beer Fermentation tank	402.4	41.6	444
Brite Tank	0	4.32	4.32
Whiskey Fermentation tank	80.1	14.9	95

Table 2.1.5 Convection and Cooling Calculations per Batch

Equipment	Energy Output Per Batch (kWh)	Energy Output Per Year (kWh)
Beer Fermenters	444	48840
Brite Tanks	9	952
Whiskey Fermenters	95	5320
Distillation	1680	94080
HEBS	248	150472
Bottling/Canning	40	4417
Total	2516	304080

Table 2.1.6 Energy Duties

2.2 Rational for Process Choice

The advantage of the hybrid brewery/distillery is the fact that the beer and liquor production processes will initially be processed by the same pieces of equipment. The main shared pieces of equipment are: mill (M-101), flex augers (P-101-P-102), hot liquor tank (TK-101), mash tun (TK-102) & mash filter (TK-105). The process becomes specialized for either liquor or beer after the wort passes through the heat exchanger (E-101). The track for liquor features three 20 BBL fermentation tanks (TK-117-TK-119), a distillation column (T-101), and appropriate pieces of equipment for whiskey dilution (TK-109), and bottling (Z-102). The beer track features five 90 BBL fermentation tanks (TK-112-TK-116), brite tanks (TK-110-TK-111), and a canning system (Z-101). The shared pieces of equipment ultimately result in a lower initial capital investment and a more efficient process.

When formatting the mass balance, it was chosen to split the beer production and liquor production into two separate spreadsheets (see appendix D). This is done for the sake of clarity and to better illustrate the differences in each process. The mass balance, and subsequent stream tables (see Appendix D), are based off a single HEBS cycle. A single HEBS cycle will produce roughly 17 BBL of raw fermentation material. For the beer process, considering that the mass balance is based off a single HEBS cycle, the 90 BBL fermentation tanks (TK-112-117) will fill in approximately 5 HEBS cycles. For whiskey production the fermentation tanks (TK-117-TK-119) and distillation column (T-101) are sized to accommodate one HEBS cycle (17 BBL) worth of material.

Traditionally, whiskey distillers use a type of distillation column called a ‘pot still’ in order to better control flavor and taste of the final product (“The Distillation in the Pot Still.”, 2017). However, in the 19th century Coffey created a modern distillation column that had several trays and produced a purer alcohol (Pyke, 1965). This innovation inspired the use of the ethanol tower (T-101) as opposed to traditional pot stills. After simulating the process in Aspen (Appendix E), the distillation column proved to output alcohol by volume percentages greater than those traditionally produced by pot stills, as well as processing the same amount of inlet wash in a shorter amount of time and with greater efficiency (“The Distillation in the Pot Still”, 2017). The designed distillation column (T-101) accurately removes volatiles, wastes, and products continuously for the 24 hour distillation period.

A major distinguishing characteristic of the hybrid brewery/distillery system is the HEBS. This system is unique to the process and typically isn’t observed in processes of this scale (Bemis). The use of this system has a variety of advantages compared to a typical 30 BBL brewing system. HEBS saves a significant amount of water (4 L water vs 7 L water to produce 1 L of wort), maximizes the amount of extractable sugars removed from malt (~100% yield vs. ~80% yield), and greatly reduces brew times to increase volume output (12 brews per 24 hours vs 4 brews per 24 hours). The major drawback to the utilization of this system is the high upfront investment; however, the system is both more efficient and sustainable in the long term. The HEBS also offers the opportunity for ease of future plant expansion. In the current design the HEBS is not run daily, and the system can easily integrate a mirrored set of process equipment to more than double wort production if run daily.

SECTION 3 EQUIPMENT DESCRIPTION, RATIONALE, AND OPTIMIZATION

3.1 Malt Mill (M-101)

The malt mill is a fine groove strip mill that contains a 304-stainless steel 27 kg grain dump bin, that is connected to a flex auger line that feeds the hopper. The mill uses a 3 HP explosion proof motor for grinding the grist (crushed malt) with an adjustable roller gap separation, for varying mill sizes. The roller gap is adjusted according to input malt and desired output grist consistency. The mill footprint is 1m x 0.6m x 1m. Milling is a manual labor process requiring the brewers to load grain and adjust roller gap to fill the hopper with grist. The mill can produce a maximum of 907 kg grist/hr. Typical mill gap dimensions range from 0.64 – 0.89 mm. Mill gap and grain size directly affect the energy demand of the mill and must be considered in calculating energy demands. For more information on energy demands of milling see Appendix B (“HEBS”).

3.2 Flex Augers (P- 101 A/B, 102 A/B)

There are two screw augers, P-101 pumps grist into the hopper and P-102 pumps grist into the mash tun. Auger lines contain two explosion proof 0.5 HP motors with maximum possible extension of 38 m. Auger lines can transfer a maximum of 1500 kg grist/min, exceeding the output of the mill, thus making the mill room production dependent on speed of milling. Additionally, auger lines can handle grain particles of maximum size 4 mm x 13mm. Based off the average malted grain size, maximal grain size should never be exceeded. Flex auger lines are also equipped with grain diverter valves, making it easy to sample, or redirect, grist. For more information on energy demands of auger lines see Appendix B (“HEBS” and Sýkorová et al. 249-258).

3.3 Hopper (TK-106)

The hopper, which stores the grist for filling the mash tun, takes up a footprint of 1.4m x 1.4m x 3m and weighs a total of 215 kg. The hopper can hold a total of 907 kg of grist and can be filled to maximum capacity in approximately 1 hour. Additionally, the hopper is made of 304 stainless steel and equipped with 4 load cells, one for each leg, to monitor total grist weight. There is a hinged access lid sealing the hopper that is accessible by a free-standing hopper step ladder, equipped with a control panel for monitoring outputs form the hopper load cells (“HEBS”).

3.4 Hot Liquor Tank (TK-101)

The hot liquor tank is a 304 stainless steel 4000 L vessel, with 10 gauge side walls and 10 gauge top and bottom. The side walls are insulated with 51 mm thick insulation and the tank is accessible through a 0.4m x 0.5m manhole. The tank is equipped with 360 degree clean in place (CIP) spray spinner. Water in the tank is heated with a 1-in-schedule 40 steam coil, with temperature control via preinstalled IDD HMI software. The hot liquor tank footprint is 1.7m x 1.7m x 3.5m and it is mounted on the brew house skid that is included in the 20 Hl system.
Insulation of the hot liquor tank is sufficient enough to neglect convective heat losses from the tank. Every HEBS cycle, the hot liquor tank is refilled with enough water to replenish water losses to the mash tun while maintaining 10% headspace. For heat duty calculations for the hot liquor tank refer to Appendix B (“HEBS”, Scheer, 2018).

3.5 Mash Tun (TK-102)

The mash tun is a 304 stainless steel, 2000L vessel with a 0.8m steam jacket with HMI temperature control capable of rising an average of 2 ºC/min. The mash tun has 10 gauge side walls and 10 gauge domed top and bottom. All of the walls of the mass tun have 12 gauge cladding. It is equipped with a 3 HP motor with variable frequency gear drive for the mash agitator. The mash tun operates with 25% headspace that is accounted for with hot liquor and grist additions. There is a 0.4m x 0.5m manhole for tank access. Overall the mash tun footprint is 1.7m x 1.7m x 3.7m and it is mounted on the brew house skid that is included in the 20 Hl system. For energy requirements for the mash tun refer to Appendix B (“HEBS” and Scheer).

3.6 Mash Filter (TK-105)

The mash filter has a maximum capacity of 800 L of mash. It contains 39 800 mm x 800 mm individual chambers that allow for nearly 98 percent extract. Individual filter plates are polypropylene with one solid plate, one membrane squeeze plate, and a media cloth per section. Media cloth lasts for approximately 2 years before replacement is required. All other components of the filtration system are GRAS (generally recognized as safe) approved by the FDA. The filtration process takes approximately 1 hour to complete running at 275 bar. A steel hydraulic cylinder with a chrome plated piston pressurizes the system. The system is fed by a pneumatic double diaphragm pump (P-105) and pressure from the mash filtration system pushes wort to the kettle tank. For energy requirements for the mash filter refer to Appendix B (“HEBS” and Scheer).

3.7 Kettle Tank (TK-103)

The kettle tank is a 304 stainless steel, 2000 L vessel with a 1-in-schedule 40 supply for steam to calandria inlet. The vessel has 10 gauge side walls with 51 mm thick insulation. The vessel also has a 0.4 m x 0.5 m manhole for tank access. CIP spray spinners turn 360 degrees allowing for the tank to be cleaned without physical entry into the vessel. The bottom of the kettle tank is also mounted with a 10 gauge steam jacket in order to maintain kettle temperature. The kettle tank occupies an overall footprint of 1.7 m x 1.7 m x 3.5 m and is mounted to the brew house skid. For energy requirements for the kettle tank refer to Appendix B (“HEBS”, Scheer).

3.8 Whirlpool (TK-104)

The whirlpool is a 304 stainless steel, 2000 L vessel with 10 gauge side walls and 10 gauge domed top and flat bottom. The vessel contains 51 mm thick insulation and a 0.4 m x 0.5 m manhole for tank access. The tank also contains 2 CIP spray spinners capable of spinning 360 degrees. The whirlpool action is induced by a 2 HP whirlpool pump that recirculates wort tangentially to the inside wall of the whirlpool. The whirlpool also contains a 38 cm trub wall baffle positioned 270 degrees from the inlet flow of the whirlpool pump to catch any excess solids. There is a turbine meter located on the whirlpool for hot liquor additions, but since the whirlpool is insulated, heat losses to convection and hot liquor additions to the whirlpool are both negligible for the overall process. For pump energy requirements for the whirlpool refer to Appendix B (“HEBS”).

3.9 Heat Exchanger (E-101)

The heat exchanger is a two-process counter flow plate and frame heat exchanger with the first pass being water, and the second being glycol. Temperature can be read off a dial thermometer and by a Resistance Temperature Detector (RTD). Flow plates are approved for food products along with EPDM gaskets and each plate is approximately 930 cm^2.

The heat exchanger was optimized to cool wort as much as possible with the first pass of water that replenishes the hot liquor tank (TK-101). The volume of water used to cool the wort on the first pass is the same volume of water that is used per batch to keep the volume of the hot liquor tank constant. A second pass of glycol cools the wort to necessary temperatures to meet fermentation requirements. Heat exchanger calculations were performed with the primary goal of keeping the mass table balanced. Plate and frame heat exchangers are well suited for industries requiring high levels of sanitation, making it the optimal choice for a brewery (Chemical Process Equipment Design). To see heat exchanger calculations, refer to Appendix B ("HEBS", Scheer).

3.10 Fermentation vessels (TK-112-TK-119)

Five conical glycol jacketed fermentation vessels (TK-112-TK-116) are used in the fermentation process for beer. Although these vessels have a working capacity of 90 BBL, the tanks use a working a volume of 87 BBL, which is equivalent to five HEBS cycles. There are three conical 20 BBL fermentation vessels for whiskey fermentation (TK-117-TK-119). The vessel is filled to 17 BBL, which is equivalent to a single HEBS cycle ("HEBS"). Headspace in the fermenters reduce the potential for a pressure buildup and a leak or spill. Each vessel is constructed out of AISI304 stainless steel 3 mm thick. There is a 2 mm stainless steel cladding between the glycol jacket and the inner vessel. All vessels are insulated with 75 mm thick polyurethane (PU). There is a 1.5mm thick dimpled jacket to allow glycol flow evenly on the surface area of the cladding (90 Barrel Brewery Fermenter Tanks). In accordance with heuristic 3 of Storage Vessels from *Chemical Process Equipment Design* vertical tanks with concrete padded support will be implemented. 20 BBL fermentation vessels were chosen for whiskey fermentation because the distillation column was optimized to process one HEBS cycle worth of beer. The small scale fermenter allows for trial recipes for future beer development.

Each beer fermenter requires 444 kWh of power per cycle and total duty of 48,840 kWh per year (Table 2.1.5.2). The majority of the energy required is from cold crashing the system from

79 ^{o}F to 34 ^{o}F. The smaller fermenters for whiskey require 95 kWh per batch and a total duty of 5,320 kWh. The heat convection coefficient is over 50 times smaller with insulation (Scheer). See Appendix B.

3.11 Brite tanks (TK-110, TK-111)

Two brite tanks (TK-110-TK-111) are used primarily for beer carbonation. Both tanks have a capacity of 90 BBL and are filled with 87 BBL of beer. These cylindrical tanks are designed for a pressure of 1-2 bar and therefore cannot be used for fermentation (90 Barrel Brewery Bright Tanks). Cold beer at 34 ^{o}F is transferred directly from the beer fermenters (TK-112-TK-116) to the brite tanks. The tanks are kept at 34 ^{o}F for one day. One batch requires 4.32 kWh of energy and both have a yearly duty of 952 kWh (Table 2.1.5.2) The only energy imputed is to compensate for heat loss from convection. In accordance with heuristic 3 of Storage Vessels from *Chemical Process Equipment Design* vertical tanks with concrete padded support will be implemented.

3.12 Glycol Unit (V-102)

The glycol unit (V-102) for the fermenters (TK-112-TK-119) and brite tanks (TK-110-TK-111) has a cooling capacity of 23.6 kW ("Chillers"). The maximum instantaneous power required is 9.56 kW, which is much less than the maximum capacity (Table 2.1.5.2). Freon is used as the coolant and glycol is used as the coolant medium. There is enough coolant capacity for additional fermenters for future scaling. The glycol unit (V-102) is capable of meeting current maximum coolant flow rate demand for fermentation vessels (TK-112-TK-119) and the heat exchanger (E-101). Refer to Appendix B.

3.13 Oxygen Tank (TK-107)

A standard oxygen tank is used to oxygenate the wort before it enters the fermenters (TK-112-TK-119). The line is saturated with 15 ppbv of oxygen. Tanks need to be replaced once every three months (Bemis).

3.14 Distillation Unit / Ethanol Tower (T-101)

The distillation unit purchased from Maleta Cyclic Distillation consists of the ethanol tower (T-101), the bottoms drum (V-103), the reflux drum (V-101), the reboiler (E-103) and the condenser (E-102). The total inlet flow rate (wash) is based on a batch process that takes 24 hours after the 14 day fermentation process. The fermentation process is based off a single HEBS cycle. This batch will need to run 56 times per year in order to meet production demands. The tower is designed to process 2352 kg/day of wash at 75°C and 1.01 bar with an ethanol mass fraction from the fermentation process of 0.1181. The column uses a reflux ratio of 50, giving 10 trays after simulation and discussion with Maleta Cyclic Distillation. Trays have 0.4 m tray separation for ease of accessibility (*Chemical Process Equipment Design)*. The original model for the Aspen can be found in Appendix E. The heat exchanger network for the distillation unit consists of a total vapor-liquid equilibrium condenser (E-102) and a kettle reboiler (E-103). The steam speed is between 0.5-1.0 m/sec and the distillate rate is about 14 kg/hr. The final ethanol product from the tower (stream 39) is around 80% ethanol by volume, which is equivalent to an 160 proof alcohol. The total thermal power of the distillation unit is 70 kW per batch, which is equal to 94,080 kWh per year. The ethanol tower (T-101) has a footprint of about 2 m in diameter and 4 m in height. The bottoms vessel (V-103) has a volume of 5 m^3 and the reflux drum (V-101) has a volume of 1 m^3.

This distillation unit is untraditional compared to those of Irish distilleries and other well-known whiskey producers. One disadvantage of using a pot still as opposed to a multiple tray column is downtime between runs. Typically, distillers have to wait for multiple fermentation cycles then transfer all of the beer to holding tanks until enough beer is produced to be moved to the distillation process (Kell, 2016). Once the distillation process begins, the pot still requires personnel to fill the still and then manually extract the wash, low wines, and spent waste (Brumder). Large distilleries use multiple pot stills in series to do this extraneous work semi-automatically, but three pot stills in series produce the same results as one multiple tray distillation column (“The Distillation in the Pot Stills”, 2017). The pot stills take more time to produce the same output and take up a larger area of the facility. Additionally, using a multiple tray distillation column removes the human interactive portion of dealing with potentially dangerous ethanol vapors (Emen, 2016). Under British law, for example, it is required that all pipework for testing must be padlocked in “spirit chests” (Appendix F) and then measure temperature, density, and resulting alcohol content to determine when the ethanol is ready to be processed forward into a consumer product (“The Distillation in the Pot Still.”). This justifies the use of a continuous distillation process in the hybrid plant.

3.15 Whiskey Dilution Tank (TK-109)

The whiskey dilution tank (TK-109) at a volume of 5 BBL mixes pure ethanol from the ethanol tower (T-101) with pure water (stream 40) from the reverse osmosis filtration unit (F-101) in order to reduce the alcohol by volume percentage of the alcohol solution from 80% ABV to 60% ABV. This dilution requires 100 L of water per batch of whiskey, or 5,561 L of water per year, at 56 batches per year. According to heuristic 1 of Storage Vessels from *Chemical Process Equipment Design*, the dilution tank is a vertical tank, standing on vertical legs.

3.16 Packaging (Z-101) (B-101)

The canner (Z-101) by American Beer Equipment has a capacity of 35 cans per minute. The canner will operate for 157 days per year. At 12 ounces per can, the plant requires 3,306,667 aluminum cans per year to package all of the product.

The whiskey barreling and storage process (B-101) requires 3,000 cases of 12 bottles at 750 mL per bottle to be produced in a single year before the aging process. This results in 137 whiskey barrels at 200 L per barrel. The barrels will be filled directly from the whiskey dilution tank (TK-109) by way of plastic tubing and gravity flow. The bunge hole (the opening) on the barrel to allow filling, tasting, and draining, has a diameter of 5.08 cm and a resulting flow rate of 132 liters per minute (Southernbarrelbrewingco.com, 2018). The production requires 2 barrels to be filled per day at about 2 minutes per barrel for 68 days per year in order for production quota to be met. After an age time of about 1 year and depending on maturity, barrel size, and material, the alcohol is confirmed a ‘whiskey’ and a total 36,000 bottles are required for packaging. The total energy output of bottling and canning process is 4,447 kWh per year.

3.17 Reverse Osmosis Filtration (F-101)

The reverse osmosis filtration, or RO Unit (F-101) for short, filters all water used throughout the process to increase product quality and process equipment quality over the plant life. The total water demands for the plant are 1,426,736 liters per year. This satisfies all needs for both the front line process, the brewery, and the whiskey production. A RO Unit that can supply the entire plant with this much water must have a product (stream 18) of 1700 liters per hour. The unit is double pass and uses 10.16 cm membranes, and the dimensions of the unit are 376 cm in length, 102 cm in width, and 208 cm in height ("Vantage M240 Reverse Osmosis Systems").

3.18 HEBS Pumps (P-103) (P-104) (P-105) (P-106) (P-107)

The HEBS contains a total of 5 pumps. (P-103), (P-105), (P-106), (P-107) are 38mm OD inlet and 38 mm OD outlet, 2 HP, 304 stainless steel, centrifugal pumps. 2 HP will allow for a maximal flow rate 378 liters per minute provided the maximal head is 15.2 m (C114md Pump). Centrifugal pumps are standard in the craft brewing industry typically ranging from 0.5 HP to 3 HP, and they are ideal for pumping high volumes of low viscosity fluid. Centrifugal pumps are also relatively cheap and require less maintenance in comparison to positive displacement pumps (Greene and Positive Displacement Vs Centrifugal). P-103 and P-107 pump fluid through the heat exchanger (E-101) and will encounter the highest head for all centrifugal pumps in the HEBS. (P-106) transfers water from the hot liquor tank (TK-101) to the mash tun (TK-102) facing heads of 1-2 m. (P-106) transfers wort from the kettle (TK-103) to the whirlpool (TK-104) facing heads of 1-2 m.

(P-105) is necessarily a 38 mm OD inlet and 38 mm OD outlet, 2 HP, 304 stainless steel diaphragm pump due to the mash mix out of the mash tun being highly viscous. A diaphragm pump is used instead of a centrifugal pump because diaphragm pumps can handle highly viscous liquids with particulate matter (Characteristics and Best Uses Of Diaphragm Pumps). Heads for (P-105) are highly dependent on viscosity of the mash mix out of the mash tun (TK - 105), but this should not be an issue provided milling operation and mash tun hydration and mixing are performed properly.

2 HP pumps are used even when lower HP pumps can be used in order to ensure HP pump requirements will always be met. Being that the plant is suited for expansion, securing pumps with scalable power is highly preferable. Each pump for the HEBS will have a spare in case of pump failure. Lastly comparing to Heuristic table 9.9 from *Chemical Process Equipment Design* NPSH operating values exceed NPSH required values according to flow rate demands which will help avoid pump damage and pumps will satisfy the upper bound of 18,927 liters per minute for single stage centrifugal pumps.

3.19 Batch Pumps (P-108) (P-110) (P-111) (P-112)

A total of 3 different centrifugal pumps will be used. 38 mm OD inlet and 38 mm OD outlet, 2 HP, 304 stainless steel, mobile centrifugal pump assembly will be used for transferring beer from fermentation tanks (TK - 112) to brite tanks (TK - 110). Since fermentation cycles are offset based off wort production; using one pump for transferring beer to the brite tank will be sufficient. The pump is capable of putting out 473 liters per minute, with 23 m of head, clearing maximum flow rate and head capacity (C114md Centrifugal Pump Assembly (1 - 2 Hp)).

P- 109 and P-110 are 38mm OD inlet and 38 mm OD outlet, 2 HP, 304 stainless steel pumps comparable to the 2 HP pumps used in the HEBS. These are capable of handling 21 m of head at 567 liters per minute clearing the 15.2 m of head requirement and the 378 liters per minute requirement.

P-111, the reflux pump, and P-112, the pump out of the distillation column, have lower flow rates and head demands justifying the purchase of a lower HP pump. The model as P-109/P-110 will be used, but instead P-111 and P-112 will be the 1 HP model which has a maximum head capacity of 15m and a maximum flow rate of 284 liters per minute. The maximum head and flow rate capacities are compatible with the simulated output of the distillation column. See Appendix E.(C114md Pump). For more information on pump heuristics see section 3.18.

SECTION 4 SAFETY & ENVIRONMENTAL FACTORS

4.1 Safety Factors

The incidence rate of occupational injury is the highest in the food and drink processing industry (Cal/OSHA Consultation Service). This means it is the most dangerous occupation out of all different types of manufacturing industries. These injuries include workplace accidents and work-related injuries. Brewery workers in Ethiopia have been reported to be exposed to various work hazards, such as excessive heat and noise levels, broken bottles, chemicals and radiation. This could result in related injuries like skin cuts and lacerations, eye injuries, respiratory problems (bronchitis and asthma), hearing impairment, skin diseases, and musculoskeletal disorder (Tezera 2).

4.2 Personal Protective Equipment

According to Masters Brewing Association, “PPE is to be used when known hazards are present that cannot be eliminated or controlled solely by administrative or engineering controls.” Personal protective equipment (PPE) ensures that the worker is safe while working in the manufacturing facility. The PPE that is unique to the brewery and distillery are ear plugs and a respirator (Brewer’s Association). The respirator or dust mask ensures worker safety when operating the mill and potentially the distillation column. The mill (M-101) should have a safeguard or cover to prevent employees interacting with the moving parts and to prevent combustible dust from spreading throughout the plant. This plant also involves very high temperatures controlled by steam in a heat exchanger (E-101–E-103).

4.3 Safety Risks and Equipment

The hazards associated with the mash tun (TK-102) are pH extremes and flow rates. If the pH is too high or too low, it has the potential to disturb the quality and flavor of the final product. Extreme pH could kill the yeast in the fermentation process, and non-optimal pH could slow down the fermentation process and then affect the final alcohol content of the beer. To prevent this from happening, pH alarms should be installed to alert workers to adjust pH appropriately or warn producers to not bottle the final product. Alternatively, pH could be measured periodically throughout the process. If the flow rate outlet from the mash tun (TK-102) to the mash filter (TK-105) is too high, too low, or nonexistent, the timing for the batch process could be interrupted. This could be caused by pump failure, blockage in pipes, or controls malfunction. In order to fix this, the blockage would have to be cleared, the process will halt, and pipes and/or pumps would have to be cleaned and replaced. The mill (M-101) poses potential risks for the personnel. If there is an overflow of malt into the mill (M-101), the grain on the floor could create a tripping hazard and add to combustible material in the event of a dust fire. Employees must notified immediately to prevent a dust fire and ensure that resources are not wasted. The fermentation tanks (TK-112–TK-119) must remain at a specific temperature as controlled by a glycol cooling jacket. If the temperature in the tanks is too high, the immediate downstream consequences are poor yeast flocculation and inadequate alcohol yield in the final product of both beer and whiskey. The fermentation reaction has the potential to release too much CO_2 that causes pressure build up in the tanks. Pressure build up could result in tank explosion and human injury as well as loss of product. Action required for this worst-case scenario is to monitor tank pressure and temperature levels and install alarms to alert workers to either act or clear the area. Additionally, CO_2 exposure has the potential to starve individuals of adequate oxygen if there are high ambient concentrations in the facility. The ethanol tower (T-101) has the potential of tower explosion if the inlet temperature and column pressure get too high. Immediate consequences of inlet temperature being above set point are low ethanol yield, unsafe ethanol vapor concentrations escaping the tower, and delay in maintenance repair due to toxicity and liquid temperatures in and around the tower. Actions required are lowering the temperatures, shutting down the process, and evaluating the product for purity and quality.

4.4 Hazardous Chemicals

There are a variety of dangerous chemicals used in the brewing process and improper handling and storage could result in disastrous consequences. The use of these chemicals is for the purpose of cleaning process equipment to remove trace materials that would otherwise impact the quality of the final product ("The Brewer's Handbook: Brewery Cleaning And Sanitation"). First, a caustic treatment is used to remove organics, followed by an acid wash to remove inorganics and mineral buildup, before finally being treated with a sanitizer to eliminate any microorganisms ("The Brewer's Handbook: Brewery Cleaning And Sanitation").

The cleaning of brewing equipment will start with the use of a caustic chemical. There are variety of options but typically NaOH or a blend containing NaOH will be used ("The Brewer's Handbook: Brewery Cleaning And Sanitation"). This is diluted before being used to clean the tanks, but the concentrate form is still quite dangerous. For the brewery, it was decided to use Crimbrew’s Crimson NaK CIP, which is a blend of sodium and potassium hydroxide for clean in place applications (Franclemont). After the caustic is used, the tanks will be rinsed with water before the acid wash (Martin). It was chosen to use Crimson NP Acid Cleanse 5 - Liquid acid descaler, which is a blend of phosphoric and nitric acid (Franclemont). The mixture effectively cleans and is more stable and less hazardous than either acid alone (Martin). Following the acid wash is the final sanitation step. In this case it was chosen to use Crimson PAA 5 - Peroxyacetic Acid 5%, which is a mixture of peracetic acid, acetic acid, hydrogen peroxide, and water (Franclemont).

The Na/KOH solution is corrosive to metals, harmful if swallowed, and causes severe skin burns and eye damage (Winter Caustic Blend). It is a very strong base and will cause violent reactions if contacted with another acid (MSDS winter caustic). When preparing the cleaning caustic solution, the caustic should be gradually added to water to avoid any violent exothermic reactions (Winter Caustic Blend). It should be stored in its sealed container in a temperature range between 16 – 40ºC (Winter Caustic Blend).

The CIP acid solution is corrosive to metals, harmful if swallowed, and causes severe skin burns and eye damage (CIP Acid). It is highly reactive, has a pH<1, and should not be introduced to other reactive bases, chlorinated products, metals or organics (CIP Acid). When dilutions are performed to prepare the cleaning solution, again, the acid solution must be gradually added to the water to avoid violent exothermic reactions (CIP Acid). It should be stored in a dry, cool, well ventilated location (CIP Acid).

The Peroxyacetic Acid 5% is an oxidizing agent, corrosive to eyes, causes skin irritation and possible burns, harmful if swallowed, and repeated inhalation of high concentration vapors will cause irritation of the respiratory system (Peracetic Acid 5%). Due to its chemical properties as an oxidant, contact with combustible material may cause fire which will result in the chemical's decomposition (Peracetic Acid 5%). This chemical should not be contacted with organics, reducing agents, caustics or metals (Peracetic Acid 5%). The chemical is considered a hazardous waste by RCRA and because of this, it must be disposed of appropriately in accordance with these regulations (Peracetic Acid 5%). The chemical must be stored in a cool, dry and well-ventilated area away from any open flames and should be kept at a temperature less than 30ºC (Peracetic Acid 5%).

4.5 Environmental Impacts Statement

The process of producing beer and liquor will contribute to greenhouse gas emissions in a variety of ways. Fermentation produces CO_2 as a byproduct, which is sanitized before being released into the atmosphere (Edward). Carbonation of beer utilizes a large volume of CO_2 and the process wastes quite a bit of CO_2 due to the filling and purging of the brite tanks before carbonation (Brite Tank Carbonation Basics). There is also a variety of energy intensive unit operations like the HEBS, cooling of the fermentation vessels, and the distillation column. All these systems are powered by electricity in some capacity and the production of this energy has an associated carbon footprint ("How We Calculate"). Additionally, the demand for malt, hops, water, and packaging materials contributes to the depletion of resources.

4.5.1 Gaseous Discharges

Compressed CO_2 for the carbonation of beer along with excess CO_2 produced from the fermentation process are the primary sources for gaseous discharges. There is an incentive to capture CO_2 and recycle it for carbonation; however, industry practice is to let the CO_2 outgas as it can contain volatile organics that impact the flavor of the product. It can also potentially contain poisonous sulfide compounds (Edward and Bassett). The other issue is the lack of viable technology aimed at CO_2 capture at this scale. One option however would be the use of a pressure cap for the fermentation tanks that seals in some CO_2 (Combs). The hesitation behind implementing this is the fact that many of the vessels utilized for breweries have rather low design pressures and pressurizing one of these tanks could have disastrous consequences if one were to rupture (90 Barrel Brewery Fermenter Tanks). The amount of waste CO_2 outgassing from fermentation and carbonation is estimated to be about 10.9 metric tons per year. The amount of CO_2 that is used for the carbonation of beer is estimated to be about 76.8 metric tons a year.

4.5.2 Liquid Discharges

The other large waste stream would be the spent cleaning agents. Often after use of the chemicals they will become inactive and can be dumped down the drain to be treated by the local water treatment plants (Edward). Thus, the use of these chemicals has a relatively minimal impact so long as they are disposed of appropriately, meaning that both the caustic and acidic cleaners are neutralized, and appropriate disposal measures are taken with sanitizers. Often tanks previously cleaned with the chemicals will be rinsed with water which is then allowed to be passed through a drain to the local water treatment plant. The water will dilute the chemicals, but improper concentrations of cleaning solution could significantly impact water pH ("The Brewer's Handbook: Brewery Cleaning And Sanitation").

4.5.3 Solid Discharges

The major stream of solid waste is spent grains, yeast, and hops. All these materials are environmentally benign and often the spent materials are given to local farmers to be used as animal feed (Edward). Otherwise, when cleaning occurs, water is used to remove the materials and the waste slurry is allowed to be passed down the drain (Edward).

It should also be mentioned that sourcing the raw materials (malt, hops, packaging materials) will include some sort of environmental impact from the production and transportation. It is desirable to source these materials in the local region, however for the purposes of this project the materials were sourced from the most convenient vendors found in the online marketplace.

4.5.4 Environmental impacts of utilities

4.5.4.1 Water

There is a large volume of water used for brewing. Both as an additive to produce the beer and liquor but also for the cleaning of equipment. The yearly amount of water used to produce liquor and beer is estimated to be roughly 1,400,000 L. This includes water for the production of beer/whisky and the water from waste streams. The volume of water needed to clean the equipment is much higher, being about 7,700,00 L. It's estimated that for every 1 gallon of beer produced somewhere between 3 to 8 gallons is used for cleaning (Agnew). In this case it was assumed to take 6 gallons of water for every gallon of beer and liquor used. The water for cleaning is a very rough estimate.

4.5.4.2 Electricity

There are associated environmental impacts from the electricity used in the process. There is an associated carbon footprint related to electricity production. Carbonfund.org estimated that for every kWh worth of electricity generated there will be 0.0005925 metric tons worth of CO_2 produced (How We Calculate). Thus, based on the energy demands to operate the brewery/distillery there will be an estimated 10.1 metric tons worth of CO_2 emissions produced per year. This is far less significant than the CO_2 demand for carbonation and waste CO_2 from fermentation processes. A table of energy demands for each major process and corresponding CO_2 footprint is summarized below:

Equipment	Energy output Per Year (kWh)	CO_2 Output Per Year (kg)
Beer Fermenters	48840	28937.7
Brite Tanks	952	564.1
Whiskey Fermenters	5320	3152.1
Distillation	94080	55742.4
HEBS	150472	55742.4
Bottling/Canning	4417	2617.1

Total	304080	180167.4

Table 4.5.4.2 Summarized table for energy requirements and CO_2 footprint on a yearly basis

4.5.4.3 Spills

Fortunately, the spilling of beer isn’t an environmental hazard, but the spilling of concentrated alcohol solution produced from distillation and even the subsequent whiskey are both flammable and should be handled cautiously. The alcohol in spilt whiskey and beer will volatize leaving the organics and water left over.

Spilling of the cleaning chemicals would be hazardous and oftentimes in addition to the acidic, caustic, and oxidizing characteristics there are other additives like chelators and surfactants which would react with soil/other organics (Martin). Extreme caution should be practiced when handling the concentrated cleaning agents as they are corrosive in nature and pose a hazard to human safety, equipment, and the environment.

4.5.5 Regulations

Since there is a large volume of CO_2 emissions involved in the process, the process must be compliant with the regulations established in the Clean Air Act which involves securing a permit to release CO_2. Following suit, there is wastewater produced from the process and often cleaning chemicals may be present in the wastewater that is being discharged. This means that the wastewater must be in compliance with the Clean Water Act in ensuring that chemicals being dumped are at acceptable levels. Additionally, the chemical room and safe handling of test reagents, caustic and acid cleaners, along with sanitizers will be supervised by OSHA through regular inspections. This also pertains to acceptable CO_2 levels in the brewery/distillery and ensuring that the work area is in compliance with OSHA standards. The sanitizer used is considered a hazardous waste by RCRA, thus disposal must be in compliance with the regulations established in the legislation (CIP Acid).

4.5.6 LCA

Impact categories were obtained from the standards committee's paper on Type III life cycle impact assessment (Life Cycle Impact Assessment Framework and Guidance for Establishing Public Declarations and Claims, 2012). The following diagram summarizes the major materials associated for each impact category relevant for the LCA:

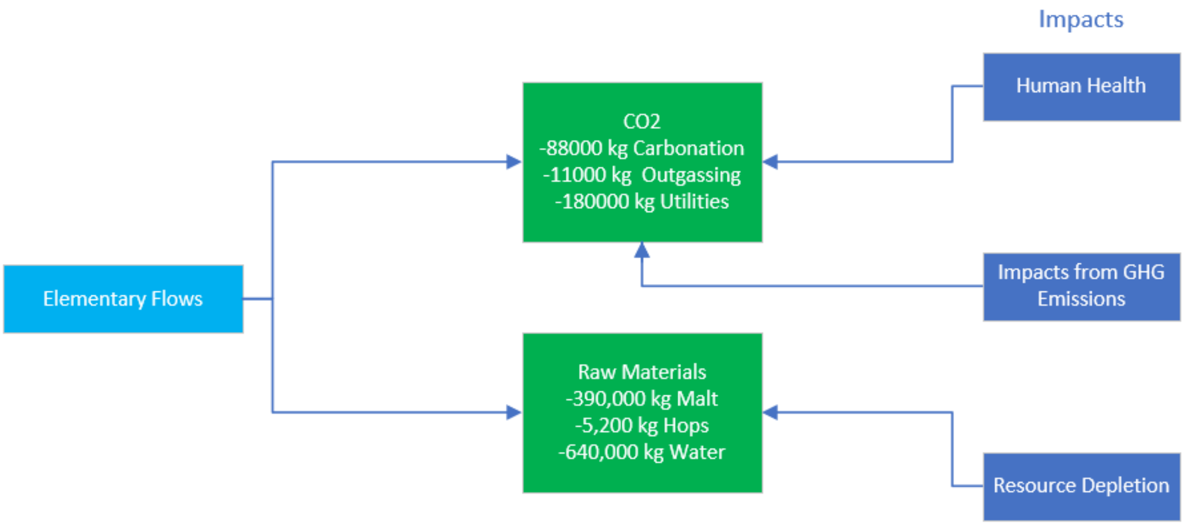


Fig 4.5.6 LCA of brewery/distillery

When examining the human health impact there exists the potential for humans to be exposed to CO_2. Exposure to small concentrations of CO_2 is harmless, however large exposures could displace the oxygen in one's body causing a series of health issues and even death ("Carbon Dioxide"). These complications are related to lack of oxygen rather than CO_2 toxicity ("Carbon Dioxide"). Otherwise, the chemicals handled during the brewing process do not pose a long-term risk to human health.

The fermentation process itself produces a large amount of CO_2 which is sanitized before being released to the atmosphere (Edward). Currently, there aren't any strong incentives or effective technologies for the capture or recycling of this CO_2 (Bassett). There is also a significant amount of CO_2 that is required when carbonating the beer and that process also involves the off-gassing of CO_2 (Brite Tank Carbonation Basics). Of course, the utilities required in the operation of all the equipment are powered by electricity which has an associated carbon footprint. These GHG emissions are of concern due to their warming effect on the climate (Pachauri, 2015).

There is a large volume of raw materials needed to be used for beer and liquor production. There is a large water demand due to its importance as a primary ingredient in the products along with its use for the cleaning of process equipment. There is also quite a large volume of malt that is being consumed while specialty hops fulfill a smaller volume. All these material demands contributes to the resource depletion impact category. Spent grains will be donated to farmers which improves in the long-term sustainability.

SECTION 5 ECONOMIC ANALYSIS

5.1 Capital and Operating Costs

The cumulative present value (Cum PV) in table 5.1 was calculated using a nominal interest rate of 20% using equation 26-13 of the appendix A. The values on this table were calculated using equations 26-10 to 26-13, which originated from chapter 23 of (Seider et al.). The plant generates profit after the first year of production. Since it takes one year for the whiskey to age, sales from whiskey is accounted for from the second year on. It was assumed that depreciation was linear over a 10 year lifespan. After 15 years of operation, the plant generates $19.9 million in profit.

	Investment						Cash	Cum PV
Year	fCTDC	CWC	D	C excl D	S	Net Earn	Flow	20%
0	$(1,821,314)	$(2,028,095)					$(3,849,409)	$(1,821,314)
1			384,941	$1,450,392	$6,613,334	$4,778,001	$5,162,942	$2,481,138

2			384,941	$1,450,392	$8,413,334	$4,144,141	$4,529,082	$5,626,334
3			384,941	$1,450,392	$8,413,334	$4,144,141	$4,529,082	$8,247,330
4			384,941	$1,450,392	$8,413,334	$4,144,141	$4,529,082	$10,431,494
5			384,941	$1,450,392	$8,413,334	$4,144,141	$4,529,082	$12,251,630
6			384,941	$1,450,392	$8,413,334	$4,144,141	$4,529,082	$13,768,411
7			384,941	$1,450,392	$8,413,334	$4,144,141	$4,529,082	$15,032,394
8			384,941	$1,450,392	$8,413,334	$4,144,141	$4,529,082	$16,085,714
9			384,941	$1,450,392	$8,413,334	$4,144,141	$4,529,082	$16,963,480
10			384,941	$1,450,392	$8,413,334	$4,144,141	$4,529,082	$17,694,952
11				$1,450,392	$8,413,334	$4,386,654	$4,386,654	$18,285,343

12				$1,450,392	$8,413,334	$4,386,654	$4,386,654	$18,777,336
13				$1,450,392	$8,413,334	$4,386,654	$4,386,654	$19,187,329
14				$1,450,392	$8,413,334	$4,386,654	$4,386,654	$19,528,991
15		$2,028,095		$1,450,392	$8,413,334	$4,386,654	$6,414,749	$19,945,343

Table 5.1 Cash Flow Statement

Book values from (Sieder et al.) were used to calculate multiple costs for the TCI. The site startup cost, C_{site}, was calculated using equation 26-1 from Appendix A. Contractor and Contingencies were calculated using equation 26-3. A warehouse is required for operation and a real estate value of $750,000 (from table 5.2) was used for the cost of land and site (“1230 S Campbell Ave, Tucson, AZ, 85713 - Distribution Property For Sale on LoopNet.com.”). The warehouse square footage is 16,940, which is comparable to Dragoon Brewery’s 18,000 square foot warehouse (Greene). There are no costs of royalties since no additional franchising and loyalty fees are required. The plant startup cost is considered in the cost for the annual energy duties.

TYPE	Cost ($)				
Total bare - module costs for process machinery	$669,602				
Total costs for spares	-				
Total bare-module cost for Storage and Surge tanks	$237,250				

Total Cost for initial catalyst charges	-				
Total bare-module cost for computers and software	$1,000				
Total Bare Module Cost		$907,852			
Site Sart Up Costs		$23,725			
Cost of Service Facilities		-			
Allocated Costs for Utilities		-			
Total Direct Permanent Investment, DPI			$931,577		
Contingencies and Contractor Fees			$139,737		
Total Depreciable Capital, TDC				$1,071,314	
Cost of Land				$750,000	
Cost of royalties				-	
Cost of plant start up				-	
Total Permanent Investment, TPI					$1,821,314
Working Capital					$2,024,119
Total Capital Investment, TC					$3,845,432

The TCI was calculated using Chapter 22 from (Seider et al.) as well as values from table 5.3, table 5.4, and table 5.5.

Table 5.2 Total Capital Investment

Type	Costs per year ($)

Materials	$1,047,071		
Energy	$21,590		
Water	$11,731		
Labor	$370,000		
COM		$1,450,392	
Reserves		$120,818	
Accounts Receivable		$575,360	
Accounts Payable		$(91,095)	
Working Costs			$2,055,474

Table 5.3 Working Costs (WC)

Material	Cost per year ($)	Vendor
Yeast	$7,793	White Labs
Two Row Malt	$281,318	Midwests Supplies
Wheat Malt	$239,442	Midwests Supplies
Munich Malt	$78,347	Midwests Supplies
Magnum GR Hops	$61,694	Hops Direct
Sorachi Ace Pellets	$110,526	Farmhouse Brewing Supply
Water for product	$1,831	Tucson Water
Cans	$231,467	Ball
Bottles	$3,181	The Cary Company
CO2	$4,093	Stoody Ind
Barrels	$27,379	MidWest Barrel Co
Total	$1,047,071	-

Table 5.4 Material Costs

Equipment Name	Equipment Number	Amount	Equipment Cost	Vendor
Distillation Column	T-101	1	$100,000	Maleta Cyclic Distillation
Distillate Vessel	V-101	1	$-	Maleta Cyclic Distillation
Bottoms Tank Volume	V-104	1	$-	Maleta Cyclic Distillation
Canner	Z-101	1	$65,000	American Beer Equipment
Barrels	Z-102	137	$27,379	Midwest Barrel Company
Reverse Osmosis Unit	F-101	1	$3,395	Evoqua
Whiskey Fermentation Tanks	TK-117, 119	3	$36,750	The Vitner Vault
Beer Fermentation Tanks	TK-112 - TK-116	5	$147,500	The Vitner Vault
Beer Brite Tanks	TK 110 - TK-111	2	$53,000	The Vitner Vault
Oxygen tank	TK-107	1	$28	Stoody Ind
CO2 tanks	-	3	$731	Stoody Ind
HEBS			$455,000	
Malt Mill	M- 101	1		IDD
Flex Auger	P-101, P-102	2		IDD
Hot Liquor Tank	TK-101	1		IDD
Mash Tun	TK-102	1		IDD
Mash Filter	TK-105	1		IDD
Kettle Tank	TK-103	1		IDD

Whirlpool	TK-104	1		IDD
Heat Exchanger	E-101	1		IDD
HEBS Pumps	P-101 - P-107	7		IDD
Pumps	P-108	2	$4,700	CPE Systems CO
	P-109 P-110	3	$7,050	CPE Systems CO
	P-111 P-112	3	$7,050	CPE Systems CO
Total Cost			$893,484	

Table 5.5 Equipment Costs

The purchase costs for all equipment were values gathered from online vendors. The vendor and quantity of equipment can be found on Table 5.5. All equipment pieces are commonly used in industry and required no theoretical calculations from Chapter 22 (Sieder et al.). Similarly, the cost of materials from table 5.4 were priced from vendors to increase the accuracy of costs. There are additional bare module costs for computer and software that are required for management, supervision, and financials. Software and systems for the HEBS are included in the total cost of the unit (“HEBS”). Additionally, temperature control systems for brite tanks (TK110 -TK111) and fermenter vessels (TK-112-TK-119) are included in the purchase costs (90 Barrel Brewery Bright Tanks).

The working costs were calculated using equation 26-9. Energy costs were calculated using the duties required from the equipment from Table 2.1.5 and multiplied by the average industrial rate for Tucson: 0.017 $/kWh (“Stable, Affordable Rates”). Additional energy charges accounted for include air conditioning, ventilation, computer power, and lighting. A value of 6.1 kWh/ft^2 of warehouse space was used to convert and find the cost needed (“Managing Energy Costs in Warehouses.”). Water costs were calculated using the volume required to clean equipment and an additional $1,846 yearly fee for the water meter (Tucsonaz.gov, 2018). It is important to note that the water in Table 5.4 was calculated exclusively as a raw material. Labor costs were calculated for 9 employees; a head brewer, a head distiller, and 7 cross-trained workers. The amount of employees chosen models Dragoon Brewery due to their similar yearly production (Greene). The reserves, account receivable, and accounts payable were calculated from equations 26-6, 26-7, and 26-8 respectively (Seider et al.).

Although the hybrid brewery-distillery is expected to generate *massive* profits after the first year, there are a few economic hazards. The largest hazard is making sure product demand is equivalent to supply. It was assumed that all the alcohol produced will be sold at $2 per 12oz beer can and $50 per 750ml bottle of whiskey. These prices for a startup may be too high considering that industry sales are heavily reliant on company reputation. The brewery-distillery would most likely produce a smaller quantity over the first two years then scale to consumer demand. This will decrease the NPV over the first two years. There will be inflation and fluctuation in utility costs; however, the percent of costs from water and electric are less than 15% of total yearly costs and should not have a drastic effect on profit. The largest portion of costs are from cans and grains, thus, if the aluminum and agricultural markets are thriving the total costs per year should decrease. On the contrary, if these markets are suffering the cost of materials can significantly affect profits.

5.2 Cost Saving Optimization

In order to optimize costs, it is important to focus on the materials required on table 5.4. Contacting a malt vendor directly and asking about wholesale pricing can reduce the total materials cost on an annual basis. Since the plant deals with large grain quantities, a yearly contract and a wholesale deal is likely. The total costs for whiskey fermenters on table 5.5 is $36,750. Instead of purchasing 3 separate 20 BBL tanks, one 60 BBL tank can be purchased for $20,000 (90 Barrel Brewery Bright Tanks). This will reduce spacing and facilitate easy expansion.

SECTION 6 CONCLUSIONS AND RECOMMENDATIONS

6.1 Process Design Accuracy

It appears that the design of traditional breweries of this scale do not involve such critical attention to details such as the ones contained in this report. Based off what was learned through a variety of brewery and distillery visits the process is much more empirical, and critical considerations of some factors (such as heat losses) are not calculated in a way similar to the process utilized. For example, beer maturation is based off the instantaneous specific gravity rather than assumed residence times (Edward). For validation, design calculations should be compared to brewery/distillery systems with similar process equipment to validate the claims contained in the report.

6.2 Sources of Error and Assumptions

- Assumption that the only chemicals involved in the fermentation process are glucose, alcohol, and CO_2.
    - We know that the fermentation process is far more complicated than the simplified version utilized in this project. Often, during the production of the wort the primary sugars aren't actually glucose but a composition of sugars like glucose, fructose and galactose (Scott Bemis). The entirety of the alcohol production book-keeping is based on the assumption of a uniform sugar, glucose. Thus, an error based off this assumption will impact the final results. The other piece to be acknowledged is the assumed lack of co-products from the fermentation process. Many other chemicals are produced besides ethanol and many of these side reactions are meticulously controlled in the brewing process (Edward). While actions are taken to control these factors (manipulation of temperature and residence times) it is incredibly difficult to predict how these other co-products will affect the quality of the product from a theoretical standpoint.
- Assumption that HEBS process will extract maximum amount of sugars from grains.
    - There is a certain sugar content associated with the malted grains used in the process. The assumption is that the maximum amount of sugars are extracted from these grains each time it is processed by the HEBS. The reality of this maximum extraction is contingent on the HEBS performance, which may not

    perform as anticipated due to inability to reproduce ideal conditions. Ultimately this may mean that the amount of raw materials and the number of fermentation cycles may be underestimated, and as a consequence the cost is less than reality.
- Assumption of a 14 day fermentation period.
    - It is clear that the fermentation process is rapid and takes a matter of days (Sheer). The extra days that the beer is spent in the fermentation tank is based on flavor profile and efforts to avoid production of other co-products (Greene). The blanket assumption for fermentation time is derived from brewery visits to Pueblo Vida, Dragoon, and Barrio. It is a fair assumption, but the possibility that it will take more or less time will significantly alter the rest of the process since the fermentation step is the limiting step. If it were to take more time, the possibility of having more fermentation vessels is a realistic expectation. Inversely, if it were to take less time the opportunity to use less fermentation tanks exists. Ultimately, the timing of the fermentation process is heavily influential on the number of fermentation tanks used.
- Assumption of Heat Transfer from equipment
    - It is assumed that that the only form of heat transfer for equipment is convection (equation 11-3). Radiation was not included in these calculations.

6.3 Recommendations

One area of potential improvement would be a more thorough investigation of CO_2 capture and recycling. An efficient recycling system could reduce environmental impacts of the process and reduce material costs due to a reduced demand for CO_2 for beer carbonation. Reducing the environmental impact also would have the added benefit of good public perception in the case that customers would be more likely to purchase the products due to positive associations.

For economics, it was assumed that all beer and liquor will be sold within a year of plant start up. It is more realistic that a smaller amount of alcohol will be produced initially, then after gaining popularity, more alcohol will be produced and sold. Raw materials would also be calculated to be purchased throughout the operating year instead of completely up front. This method will generate a more accurate and dynamic cash flow sheet. Additionally, the facility cost would be more accurate if the economic analysis included reinforced concrete floors.

With further investigation, the accuracy of our design could be improved upon. Closer collaboration with local brewers and distillers could address the inaccuracies in our assumptions and design parameters. And taxes.

SECTION 7 NOMENCLATURE AND EQUATIONS

7.1 Mill

7.2 Flex Auger

7.3 HEBS

7.3.1 Hopper

7.3.2 Pumps

7.3.3 Heat Exchanger

7.3.4 Hot Liquor Tank

7.3.5 Whirlpool

7.3.6 Mash Tun

7.4 Fermenters

ermenter tank heat transfer coefficient

ermenter tank heat transfer coefficient

7.5 Brite Tank

Tank heat transfer coefficient

7.6 Glycol Cooling Unit

7.7 Distillation

7.8 Packaging

ID = *Inner Diameter (cm)*

7.9 Economics

C_{Site} – Cost of Site Start Up

C_{TBM} – Total Bare Module Cost

DPI –Total Direct Permanent Investment

C_{cc} – Cost of Contingencies and Contractor Fees

TDC – Total Depreciable Capable

TCI – Total Cost of Investment

C_L = Cost of Land

C_S = Cost of Start up

C_R = Cost of Royalties

COM – Cost of Manufacture

C_M – Cost of Materials

COL – Cost of Labor

C_E = Cost of Energy

C_W – Cost of Water

AR – Accounts Receivable

AP – Accounts Payable

WC – Working Costs

Net Earns

D – Depreciation

C excl D – Costs Excluding Depreciation

CF – Cash Flow

PV – Present Value

CumPV – Cumulative Present Value

n – year

PV_{n-1} – Previous Year Present Valu

SECTION 8 REFERENCES

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Appendices

Appendix A. Equations

Equipment

Refer to Section 7 for variable nomenclature.

Equation 1-1

Equation 1-2

Equation 1-3

Equation 2-1

Equation 2-2

Equation 3-1

Equation 3-2

Equation 4-1

Equation 4-2

Equation 4-3

Equation 5-1

Equation 5-2

Equation 5-3

Equation 5-4

Equation 5-5

Equation 5-6

Equation 5-7

Equation 6-1

Equation 6-2

Equation 7-1

Equation 7-2

Equation 8-1

Equation 8-2

Equation 11-1

Equation 11-2

Equation 11-3

Equation 11-4

Equation 11-5

Equation 11-6

Equation 11-7

Equation 12-1

Equation 13-1

Mass balance

Equation 13-2

Equation 13-3

Equation 13-4

Equation 14-1

Equation 15-1

Equation 15-2

Equation 15-3

Equation 15-4

Equation 16-5

Multiplier for Beer Recipe Scale up = 527Gallon/3.113Gallons

Equation 16-1

Equation 17-1

Equation 18-1

Equation 18-2

Equation 19-1

Equation 19-2

Equation 19-3

Equation 19-4

Equation 19-5

Equation 20-1

P = Pressure (atm)

T = Temperature (K)

R (L*atm/mol K) = 0.082057

V= Volume(L)

Equation 21-1

Equation 22-1

Equation 23-1

Equation 24-1

Equation 25-1

Equation 25-2

Economics

Equation 26-1

Equation 26–2

Equation 26–3

Equation 26-4

Equation 26–5

Equation 26-6

Equation 26-7

Equation 26-8

Equation 26-9

Equation 26-10

Equation 26-11

Equation 26-12

Equation 26-13

Appendix B. Calculations

Calculations were submitted to D2L

Appendix C. Excel Sheets

All excel sheets were submitted to D2L

Appendix D. Mass and Energy Balance

For the mass balance see Table 2.1.4.1 & Table 2.1.4.2 as the stream table is identical to the mass balance.

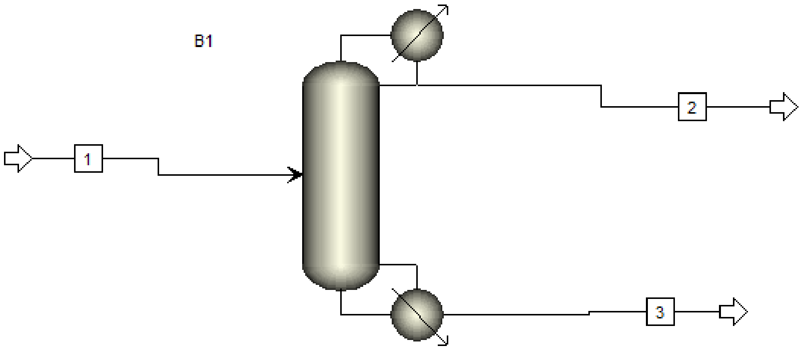
Equipment	Energy Output Per Batch (kWh)	Energy Output Per Year (kWh)
Beer Fermenters	444	48840
Brite Tanks	9	952
Whiskey Fermenters	95	5320
Distillation	1680	94080
HEBS	248	150472
Bottling/Canning	40	4417
Total	2516	304080

Table D.1 Energy Balance

Appendix E. Aspen Output

INPUTS		
water	0.8819	mass frac
ETOH	0.1181	mass frac
wash total in	2351.53	kg/ day
Reflux Ratio	1.5	mass

Temperature	75	ºC
Pressure	1.01325	bar
# trays	6	From DSTW
distillate rate	13.817	kg/hr
feed tray	4	
stage 1	1.01325	bar



RADFRAC Distillation Column for Whiskey

Stream Results	1	2	3
Substream: MIXED			
Mole Flow kmol/hr			
WATER	4.796424	0.1826726	4.613749
ETHANOL	0.2511771	0.2284864	0.0226934
Total Flow kmol/hr	5.047602	0.411159	4.636443
Total Flow kg/hr	97.98042	13.81705	84.16345
Total Flow l/min	1.783503	0.2972323	1.530281
Temperature C	75	79.39591	98.53801
Pressure bar	1.01325	1.01325	1.01325
Vapor Frac	0	0	0
Liquid Frac	1	1	1
Solid Frac	0	0	0
Enthalpy cal/mol	-67241.41	-65711.7	-66899.26
Enthalpy cal/gm	-3464.038	-1955.407	-3685.384
Enthalpy cal/sec	-94279.96	-7504.989	-86159.61
Entropy cal/mol-K	-38.05704	-58.11242	-35.10125
Entropy cal/gm-K	-1.960563	-1.729273	-1.933677
Density mol/cc	0.0471693	0.0230548	0.0504966

Density gm/cc	0.9156175	0.7747615	0.9166445
Average MW	19.41128	33.60512	18.15259
Liq Vol 60F l/min	1.686452	0.2764819	1.409972
CONDENSER / TOP STAGE PREFORMANCE			
Name	Value	Units	
Temperature	79.3959119	C	
Heat duty	-2735.1587	cal/sec	
Distillate rate	0.41115902	kmol/hr	
Reflux rate	0.61673854	kmol/hr	
Reflux ratio	1.5		
REBOILER / BOTTOM STAGE PREFORMANCE			
Name	Value	Units	
Temperature	98.5380056	C	
Heat duty	3350.56725	cal/sec	
Bottoms rate	4.63644251	kmol/hr	
Boilup rate	1.2124688	kmol/hr	
Boilup ratio	0.26150843		

Appendix F. Web Print Outs

Refer to D2L submissions

Appendix G. Meeting Minutes and Phone Logs

Refer to D2L submissions