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Social Ecological Economic Development Studies (SEEDS) Sustainability Program

Student Research Report

UBC AMS Microbrewery

Food and Beverage Innovation Center (FBIC) – Opportunities for Waste and Emissions Reductions

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EXECUTIVE SUMMARY

Brewing is a very energy and water-intensive process. The team has been tasked to design a microbrewery on the UBC campus with the collaboration of the UBC AMS. This report focuses on the design of a sustainable microbrewery that uses efficient methods for waste management.

The reactants needed for the brewery process are yeast, hops, malt/barley grains, and water. The microbrewery is divided into two sides: the hot and cold sides. The hot side contains the mash/lauter tun and hops boiler. The mash/lauter tun is used to mash grains to convert starch to sugar and then separate wort from the undissolved spent grains. The hops boiler is used to extract flavor from hops. The cold side encompasses the fermentation tank and the bright tank.

The market analysis conducted on the brewing business shows that their consumption can be almost cut in half by recycling the water and energy streams. In addition, two control loops will be implemented for this process, with simple control strategies being used due to the process being a small-scale batch process. Both of these will be temperature control loops applied on the fermentation tank (R-100) for optimum yeast metabolism and the bright tank (V-103) to keep the beer at a cool temperature before packaging. Pressure relief valves are also installed on the tanks to release any build-up pressure occurring; no further equipment protection measures are required as this is a small-scale production that will not have hazardous levels of carbon dioxide or achieve high pressures. The final design's environmental and economic analyses have been conducted, and analysis has been described in the report below. It was found that for an initial investment of $1.3M, gross revenue of approximately $350k can be expected.

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NOMENCLATURE

BFD - Block Flow Diagram

PFD - Process Flow Diagram

P&ID - Process and Instrumentation Diagram

carbon dioxide - Carbon Dioxide

HX - Heat Exchanger

USD - US Dollar

CAD - Canadian Dollar

kW - kiloWatts

kJ - kiloJoules

Kg - kilograms

Cp - Heat Capacity

L - Latent Heat

M - Mass

Q - Energy

HL - HectoLitres

Bbl - beer barrels

TT - Temperature Transmitter

TC - Temperature Controller

PT - Pressure Transmitter

LT - Level Transmitter

pHT - pH Transmitter

INTRODUCTION

The food and beverage industry is an ever-growing industry with a current global market of $184.5 billion in 2020 and is expected to reach $274.5 billion by 2025 [1]. Beer is the fifth most consumed beverage globally, with about 1.91 billion hectolitres of beer produced in 2019 [2]. Beer is a water and energy-intensive process that needs around 10L of water to produce 1L of beer. The substantial amount of beer produced annually gives rise to research focused on utilizing waste streams and making the process more energy efficient. Group P10 has been handed a project specified by the UBC AMS to tackle this issue. The project consists of building a sustainable microbrewery that could fit into 800 ft2, with the expected output of the beer product being 1000 liters per batch. The brewery process is relatively linear, as only two streams are going into the reactor, the yeast stream, and the cooled wort stream; it was therefore concluded that the batch reactor is the ideal reactor since it has a significantly faster residence time than other reactors. On average, four batches per month are planned throughout the year. The feed consists of malted barley, hops, yeast, and water. Aside from the beer, the output would be spent yeast, hops, malt, wastewater, and carbon dioxide, which are optimized for sustainability and efficiency. The size of the brewery located on the University of British Columbia campus inside the AMS Nest limits the potential units that can be accommodated for the process.

MARKET AND COMPETITIVE ANALYSIS

The process of making beer production a more efficient process is limited by the project's financial aspect, not the lack of available technologies. The sustainability options are also limited by the lack of available space and scale of production in microbreweries. In general, smaller breweries use more energy per 100 liters as the base energy requirement does not change, even for smaller volumes. The total energy per gallon of beer is around 50 to 66 kW/bbl [3]. The total energy is divided into electrical and thermal energy, with electrical energy accounting for around 70% of the total energy needed. At 6 cents per kW of energy, the cost for a barrel of beer is 3.30 to 4.26 USD. Revenue in the Beer segment amounts to USD 552,404M in 2021. The market is expected to grow annually by 9.13% (CAGR 2021-2025) [4].

As a brewery consumes a lot of water and energy, the goal of the study in place is to reduce the amount of water and disposed waste to produce a high-quality beer. A lower efficiency brewery can take up to 10 L of water to produce 1 L of beer, while the wastewater leaving the system can be around 8 L. Allowing for a more efficient process, a brewer can potentially consume around 5 L of water instead [4.1]. Inefficiencies arise from disposing of heat exchanger water, using an excess amount of water during the lautering process, overheating within the hops boiler, and minor equipment leaks. These inefficiencies can be prevented by regular equipment maintenance, water recycling systems, batch control systems and batch planning. In addition, a more diligent brewing practice will prevent the need to dispose of batches due to wrong composition and concentrations. Temperature and level control systems can reduce energy usage and prevent bad batches.

BLOCK FLOW DIAGRAM

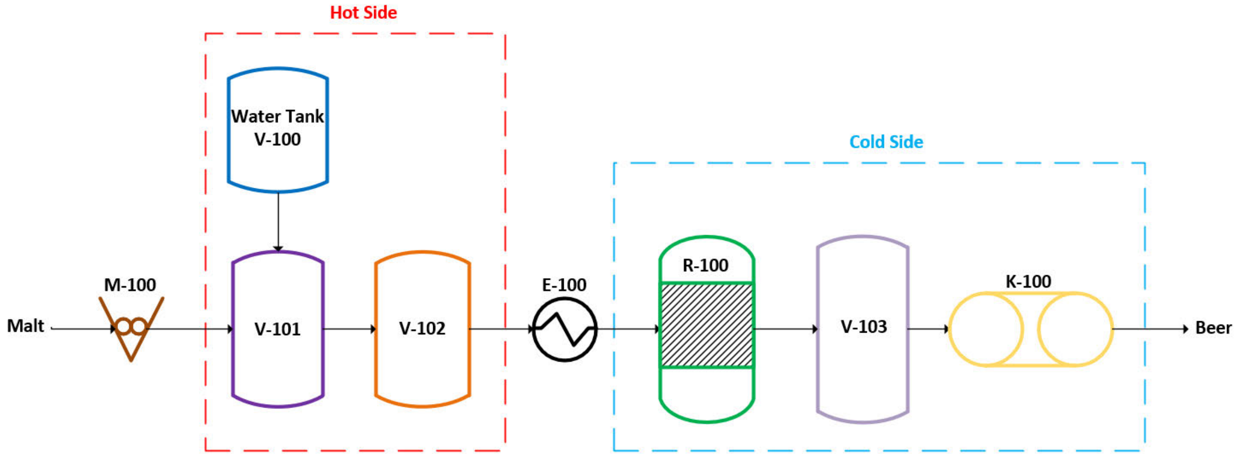


Figure 1: Block Flow Diagram

The brewery process has two main sides, the hot and cold sides. The process starts hot and transitions to the cold side through the cooling section before the cooling block. The water is first stored in a jacketed storage tank where it can be boiled before brewing to sterilize the water.

Parallel to this, the grains are milled at the milling station and then transported into the mash/lauter tun for mashing, where the grains are mixed with clean water to create a mixture called wort. Next, the wort goes through a process of lautering where the suspended solids of grains are separated, and the wort has been adjusted to acceptable turbidity. Next, hops are added to the wort, and the new mixture is heated up to extract flavors from the hops. Next, the hops are separated via whirlpooling equipment inside the hops boiler, using centrifugal force for separation. Afterwards, the wort mixture is cooled off using the heat exchanger, and the brewery process transitions from the hot side to the cold side.

The cooled wort is sent into the reactor, the fermentation tank, where yeast is then added to start the fermentation process. Fermentation can take anywhere from two to eight weeks, depending on the type of beer produced. This mixture can now be called beer. The beer is then sent to the bright tank for conditioning while the yeast settles at the fermenter's conical bottom. Additional flavoring and fining products can be added to the bright tank, and the beer is left to age for a couple of days. Carbon dioxide is also added to the bright tank for carbonation. The beer can now be processed for further packaging.

PROCESS SYNTHESIS

The design of the process started with industrial-scale research since most microbreweries do not have documented block flow diagrams or process flow diagrams. After initial research, a block flow diagram was created with the stages needed for the brewery process. Next, a process flow diagram was created with the basis of a block flow diagram. Since these designs have been based on specifications for an industrial-scale process, iterations were required for the microbrewery design. The first of these iterations are the vessels. The industry uses vessels [5] to store the initial reactants and intermediary products. These vessels also allow storage of waste streams where they can be potentially filtered for reuse. However, space constraints do not allow the space needed for these pieces of equipment in the design.

The process flow diagram has been designed with these constraints in mind. The chosen pieces of equipment for these diagrams were the milling station, mash tun, lauter tun, hops boiler, whirlpool, wort clarifier, fermentation tank (reactor), bright tank, centrifuge, and the keg filling station. A visit to the Slow Hand Microbrewery changed the group's initial design to be more compact as this allows more efficient use of space. The latest version of the process flow diagram combines the mash tun and lauter tun; hops boiler and whirlpool, respectively. Centrifuge after the bright tank is removed as the wort clarifying is done during the whirlpooling stage. According to brewery industry reviews and the co-owner of Slow Hand Microbrewery, the main difference between the separate equipment and the combined equipment is its ability to run several batches at the same time [6]. Furthermore, options such as multiple heat exchangers and various filters were explored but were not included in the final design.

Throughout term one, certain choices were made that affected the team's overall process flow diagram. Many of these choices, such as reactants, product type, and such, were kept constant as there was no need to change any of them. The batch size was determined through the fermentation tank chosen by the AMS representative, considering space constraints.

EQUIPMENT DESCRIPTION AND DESIGN

M-100, The Milling

This equipment is used for milling, as the name indicates. The grains used for the brewing process are milled into fine particles to prepare for the rest of the stages with this equipment. The capacity of the milling station is 150 kg/hr to 300 kg/hr.

V-100, Water Storage Tank

The city water is used for the brewing process; however, it is quite challenging to pump directly to the different stages, so for time and work efficiency, the water required for the process is stored in a jacketed vessel for sanitizing purposes. The maximum and minimum design temperatures for this vertical tank are 100°C and -10°C, respectively, with the tank operating between 0.9 and 1.3 atm. These design parameters are determined using the material of construction. The vessel height and diameters are 1.1m and 1.83 m^3. These specifications are chosen based on supplier values that meet the capacity requirements.

V-101, Mash/lauter tun

This equipment is a combination of mash and lauter tun. Some breweries have them as two separate components, while other microbreweries have them combined as a single tank due to spacing restrictions. The process happens consecutively inside this equipment. First mashing happens when the water enters at 25°C and is mixed with the milled grains to create a mixture called wort. After this mixture is made, lautering starts where the spent grains are allowed to settle at the "false bottom," and this forms a grain bed. The wort is filtered through this cake and then recirculated back from the top to be filtered again during the recirculation process. Next, more water is added to decrease the turbidity. This recirculation process is also known as "Vorlauf ." The mash/lauter tun tank operates at a pressure of 1 bar and can fit 1548 kg/batch while having a residence time of 60 mins. Once the desired turbidity and viscosity of the wort are achieved, it moves onto the next stage. The grain bed is collected from the false bottom. The grain bed consisting of spent grains is a waste stream.

V-102, Hops Boiler, and Whirlpooling

This equipment is also a combination of two processes which are hops boiling and whirlpooling. At this stage, the hops are added for flavoring purposes, and the mixture is heated up to extract the maximum amount of flavor. After this boiling process, the mixture enters the whirlpooling stage. The centrifugal forces are used to create a whirlpool so that the solid particles such as hops are accumulated at the bottom. The wort mixture, which is free of solids, is pumped into the next stage. This equipment is jacketed for heating purposes. The 4.1 m^3 vertical vessel is made of 304 food-grade stainless steel with a 1.42 m diameter. The Whirlpool operates between -190°C and 800°C with an operating pressure ranging between 0 and 4 atm.

E-100, Heat Exchanger

At this point, the hot side of the process needs to transition into the cold side, and thus a heat exchanger is used to cool off the wort to 20°C. The cooled-off wort goes into the fermentation tank. The heat exchanger in use is made of Carbon steel 316L and can operate at up to a temperature of 150°C and a pressure of 10 atm. Based on the operating parameters for the process, the choice of the material and capacity fit the given parameters.

R-100 (A & B), The Fermentation Tanks

Yeast is added to the fermentation tank. Next, the yeast will start to consume the sugar to produce the alcohol. This process is exothermic and can take two to eight weeks to complete. The bottom of this reactor is conical so that the yeast will accumulate at the cone for ease of disposal. The reactor has a rake inside to separate the settled yeast during the transfer of beer into the bright tank. The reactor temperature needs to be kept relatively constant, and because of that, this reactor is jacketed, and glycol is used to cool off the excess heat produced from the reaction. The reactor operates between 0°C and 40°C with a pressure ranging between 0atm and 3atm. The 1200 L reactor has a 60° conical angle and is 2.438 m heigh with an outside diameter of 1.1m. The reactor volume was chosen by the team's sponsor; after checking multiple vendors for their sizing, the previously mentioned parameters were chosen based on the 1200 L reactors they had to offer.

V-103, The Bright Tank

The beer is pumped to this vessel for conditioning. If wanted, more flavoring can be added at this stage. The beer rests in this tank for a couple of days. Then, the carbon dioxide is added from the bottom of this vessel for the carbonation of the beer. The bright tank can operate at temperatures between -190°C and 800°C, with the operating pressure ranging between 0 and 4 atm. This 1.7 m^3 vessel is also jacketed, and the beer inside is cooled off with glycol through the jacket for aging purposes. The design condition temperatures are determined using the material of construction.

K-100, Keg Filling Station

The cooled beer can be sent to the keg filling station, where the beer is pumped into the kegs. The beer is now ready.

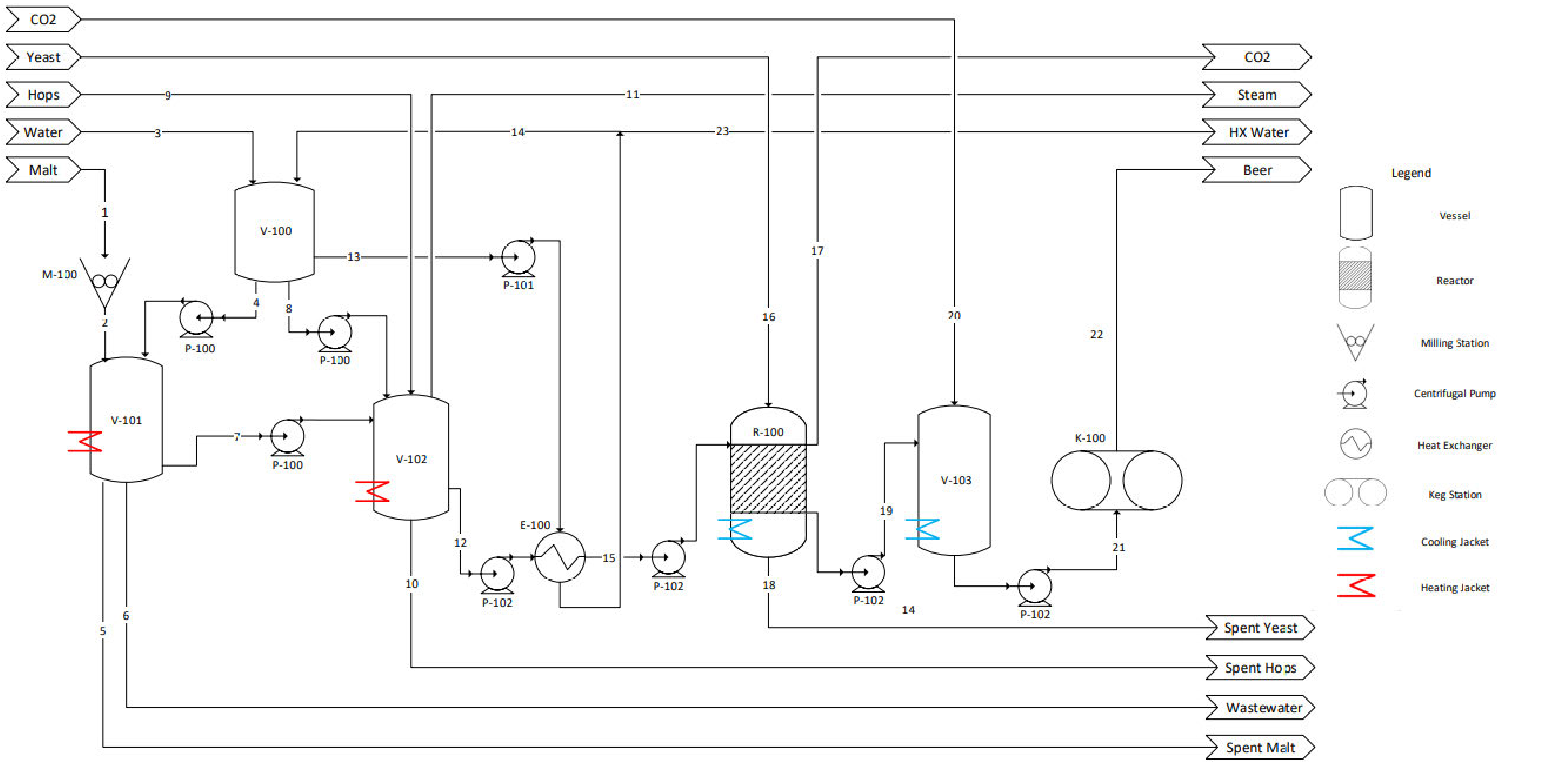
P-100,101,102, Centrifugal Pumps

Centrifugal pumps are used in the process of brewing. Some of the pumps are re-attached through different equipment for pumping between stages. One pump can be used between the processes of the hot side, and another one can be used for the cold side. The last pump is exclusive to the heat exchanger. The pump operates between 60°C and 75°C with an operating pressure ranging from 99 to 103 kPa.

ASSEMBLY OF DATABASE

For this project, several property data were collected for the microbrewery design and the initial data set was used for the mass balance of a brewery. Since beer making is a biological process, the kinetic values are harder to find, and the ones that can be found are experimental with caveats. Therefore, an industrial-scale brewery design is used to scale down for a microbrewery [5]. The mass balance, energy balance, pieces of equipment, and incoming and outgoing streams were modified according to the scale and design of this project. The production of the microbrewery is determined to be 1000 liters due to the reactor size given by the AMS (1200 liters). For energy balance, values such as latent heat and heat capacity are used for the calculations, and the values for those data points are extracted from the NIST Workbook. In addition, some specific values, such as for hops and malt, have been determined through brewing literature [7].

PROCESS FLOW DIAGRAM (PFD)



Notes	Revision	Description	Date	Worked By	Approved By		UBC Engineering Ltd.	
	A	Preliminary PFD	11/5/2021	SA	AW	This drawing is the property of UBC and its content is confidential and shall not be copied without permission	Capstone Project - FBIC Brewery	
	B	Simplified Proces	11/25/2021	SA	AW		Microbrewery Process Flowsheet	Group P10
	C	Term 2 Updates	4/10/2022	SA	AW			

Figure 2: Process Flow Diagram

STREAM TABLES

Table 1: Stream Table and Mass Balance

Stream Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
From	Malt	M-100	Wate r	V-100	V-101	V-101	V-101	V-100	Hops	V-102	V-102	V-102	V-100	E-100	E-100	Yeast	R-100	R-100	R-100	CO2	V-103	K-100	E-100
To	M-100	V-101	V-100	V-101	Spent Malt	Waste water	V-102	V-102	V-102	Spent Hops	Steam	E-100	E-100	V-100	R-100	R-100	CO2	Spent Yeast	V-103	V-103	K-100	Beer	HX Water
Temperature(C)	25	25	25	25	70	70	70	25	25	95	100	95	20	57.5	20	20	20	20	20	10	10	10	20
Pressure(atm)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Mass flow rate (kg/batch)	285	285	4,394	1,650	228	1,353	1,901	57	4	740	172	1,051	2,102	963	1,051	10	48	10	1,018	2.2	1,007	1,007	1,139
Component mass flowrate (kg/batch):																							
Malt	285	285	0	0	45	0	239	0	0	48	0	191	0	0	191	0	0	0	95	0	95	95	0
Hops	0	0	0	0	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
Yeast	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0	10	13	0	0	0	0
Water	0	0	4,394	1,650	183	1,353	1,663	57	0	688	172	860	2,102	963	860	0	0	0	860	0	860	860	1,139
CO2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	48	0	2.3	2.2	5	5	0
Alcohol	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	48	0	48	48	0

(green)	Inlets
(red)	Outlets

PROCESS DESCRIPTION

The process starts with malted barley passing through the milling machine to grind the grains, and water is then added through a pump from the water vessel (V-100) to the mash/lauter tun (V-101). In this step, the mash/lauter tun is used to create the wort mixture with milled grains and water. During this, the mixture, called wort, is also heated for solubility and sterilizing purposes. Spent grains are separated from the process, and it is also used to clarify the wort early on. The process works by having the grains settle at a false bottom to create a grain bed, which acts as a filter for the liquid mixture to go through. The mixture is then recycled back to the mash and lauter tun, and it is filtered through the grain bed again until the mixture is clear enough. The water is recycled through the heat exchanger and sent back to the water vessel for future use. Next, hops are added to the wort in a boiler (V-102), which gives a bitter taste to the beer by extracting the oils out of the hops to balance out the sweet wort and give the beverage a bitter flavor. The mixture is boiled for around an hour before being sent to the next stage. The wort/hop mixture is then sent at a high velocity to the whirlpool to cause the liquid to start spinning and push the solids down at the center. Whirlpooling is used to separate spent hops from wort. As the liquid hits the sides and the bottom of the container, the friction causes it to slow down, creating a pressure gradient that collects the solids in the center.

After the wort is separated from the hops by a whirlpool, the wort goes through a liquid-to-liquid heat exchanger (E-100) in which the wort is cooled from 90℃ to around 20℃. Next, the cooled-down wort is pumped via centrifugal pump to the chosen fermentation tank (R-100). The cold temperature aids with the settling of any suspended solids via sedimentation left to get a clearer wort. The yeast is also added at this stage, where the fermentation reaction will happen. In the fermentor, the wort and yeast are left there for four to six weeks; during that time, the yeast will consume the glucose/sugar available in the wort to produce carbon dioxide and alcohol. Since fermentation is an exothermic reaction, the fermenter is jacket cooled to keep the temperature around 20-25℃ as temperatures higher than those can form other byproducts which are undesired. The fermentor has a conical-shaped bottom to trap the yeast, which can be used for the next batch. The beer exiting the fermenter is then sent to a bright tank (V-103) and is left there for about 48 hours. The bright tank is cooled via a cooling jacket to cool the beer to around 20℃. The cooling is necessary as it reduces foaming while filling the beer. The beer is then carbonated further until the desired amount of carbonation is obtained. Further clarification can happen at this stage if necessary. At this point, the final product of beer is ready and just needs to be packaged. The chosen technique to fill the beer is via a counter-pressure keg filling system (K-100). This process works by filling the keg with carbon dioxide to push all the oxygen out to prevent the beer from oxidizing; as the carbon dioxide is then slowly released from the pressurized keg, the beer slowly displaces the carbon dioxide in the keg.

ENERGY BALANCE

An energy balance was performed on each piece of equipment of the design and can be seen in Table 1 below. Mash/lauter tun and hops boiler are equipment for the hot side, and the streams are heated using steam through a steam jacket in the equipment. The steam is at room pressure for the mash/lauter tun, and the temperature is 70℃ to heat malt and water, whereas, for the hops boiler, the temperature is 95℃ to heat the wort. The temperature changes in the fermenter reactor by 2 to 3 degrees and is kept at 15°C to 20℃. The temperature is maintained by a cooling jacket containing glycol. A heat exchanger is also used to cool down the wort using water from the water tank. Cool water at 20℃ goes in and cools the wort from the 95℃. Therefore, 2102 kilogram of water is needed to cool off the 1051 kilogram of wort. More water from the Metro Vancouver water system is added to the process to accommodate the other water needs of the project. The specific heat capacity of wort and water is assumed to be the same for the calculations. However, the amount of water needed to cool off the wort is higher than the amount of wort because of this assumption. 963 kilograms of the water are recycled, and 1139 kilograms of water are disposed of. The disposed cooling water can be recovered if there is another storage tank.

Table 2: Energy requirement for pieces of equipment

Equipment Name	Equipment Number	Energy Required (kJ)	Utility Used for Energy Required
Mash/Lauter Tun	V-101	267764	Heating jacket (water)
Hops Boiler	V-102	176868	Heating jacket (water)
Wort Cooler	E-100	(43759)	Cooling water
Fermenter	R-100	N/A	Glycol
Bright Tank	V-103	(30506)	Glycol

EQUIPMENT LIST

The finalized equipment list is shown below in table 3. These pieces of equipment are also described in the process synthesis.

Table 3: Equipment List

Equipment	Equipment Number	Equipment Type	Quantity	Flow Fluid
Malt Crusher	M-100	Mill	1	Malt
Mash/Lauter Tun	V-101	Vessel	1	Malt + Water Slurry
Water Vessel	V-100	Vessel	1	Water
Hops Boiler + Whirlpool	V-102	Boiler	1	Malt + Water + Hops Slurry
Wort Heater	E-100	Heat Exchanger	1	Malt + Water + Hops Slurry
Fermentor	R-100	Reactor	1	Malt + Water + Hops + Yeast Slurry
Bright Tank	V-103	Vessel	1	Malt + Water + Hops + Yeast Slurry
Keg-Filling Station	K-100	Packaging	1	Malt + Water + Hops + Yeast Slurry
Centrifugal Pumps	P-100, P-101, P102	Mass Transfer	3	Water+Wort+Beer

PROCESS AND INSTRUMENTATION DIAGRAM (P&ID)

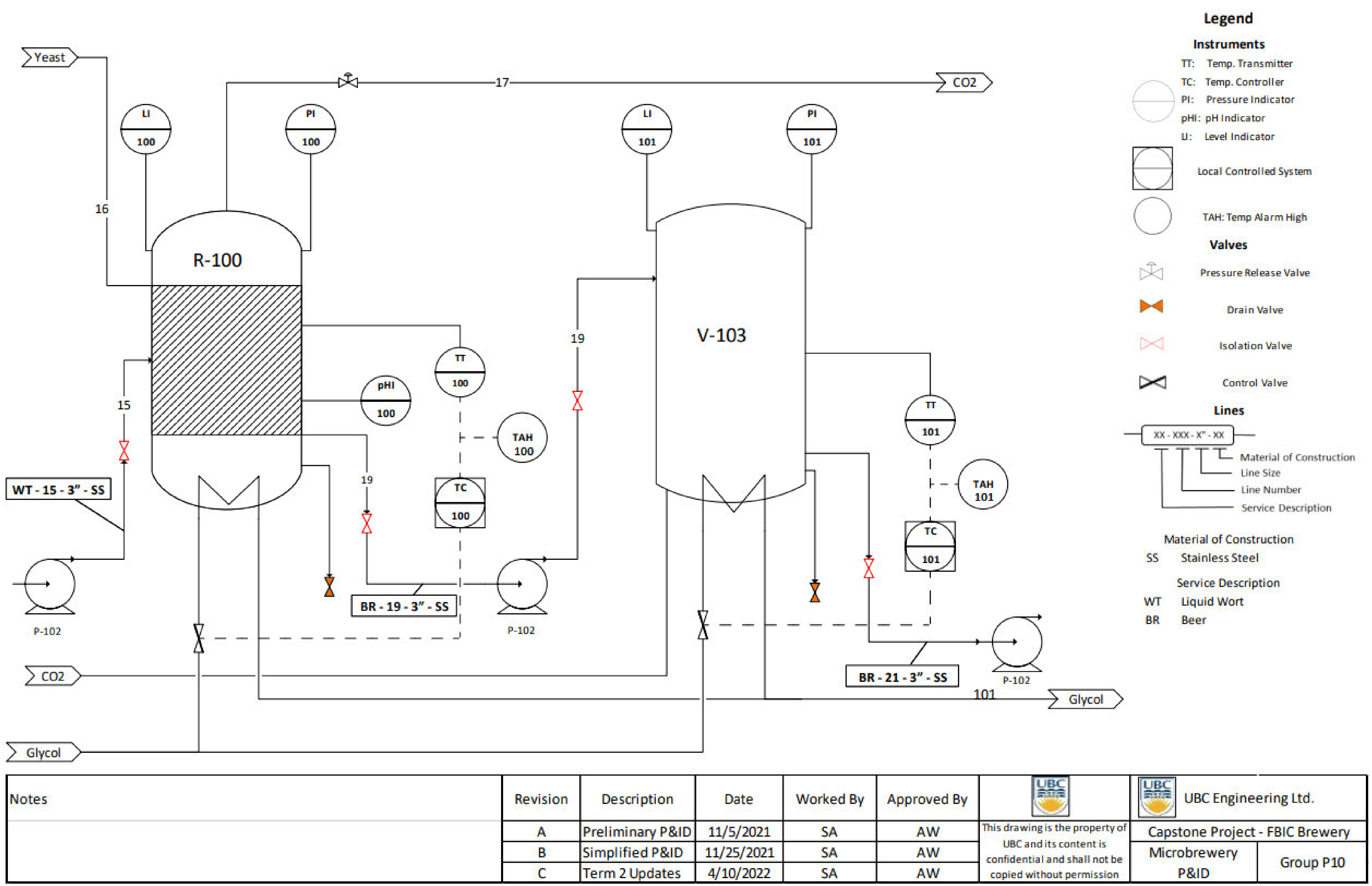


Figure 3: P&ID

P&ID CONTROL LOOP NARRATIVE

CONTROL SYSTEMS

Two feedback control loops will be implemented for the process. Simple control strategies are used because the process is a small-scale batch process.

R-100 (Fermentation Tank) Temperature Control Loop

With beer production being a biological process, controlling the tank temperature throughout the fermentation process is essential. The temperature is controlled for optimum yeast metabolism. The controlled temperature range varies depending on the desired type of beer. For this process, the temperature of the fermentation tank is measured by a temperature transmitter (TT 100). Depending on whether the measured value is higher or lower than the operator-set temperature range, the transmitter will send an electric signal to the temperature controller (TC 100) to either increase or decrease the amount of energy removed through the cooling coils.

V-103 (Bright Tank) Temperature Control Loop

Once the beer has been fermented for a certain amount of time, the yeast and other impurities are settled, and the finished beer is sent to the bright tank, ready for further packaging. The beer is kept at a cool temperature before further packaging, and this is done using a similar control loop as the fermentation tank. The vessel’s temperature is measured by a temperature transmitter (TT 101), and this signal is sent to the vessel’s temperature controller (TC 101), which increases or decreases the amount of energy removed through the cooling coils, depending on the operator set-point.

Isolation Valves, Drain Valves, and Maintenance Access

Isolation valves are mainly installed on pipe streams coming in and out of the tanks that contain non-gaseous components. The presence of isolation valves also allows maintenance on pipelines without potential contamination of the product in the tanks. These pipelines are removable hoses that are going to be connected to the main valve control board. In addition, drain valves are installed after each isolation valve on the pipeline, as well as at the bottom of the tanks. Their installation allows for more straightforward methods of disposal if required.

Equipment Protection and Control Safety Logic

As this is a brewing process at a smaller scale of production, the accumulation of hazardous levels of carbon dioxide is unlikely, nor are high pressures within tanks achieved. However, pressure transmitters are installed on the tanks and an outlet stream of carbon dioxide gas to allow for monitoring. In addition, pressure relief valves are installed on gaseous streams to allow for easy release of any build-up pressure that may occur during the process.

Pipe Specifications

Beer can be considered a Newtonian liquid, and thus 3” stainless steel pipes will be used throughout the brewery. Steel pipes may be used for the transport of water from the water vessel throughout the brewery house, as well as for any waste effluent. Furthermore, polyvinyl chloride pipes (PVC) will be used for lines containing the excess carbon dioxide and carbon dioxide for carbonation, as it is a cheaper alternative to stainless steel at lower operating pressures. Polypropylene-R or Aquatherm pipes are commonly used for cooling systems in breweries [8].

Control Loop Narrative

Table 4: Control Logic Narratives

Control Logic Narrative: Fermentation Tank (R-100)	
Description	Temperature of the fermentation tank is adjusted to maintain tank temperature at 20°C.
Control Loops	TT100 measures the tank temperature and TC100 adjusts the flow control valve of the glycol stream.
Alarms	A high temperature alarm (TAH 100) is used to prevent the tank from reaching too high of a temperature such that it disrupts fermentation.
Trips	N/A

Control Logic Narrative: Bright Tank (V-103)	
Description	Temperature of the bright tank is adjusted to maintain tank temperature at 10°C.
Control Loops	TT101 measures the tank temperature and TC101 adjusts the flow control valve of the glycol stream.
Alarms	A high temperature alarm (TAH101) is used to prevent the bright tank from reaching too high of a temperature such that it reduces the quality of the final product.
Trips	N/A

PLANT LAYOUT

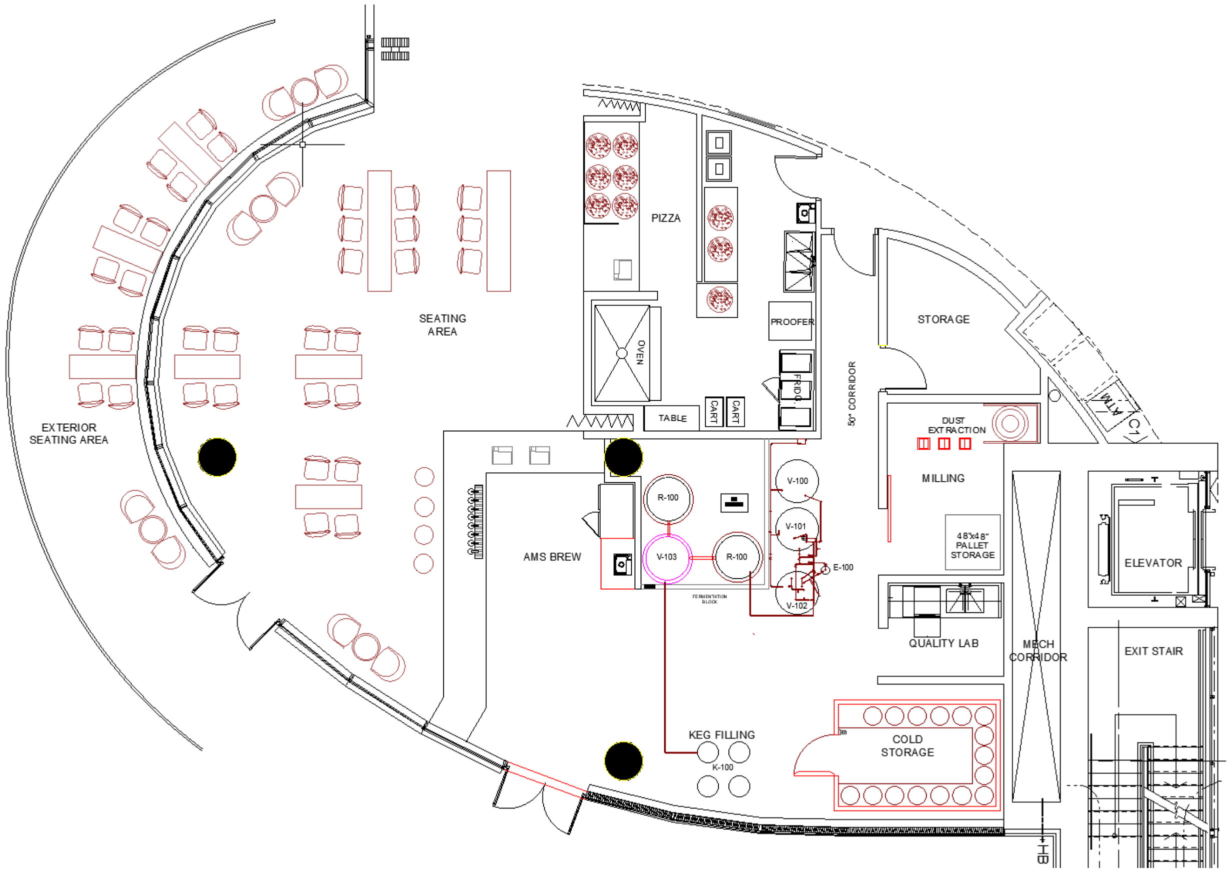


Figure 4: Plant Layout

The plant will be located on the University of British Columbia campus, specifically inside the AMS student nest on the ground floor south side of the building. The building is accessed via the University Boulevard road or the East mall pedestrian road. The blueprint and the plant area are provided by the sponsor of the project [9], Michael Kingsmill from the AMS. The space utilization was then completed by adding the equipment and dividing the area available accordingly; above is figure 4, which shows the completed plant layout of the project. The area will be split into two parts, a seating area and the backroom area. The seating area is divided into an interior and an exterior part. The backroom is more complex, having a quality lab, storage, fridge, milling room, fermenting block, and the brewhouse. The microbrewery offers four access points in total, 2 for the seating area and 2 for the back storage and brew area. Each area has one door connecting them to the rest of the building and one door that exists outside the building. One access point is a loading zone located on the south of the plant, and it comes with two doors that can fully open and offers a sufficient opening to fit the equipment and material.

Most of the equipment (R-100, V-100, V-101, V-102, and V-103) needed to start the brewing is placed in the middle of the backroom area in the fermentation block, and that is to allow for the beer to be sent out to other stations without having to cross the whole facility and minimize tripping hazards. The fermentation block is enclosed with a curb to contain any spillage. This drainage curb is meant to direct all of the spilled liquid into the sewage system, preventing possible hazards. The milling station is placed in a separate room equipped with a dust extraction system as milling barley produces a lot of fine particles that can be carried around by air; the room has a sliding door not to block the corridor in the back room. The keg filling station is placed next to the fridge to cool the kegs as soon as they are filled. A ventilation system is implemented all over the plant to ventilate the area as there will be steam buildup and will humidify the surrounding air, which can damage walls and offer an unpleasant environment. In case of a fire, the facility is equipped with fire extinguishers and has full sprinkler coverage; for evacuation, the two doors on the south side of the plant connect immediately to the outside as it is located on the ground floor.

HAZARD AND OPERABILITY ANALYSIS (HAZOP)

Hazard and Operability Analysis (HAZOP) is a structured and systematic technique for system examination, and risk management was performed on a micro-brewery to identify strategies for risk management.

In the CHBE Capstone course, in order to ensure an in-depth analysis and to simulate the rigour with which an actual HAZOP is conducted, it is recommended to pick only one node and focus on it rather than perform HAZOP for the entire process. However, in this project, HAZOP was performed on the whole process.

A variety of deviations could happen, including flow, temperature, leakage, pressure, etc. These hazards compromise employee safety and can jeopardize the entire product of the process, which is beer. Through these analyses, the causes and consequences are analyzed carefully for each deviation to realize the best practical safeguards and prevent any hazards from occurring by implementing alarms, control systems, and frequent inspections.

As part of the analysis, a risk factor is applied to each deviation based on the severity and the likelihood of the hazard. Accordingly, by studying the existing safeguards, the risk of each deviation is analyzed and reported. As a result, due to the existing safeguards, the risk rank for most of the deviations was low, and the only risk which ranked medium was "Workplace Safety Hazard" due to the high humidity produced by the process, which can be lowered by installing ventilation.

Deviations in the system can potentially lead to negative consequences. The consequences associated with a brewery can be either a leakage/rupture form or batch contamination. The deviations leading to leakage can happen for a variety of different reasons, including pipe connection issues, valve problems, drain clogging, or pump failure, while the deviations associated with batch contamination are incorrect amounts of water, a heating/cooling system malfunction, or a misdirected flow.

Several recommendations and required safeguards have been provided by studying the deviations and their consequences carefully. Some of the required safeguards include:

1. *Utilizing pipe clamps and check valves*: clamps are an efficient and tidy way to restrain, secure and guide tubing or conduit for a range of purposes. Moreover, check valves would help to prevent backflow in the process.

2. *Labeling the pipe*s: proper labeling can prevent incorrect connections.

3. *Installing level control system*: level control systems halt excessive water in the system. They can also prevent bad batches due to wrong concentrations while reducing wastewater generated.

Besides the above-mentioned required safeguards, several recommendations have been suggested to lower the risk as much as possible such as maintaining and inspecting the plant frequently, isolating pipes, and regularly performing quality control on the batches. The HAZOP analysis conducted for this process showed a majority of low (L) risks that were evident in the design. The reasoning behind this is that the potential hazards found either had a low frequency of occurring, or a low severity of subsequent consequences.

STARTUP AND SHUTDOWN PROCEDURE

For this project, the start-up shutdown procedure is replaced by an operating procedure. Beer production is a batch process where equipment is started and shut down sequentially. Therefore, an operating procedure is more relevant than a start-up and shutdown procedure. The emergency shutdown procedure is not included as it lies outside the scope of this project.

PLANT STARTUP

This process is started from front to back as this is a batch process.

- The Hot water storage tank should have the water at room temperature before the process starts.
- The barley grains should be milled with M-100.
- The grains from M-100 to mash tun (V-101) will be transferred by hand
- Pump (P-100) the water from the storage tank (V-100) to the mash tun/lauter tun (V-101)
- Turn on mash tun (V-101) and adjust the temperature controller. The temperature of the mash/lauter tun is set to 70 degrees Celsius
- Pump (P-100) the wort from the mash tun (V-101) to the hops boiler/whirlpool (V-102)
- Connect the water pipe from the heat exchanger (E-100) to the water vessel (V-100). The heat capacity of wort can be assumed to be the same as water and the amount of room temperature water can be calculated from that.
- Pump (P-100) the wort to hops boiler/whirlpool (V-102)
- Turn on the heating jacket for V-102 and set the temperature to 95 degrees Celsius.
- Turn on the heat exchanger (E-100) and pump (P-101) the room temperature water from the water storage tank (V-100).
- Transfer wort from V-102 to fermentor (R-100) through the HX using the pump (P-102). From start to this step should take 8 to 10 hours.
- Add yeast to the fermentor and turn on the cooling jacket. The reactor needs to be cooled with glycol circulating through the jacket and the temperature will be set between 15 to 20 degrees Celsius depending on the beer type. The fermentation step takes 2 weeks.

- Transfer beer from fermenter to bright tank (V-103) using a pump (P-102). The beer needs to be aged for 2 days in a bright tank.
- Carbonate the bright tank using carbon dioxide tanks.
- After completion transfer beer from the bright tank (V-103) to the keg-filling station (K-100) using a pump (P-102) for packaging of the beer

PLANT SHUTDOWN

The brewing is a batch process and due to the logistics of microbrewery any equipment which is not in use will be turned off as soon as possible. For example, once the wort reaches the fermenter every other equipment on the hot side of the process can be turned off.

- After the milling is done the station (M-100) can be turned off and the machinery can be cleaned off.
- After the pumping process is done, clean all pumps (P-100, P-101, P-102) by pumping clean water through them.
- The mash tun/lauter tun (V-101) can be turned off and the cake bed formed at the false bottom can be removed and disposed of.
- After the wort is transferred to the fermenter (R-100), the hops boiler/whirlpool (V-102) can be turned off along with its heating jacket.
- Hops boiler/whirlpool (V-102) should be cleaned once it cools off to room temperature.
- Turn off the heating jacket for the reactor (R-100) after the beer is pumped to the bright tank (V-103).
- Remove any yeast left in the tank and clean out the fermenter after shutdown.
- Turn off carbon dioxide tanks after checking all fittings.

- After the beer is filled to the kegs (K-100) then the bright tank pressure valves should be opened to ensure that there is no pressure build-up inside the tank.
- Turn off all water pipes.
- Ensure all kegs have been stored safely in the fridge.
- Ensure any spillage that may have occurred has been cleaned and equipment is ready to use for the next batch.

CIP PROCEDURE

The CIP procedure is done at the end of every batch. It is done to clean and sanitize the machines, without disassembly, in preparation for the following batch.

- A pre-rinse with water, or a slightly caustic solution, is done throughout the system to wash out the majority of the solids that have been left behind.
- A caustic (NaOH) rinse is followed to break down the organic compounds and can be recaptured again to be reused for up to a few cycles.
- The system is then rinsed again with water, which can be recaptured for future CIP usage.
- An acid (H_3PO_4) rinse is followed to remove any beerstone build-up, which is a precipitate that is formed due to the caustic rinse, hard water minerals (i.e. calcium, magnesium), and proteins in the form of amino acids.
- The system is once again rinsed with water, which can also be recaptured for future CIP usage.
- A final sanitizing rinse is done using peracetic acid to prepare the system for the next batch.

ECONOMIC ANALYSIS

TOTAL CAPITAL EXPENDITURE (CAPEX)

EQUIPMENT COST BREAKDOWN

For this project, all values are reported in Canadian Dollars (CAD). The exact equipment cost is confidential; therefore, approximate costs are provided for the equipment breakdown. The cost data was received from the project sponsor and sourced from an equipment manufacturer. Table 5 below shows an approximate equipment breakdown.

Table 5: Equipment Cost Breakdown

Equipment Description	Number of Equipment	Total Estimated Cost (CAD)
Mash/lauter tun	1	60,000
Hops Boiler	1	40,000
Controllers and Valves	-	20,000
Pumps	3	15,000
Milling Station	1	25,000
Fermenters	2	30,000
Bright Tank	1	15,000
Temperature Control System	-	25,000
Keg Station	1	30,000
Miscellaneous	-	40,000
Total	10	300,000

TOTAL CAPITAL EXPENDITURE (CAPEX)

Capital expenditure is a combination of direct and indirect costs. The costs are estimated using Lang factors for a solid-liquid processing facility. The Lang Factor is an estimated ratio of the total cost of creating a process within a plant to the cost of delivered equipment. The delivered equipment cost is 110% of the purchased equipment cost. However, not all the costs identified in the Lang factor apply to this microbrewery. For example, cost estimates for yard improvements, land and service facilities do not apply as it is a brownfield project with different requirements. Total direct plant (TDP) costs account for delivered equipment, installation, instrumentation & piping, electrical, and building services. TDP accounts for 55% of the CAPEX. Indirect costs account for 16% of the CAPEX and include engineering services and construction costs. Working capital is approximated as ~15% of the CAPEX. Table 6 has a detailed breakdown of CAPEX.

Table 6: Total Capital Expenditure - CAPEX

	Lang Factor (Solid-Fluid)	**Cost (CAD)**
Direct Costs		
Purchased Equipment	-	300,000
Delivered Equipment	1	330,000
Installation	0.39	128,700
Instrumentation	0.13	42,900
Piping	0.31	102,300
Electrical	10	33,000
Building and Services	29	95,700
Total Direct Plant Cost	222	732,600
Indirect Costs		
Engineering and Services	32	105,600
Construction Expenses	34	112,200
Total Indirect Costs	-	217,800
Total Direct and Indirect Costs	288	950,400
Contractors Fee (5%)	18	59,400
Contingency (10%)	36	118,800
Fixed Capital Investment (FCI)	342	1,128,600
Working Capital (15% TCI)	74	205,920
Total Capital Investment	416	1,372,800

ANNUAL OPERATING COST

The total operating costs are estimated to be $210,000. Operational costs are calculated on an annual basis for this project. The annual cost is estimated assuming that four batches are produced monthly. Raw materials, utilities, operation labor, and revenues are calculated individually, while the other values are calculated using estimates from literature resources (10). For maintenance and operating supplies, the lower end of the estimation chosen as that is assumed to be more accurate because the maintenance process is relatively simple. These costs mentioned above are part of the direct production costs and account for 58% of the OPEX. Table 7 below shows a breakdown of the annual operating costs.

Table 7: Annual Operating Cost - OPEX

Description	Calculation Basis	Cost (CAD)
Raw Materials	Calculated from Mass Balance	11,025
Operation Labour	Calculated from avg cost	81,738
Utilities	Calculated from avg brewery energy usage	5,313
Maintenance and Repairs	2% of FCI	22,572
Operating Supplies	10% of Maintenance & Repairs	2,257
Direct Production Cost (DPC)		**122,905.20**
Local Taxes	2% of FCI	22,572
Insurance	Avg annual BC brewery insurance	15,000
Fixed Charges		**37,572**
Plant Overhead Costs	10% of TPC	**21,115**
Manufacturing Costs	Sum of DPC, Plant Overhead, Fixed Charges	**181,593**
Administrative Costs	4% of TPC	8,446
Distribution and Selling Costs	10% of TPC	21,115
General Expenses		**29,562**
Total Product Cost (TPC)		211,154

Yeast, hops and malt contribute to the cost of the raw materials, which is estimated to be $11,000. The cost of water required is calculated as part of utilities. The amounts are determined using the mass balance in the PFD. Three principal utilities are used for the brewing process that is: electricity, natural gas, and water. The cost estimate for water used here is the same as raw material water which is why the cost is only included in utilities and not as part of raw materials. Only two operational workers are required for the process, one full-time and one part-time. The full-time brewmaster will be available to oversee the operation each working day. The part-time brewmaster will be working on brewing days. A detailed breakdown of each component can be found in appendix F.

REVENUE

The revenue is calculated on four batches per month basis. The estimated selling price for one litre of beer is set at $8. This selling price is estimated from a cost comparison across other BC craft beers in the target market. Given that each batch is 1000L, it is assumed that roughly 5% will be lost in packaging and spillages. Therefore, the final product volume is estimated to be 950L of beer per batch. The estimated monthly and annual revenue is $30,000 and $360,000, respectively.

ECONOMIC ASSESSMENT

Initial gross revenue is expected to be approximately $360,000, with an initial net profit of $150,000. It is assumed that the facility will operate at a fixed capacity for the next ten years, with a salvage value of $30,000 at the end of the 10-year period, which is estimated as 10% of the equipment cost. The payback period is estimated to be seven years, with an internal rate of return of 12%. Figure 5 below shows the expected cash flow diagram for the 10-year period.

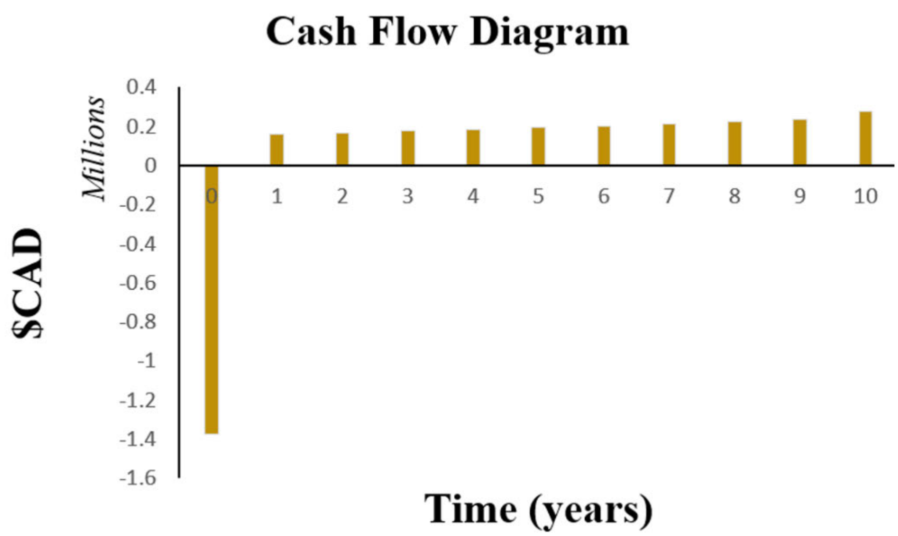


Figure 5: Cash Flow Diagram

ENVIRONMENTAL ANALYSIS

The Microbrewery is a brownfield project as the brewery will be built on a pre-existing area in UBC AMS Student Nest. As it is mentioned in the plant layout, there are two entrances to transport the equipment for this project, with one of them being an exit to the outside of the building. If needed, the equipment can be transported from the shipping/receiving area of the UBC AMS Student Nest and then received through the inside of the building entrance. These entrances can also be seen in the figure below.

The Province of British Columbia has regulations in place to review projects which will be built inside the province under the BC Reviewable Projects Regulation. This particular act defines what type of projects and discharges are required to be reviewed by BC, and the microbrewery waste streams are well within the regulations. Brewing is also not a directly specified field under this Environmental Assessment Act of Reviewable Projects Regulation. While this project is not under the reviewable act, it must follow the municipal bylaws and provincial general regulations such as

Sewerage System Regulation and Greenhouse Gas Industrial Reporting and Control Act. This project also needs to follow the Fermentation Operations Bylaw of Metro Vancouver.

The permits required for this brewery are the Manufacturer's License which is required to produce alcoholic beverages, and a liquor permit is needed to sell the said alcoholic beverage. While they are not necessarily environment-related, there are still two permits required for this facility's operation. In addition, there are three main waste streams which are solids, liquids, and gas.

GAS EMISSIONS

Carbon dioxide is produced during the fermentation process, and the amount of carbon dioxide produced during a batch is 48 kilograms. This carbon dioxide is considered biogenic, and thus it does not need to be reported according to BC regulations. Furthermore, the carbon dioxide amount which requires reporting is 10000 tonnes according to Greenhouse Gas Reporting Regulations[15], and this brewery design only produces 2 tonnes of carbon dioxide per year.

Another consideration is the carbon dioxide production from using natural gas to heat jacketed equipment. 3.4 GJ is the amount of energy that is needed from natural gas combustion[12], and the amount of carbon dioxide which is released from this act is estimated to be around 53 kilograms per batch (2.5 tonnes per year) [11]. This is also within the regulations, and it does not need to be reported to the provincial government.

SOLID WASTE

Three types of solid waste streams exit the project. The spent malt grains (45 kg/batch) from the mash and lauter tun, spent hops (4kg/batch) from the hops boiler/whirlpool vessel, and the spent yeast (10kg/batch) from the fermenter. The best and cheapest way to dispose of these solids for a microbrewery is to partner with farms to arrange pick-ups or drop-offs. The farms use these solids as animal feed which is also a more sustainable option than composting. Otherwise, these solids would need to be disposed of as organic waste, which would also cost some extra money.

LIQUID WASTE

There are four waste streams from the process for liquid: wastewater from the lautering process, hops boiling process, cooling water from the heat exchanger, and, in some instances, batch disposal. Each of these processes has its own rules regarding its disposal.

The cooling water from the heat exchanger will be recycled as much as possible to the water storage tank; however, the excess amount will need to be discharged into the sewage system. The recycled amount of water is 963 kg/batch. The cooling water that needs to be disposed of is 1139 kg/batch. This water is subject to Vancouver Sewage Bylaws [13] and Fermentation Operation Bylaws [14]. Cooling water is free from solids and contaminants, and thus it is allowed to be discharged into sewage according to Sewage Bylaws. According to Fermentation Operation Bylaws, any discharge between 200 to 2000 litres in a single day requires the brewery to notify the city about the discharge. The wastewater from the hops boiling and lautering process can be disposed of on different days if needed. Otherwise, the brewery would need to apply for city permission to dispose of all the wastewater on the same day. This is also true for other liquid disposals from these processes, as these process waste streams do not exceed this amount. It is also recommended that another water storage tank be purchased after the operation starts to store more of the cooling water to decrease the water usage of the process.

Table 8: Liquid Waste Streams

Waste Liquid	Amount (kg/batch)
Batch Disposal	1007 (beer)
Wastewater from lautering process (from slurry and inside the vessel)	1535 (wort)
Wastewater from hops boiling process(includes condensed steam)	859 (wort)

Batch disposal and wastewater from the other process are also within the guidelines which are discussed for the cooling water; however, these waste streams are also subject to additional regulations under the Fermentation Operation Bylaws. These streams can be seen in table 8. The maximum suspended solids amount which can be discharged is 600 ppm [K-4], and the typical brewery wastewater will have around 50 to 500 ppm [16]. These liquids will need to be tested for pH before disposing of them, as disposal's pH allowance is between 5.5 to 10.5. Therefore, typically the wastewater should be around 6 to 7 pH. For the instances where pH is found to be more acidic, the waste can be neutralized in the containers with food-grade approved bases such as baking soda and calcium carbonate [17].

Other than the primary process itself, the CIP process also produces wastewater during the cleaning of the equipment. The caustic chemicals (specifically sodium hydroxide and phosphoric acid) are used to create a mixture that is used to wash the equipment. The rinse water needs to be tested for pH before it can be disposed of due to the Sewage and Fermentation Operations Bylaws.

RECOMMENDATIONS

IMPLEMENTED RECOMMENDATIONS FROM TERM 1

2-Vessel CIP equipment is recommended instead of manual cleaning because, according to resources, automated cleaning saves up to %40 of water during the cleaning phase [16]. The plant layout is designed to accommodate the equipment as well. The brewery is also designed with a 2-vessel brewhouse instead of a 3-vessel brewhouse to allow more space to work for the brewmaster and to accommodate CIP equipment.

FUTURE IMPLEMENTATIONS

The following brewing schedule is recommended for the brewery. The optimal setup of having two fermenters and one bright tank provides four batches of thousand litres, in total approximately 4000L per month.

Batches are added alternatively for fermenting after every two weeks. A gap of two days is given to perform CIP. A similar procedure is implemented for the bright tank, a batch is produced every week, and sufficient time is left for cleaning. It should be noted that during the first month after equipment setup, there will be a wait time of two weeks for the initial batch brew, but for subsequent months four batches per month can be expected.

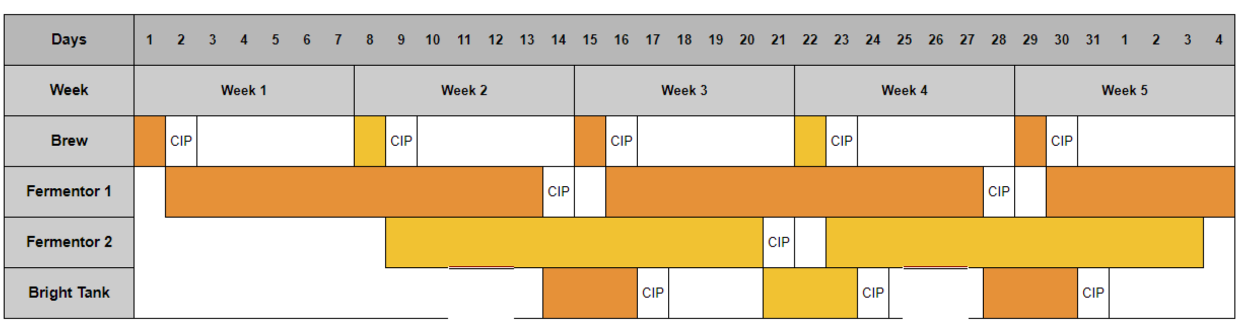


Figure 6: Recommended Brewing Schedule

Another recommendation that group P-10 suggests is to look into adding another water storage tank to recycle more of the cooling water that is used on the heat exchanger. The current design tries to recycle as much as possible with the existing water tank; however, the size of the water tank is the limiting factor. Initially, all of the water inside the water tank is used as more water to the tank is added from the city system as needed throughout the process. Because of that, more water is in the process than what that one water storage tank can hold. According to resources, when considering the disposal of spent material, it is feasible to reuse this organic waste as biomass [18] for energy generation or fertilizers for crops.

An additional small storage tank can be added as part of the CIP system to collect the CIP water. The final rinse water for equipment cleaning generated during CIP can be collected in the storage tank. This water can be used for the pre-rinse stage for the following equipment. This practice alone can reduce the water used during CIP by 40% [16]. The tank size should be large enough to prevent overflow by ensuring the volume of water of the final rinse and pre-rinse is approximately the same.

CONCLUSION

This term, group P-10 has performed the HAZOP study, startup and shutdown procedure, environmental analysis and economic assessment for the process. In addition, equipment sizing has been done this term along with the final energy, and the mass balances have been prepared for the current process design, which produces 1000L of beer per batch and four batches per month. Control narratives have also been updated for the fermenters and bright tank.

The final design of the AMS microbrewery that has been designed by P-10 is presented in this report. Final iterations have been made upon the analysis of economic and sustainable process steps. In doing so, a feasible waste management system for both solid and liquid waste has been designed. In terms of waste management, P-10 has worked on recycling the spent grains from the lauter tun and the spent yeast from the fermentation tank. The goal is to recycle solid waste into reusable materials and energy sources such as animal feed, biomass, and fertilizers. In terms of water treatment, the aim is to recycle the water using CIP techniques and cooling water from the heat exchanger. The final design's environmental and economic analyses have been done, along with the optimization of the design, hazard, and operability. Apart from the implemented solutions of waste management and economic surplus, multiple recommendations have been provided to improve the overall process.

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Professor, UBC CHBE

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Mr. Sergio Berretta,

Adjunct Professor, UBC CHBE

- Provided feedback

Mr. Michael Kingsmill

AMS Executive, UBC

- Describe stakeholder requirements
- Provided feedback on progress

Dr. Kerwin Wong

Brewer, Slow Hand Beer Company

- Gave us a tour of the brewery
- Provided advice on our project

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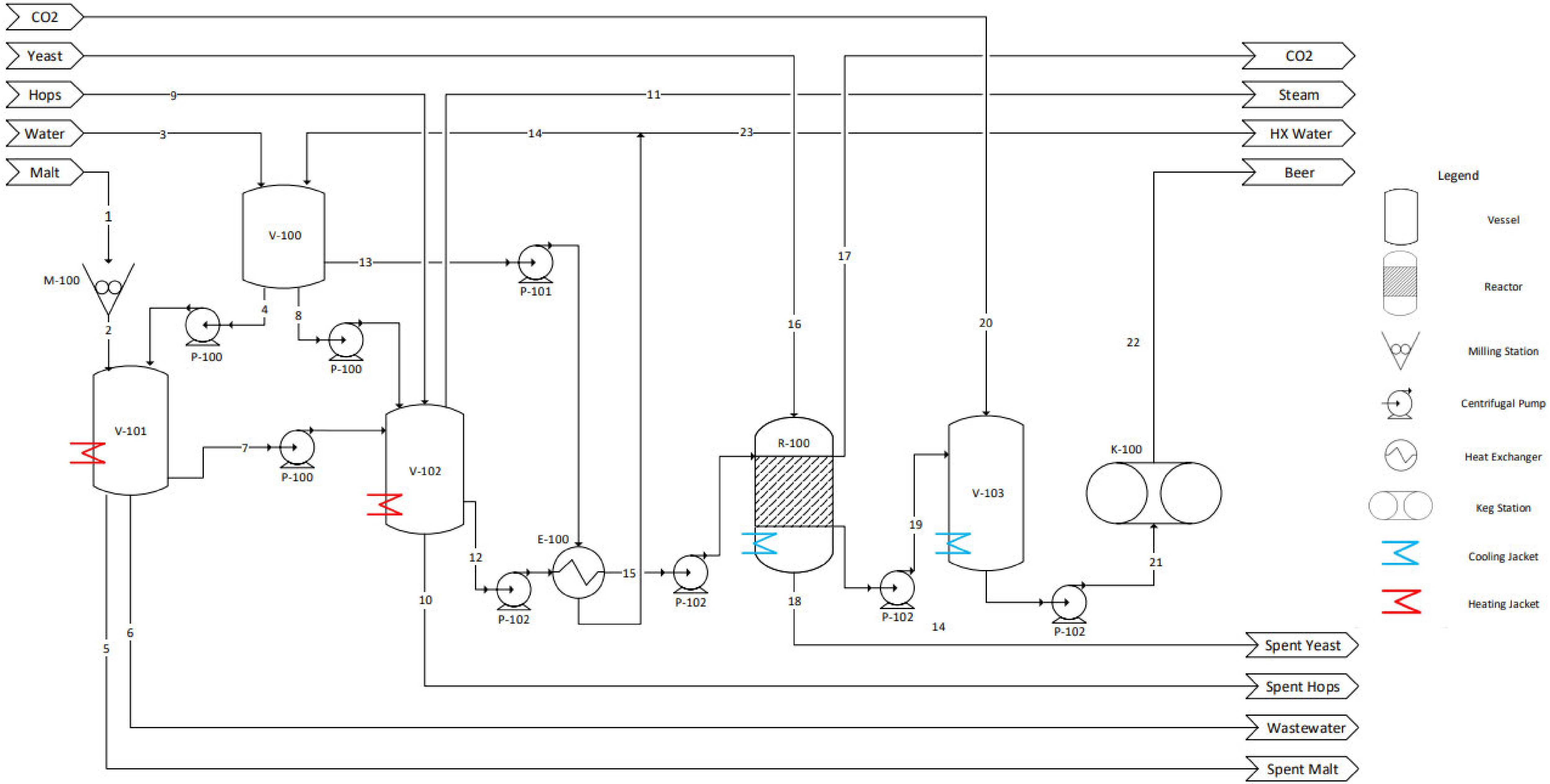
APPENDIX A: PFD & P&ID

PROCESS FLOW DIAGRAM (PFD)



Notes	Revision	Description	Date	Worked By	Approved By		UBC Engineering Ltd.	
	A	Preliminary PFD	11/5/2021	SA	AW	This drawing is the property of UBC and its content is confidential and shall not be copied without permission	Capstone Project - FBIC Brewery	
	B	Simplified Proces	11/25/2021	SA	AW		Microbrewery Process Flowsheet	Group P10
	C	Term 2 Updates	4/10/2022	SA	AW			

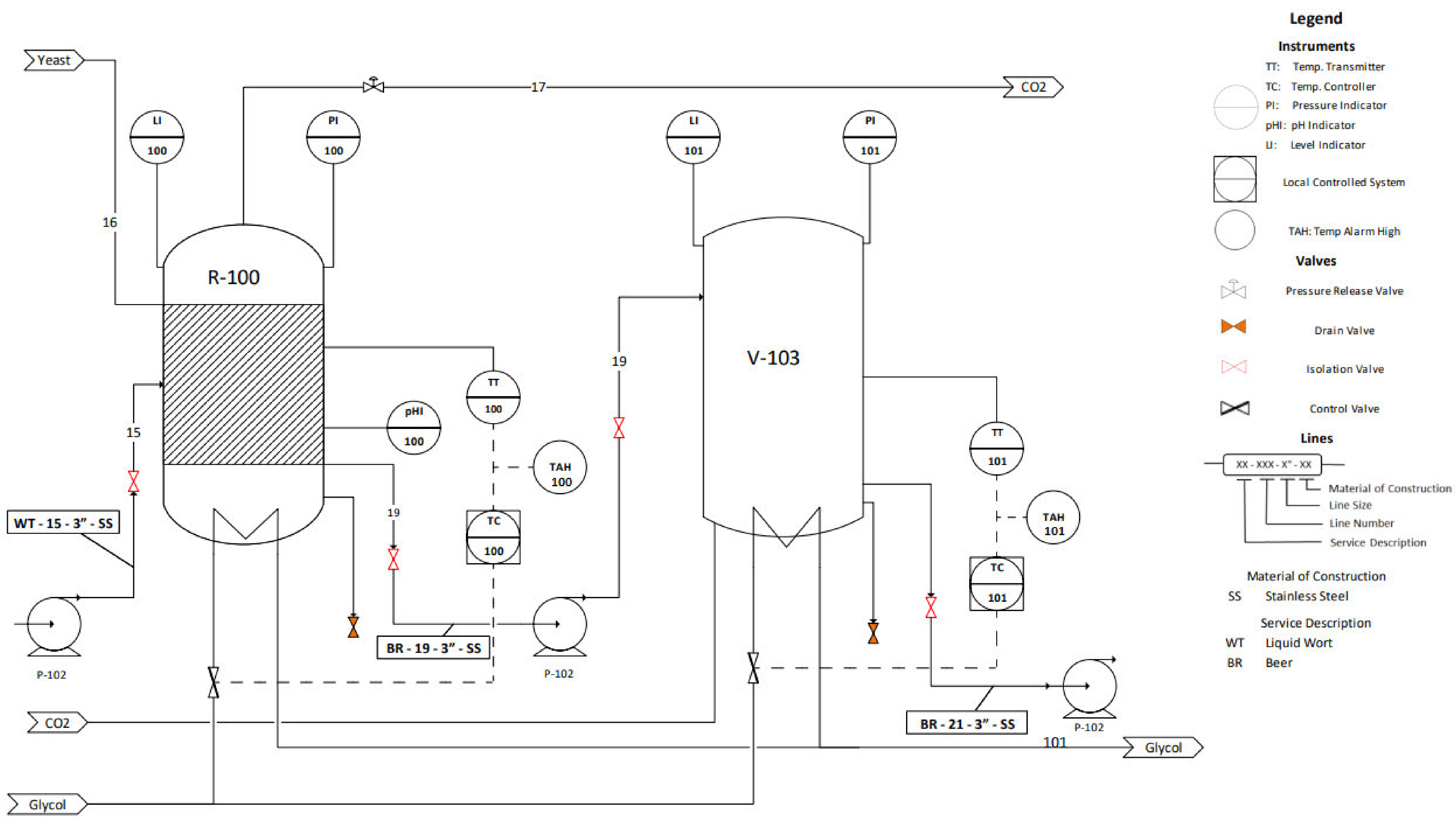
STREAM TABLES

Table 9: Stream Table and Mass Balance

Stream Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
From	Malt	M-100	Water	V-100	V-101	V-101	V-101	V-100	Hops	V-102	V-102	V-102	V-100	E-100	E-100	Yeast	R-100	R-100	R-100	CO2	V-103	K-100	E-100
To	M-100	V-101	V-100	V-101	Spent Malt	Waste water	V-102	V-102	V-102	Spent Hops	Steam	E-100	E-100	V-100	R-100	R-100	CO2	Spent Yeast	V-103	V-103	K-100	Beer	HX Water
Temperature(C)	25	25	25	25	70	70	70	25	25	95	100	95	20	57.5	20	20	20	20	20	10	10	10	20
Pressure(atm)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Mass flow rate (kg/batch)	285	285	4,394	1,650	228	1,353	1,901	57	4	740	172	1,051	2,102	963	1,051	10	48	10	1,018	2.2	1,007	1,007	1,139
Component mass flowrate (kg/batch):																							
Malt	285	285	0	0	45	0	239	0	0	48	0	191	0	0	191	0	0	0	95	0	95	95	0
Hops	0	0	0	0	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
Yeast	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0	10	13	0	0	0	0
Water	0	0	4,394	1,650	183	1,353	1,663	57	0	688	172	860	2,102	963	860	0	0	0	860	0	860	860	1,139
CO2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	48	0	2.3	2.2	5	5	0
Alcohol	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	48	0	48	48	0

(green)	Inlets
(red)	Outlets

PROCESS AND INSTRUMENTATION DIAGRAM (P&ID)



Notes	Revision	Description	Date	Worked By	Approved By		UBC Engineering Ltd.	
	A	Preliminary P&ID	11/5/2021	SA	AW	This drawing is the property of UBC and its content is confidential and shall not be copied without permission	Capstone Project - FBIC Brewery	
	B	Simplified P&ID	11/25/2021	SA	AW		Microbrewery P&ID	Group P10
	C	Term 2 Updates	4/10/2022	SA	AW			

APPENDIX B: SAMPLE CALCULATIONS

Energy Balance Calculations:

$$Q = m*c*\Delta T$$

Where
Q = heat energy in kJ
m = Mass of material in kg
c = heat capacity in kJ/kg.K
ΔT = change in temperature in

$$Q = mL$$

Where
Q = heat energy in kJ
m = Mass of material in kg
L = latent heat of material in kJ/kg

Mash -Lauter Tunl (V-101)

		Input		Output		
Material	Heat Capacity (kJ/kg.K)	Quantity (kg)	Temperature ©	Quantity (kg)	Temperature ©	Energy Difference (kJ)
Malt	2	228	25	228	70	18878
Water	4	1320	25	1320	70	248886
					Total	**267764**

Utilities	Latent Heat (kJ/kg)	Quantity (kg)	Temperature ©	Quantity (kg)	Temperature ©	Energy Difference (kJ)
Steam (1bar)	2258	119	100	1	100	**267764**
					Total	-

Hops Boil (V-102)

Material	Heat Capacity (kJ/kg.K)	Input Quantity (kg)	Input Temperature ©	Output Quantity (kg)	Output Temperature ©	Energy Difference (kJ)
Malt	2	228	70	228	95	10488
Water	4	1320	70	1320	100	165924
Hops	2	4	25	4	95	456
					Total	**176868**

Utilities	Latent Heat (kJ/kg)	Quantity (kg)	Temperature ©	Quantity (kg)	Temperature ©	Energy Difference (kJ)
Steam (1bar)	2163	82	134	2163	134	**176868**
					Total	**176868**

Fermentor (R-100)

Material	Heat Capacity (kJ/kg.K)	Input Quantity (kg)	Input Temperature ©	Output Quantity (kg)	Output Temperature ©	Energy Difference (kJ)
Wort:						
Malt	2	153	20	153	20	
Water	4	688	20	688	20	-
Hops	2	0	20	0	20	
Yeast	4	8	20	8	20	
					Total	0

Heat Exchanger (E-100)

Material	Heat Capacity (kJ/kg.K)	Input Quantity (kg)	Input Temperature ©	Output Quantity (kg)	Output Temperature ©	Energy Difference (kJ)
Purified water	4	770	25	770	85	193578
Wort:						
Malt	2	153	95	153	20	-21114
Water	4	688	95	688	20	-216204
Hops	2	0	95	0	20	-19
					Total	**-43759**

Bright Tank (V-103)

Material	Heat Capacity (kJ/kg.K)	Input Quantity (kg)	Input Temperature ©	Output Quantity (kg)	Output Temperature ©	Energy Difference (kJ)
Wort:						
Malt	2	76	20	76	10	-1391
Water	4	688	20	688	10	-28827
Hops	2	0	20	0	10	-3
Yeast	4	8	20	8	10	-285
CO2	1	2	10	4	10	0
					Total	**-30506**

Utilities	Latent Heat (kJ/kg)	Quantity (kg)	Temperature ©	Quantity (kg)	Temperature ©	Energy Difference (kJ)
Ethylene Glycol	800	38	15	25	15	**30506**
					Total	-**30506**

Line size calculation : Liquid Sample Calculation

Media Inlet to Fermentor : R-100

$V = 4.1\,m^3$ fill in 15 mins

* The sample calculation will show the methodology applied to all line size calculation

$$Q = V/t = \frac{4.1\,m^3}{900\,s} = 4.556 \times 10^{-3}\ m^3/s$$

Recommended velocity : $v = 3\,m/s$

$$A_p = Q/v = \frac{4.556 \times 10^{-3}\,(m^3/s)}{3\,(m/s)} = 1.5185 \times 10^{-3}\ m^2$$

$$D_p = \sqrt{4 A_p / \pi} = 0.04397\,m \times 39.37\ \frac{in}{m}$$

$$D_p = 1.73 \text{ inches}$$

$Q = m \cdot c \cdot \Delta T$

For Heat Exchanger

95° → 20° cooling required

Wort amount = 1051 kg/batch

assume c is same for wort and water as research shows that they are similar.

→ mid point is 57.5°C ↓ where max cooling happen

$m_c \cdot \not{c} \cdot \Delta T = m_2 \not{c} \cdot \Delta T$

$(1051) \cdot (75°C) = m_2 \underbrace{(57.5 - 20)}_{37.5°C}$

$M_2 = 2102$ kg of water needed

2102 - 963 = 1139 kg has to be disposed of

↓ (963) recyclable amount=

Mass balance for HX

$Q = m \cdot c \cdot \Delta T$

For Heat Exchanger

95° → 20° cooling required

Wort amount = 1051 kg/batch

assume c is same for wort and water as research shows that they are similar.

→ mid point is 57.5°C ↓ where max cooling happen

$m_1 \cdot c \cdot \Delta T = m_2 \cdot c \cdot \Delta T$

$(1051) \cdot (75°C) = m_2 \underbrace{(57.5 - 20)}_{37.5°C}$

$M_2 = 2102$ kg of water needed

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Line size calculation : Liquid Sample Calculation

Media Inlet to Fermentor : R-100

* The sample calculation will show the methodology applied to all line size calculation

$V = 4.1\,m^3$ fill in 15 mins

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Recommended velocity : $v = 3\,m/s$

$$A_p = Q/v = \frac{4.556 \times 10^{-3}\,(m^3/s)}{3\,(m/s)} = 1.5185 \times 10^{-3}\ m^2$$

$$D_p = \sqrt{4A_p/\pi} = 0.04397\,m \times 39.37\,\frac{in}{m}$$

$$\boxed{D_p = 1.73\ \text{inches}}$$

Hilroy

APPENDIX C: EQUIPMENT LIST AND SPECIFICATION SHEET

Malt crusher / Milling station (M-100)

UBC	Data Sheet - Malt Crusher	Equipment Number
	UBC Engineering Ltd - Capstone Project Standard	M-100

Unit Name: Malt Crusher

ISSUED FOR:	Proposal		
SERVICE	Milling the Malt for Brewery		
Malt Crusher Details			
	Length	Width	Height
Dimensions:	600 mm	570 mm	1085 mm
Weight:	150 kg		
Motor Power:	3000 W		
Roller Type:	Double		
Material:	Carbon Steel		
OPERATING CONDITIONS			
	Min	Max	
Capacity:	150 kg/hr	300 kg/hr	
Power	1500 W		
Voltage	280 V		
MATERIAL PROPERTIES			
Description:	Malt		
Moisture Content	Standard		

NO	DATE	REVISION DESCRIPTION	BY	APVD
1	O1/02/2022	FOR QUOTATION	MK	

Reference https://www.alibaba.com/product-detail/Malt-Crusher-TONSEN-Malt-Crusher-Grain_62442170950.html?spm=a2700.galleryofferlist.normal_offer.d_title.5a6f5a0fPgVOMo&s=p

Water Storage Tank (V-100)

	DATA SHEET - TANK	Tank Tag Number
	UBC Engineering Ltd - Capstone Project Standard	**V-100**
PLANT: FBIC Microbrewery	P&ID Number	PROJECT No.

Unit Name: Hot Water Tank

ISSUED FOR: PROPOSAL PURCHASE AS BUILT

SERVICE: **Storage of Hot Water for use throughout Brewery**

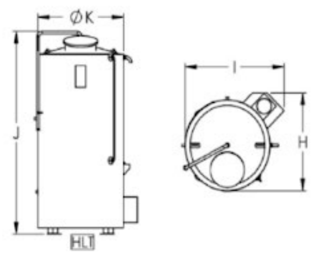
OPERATING CONDITIONS

	MAX	NORM.	MIN.
FLUID TEMPERATURE - C	100	70	25

MATERIAL PROPERTIES

MATERIAL DESCRIPTION: **Water**

DESIGN FLUID DENSITY; **998 KG/M3**



TANK DETAILS

INDOOR OUTDOOR

- DESIGN CONDITIONS -		TANK GEOMETRY -	
		TANK POSITION:	Vertical
		VOLUME - M3:	1.84
MAX DESIGN TEMPERATURE - C	100	ASPECT RATIO (HEIGHT/DIAMETER)	1.1
MIN DESIGN TEMPERATURE - C	-10		
MAX DESIGN PRESSURE - BARA	1.3	MATERIAL OF CONSTURCTION:	304 Food Grade SS
MIN. DESIGN PRESSURE - BARA	0.9		

NO.	DATE	REVISION DESCRIPTION	BY	APVD.
	Feb 1 2022	For quotation purposes	SB	RP

Note for Appendix: The design condition temperatures are determined using the material of construction. The vessel height and diameter are taken from specifications provided by one of the vessel supplier found online, that met the capacity requirements. (Portland Kettle Works)

Mash/Lauter Tun (V-101)

	Data Sheet - Mash/Lauter Tun	Equipment Tag
	UBC Engineering Ltd - Capstone Project Standard	V-101
PLANT: FBIC MICROBREWERY	P&ID NUMBER	PROJECT NUMBER

Unit Name: MASH/LAUTER TUN

1	ISSUED FOR:		☑ PROPOSAL		☐ PURCHASE	☐ AS BUILT	
2	SERVICE:	GRAINS ARE MIXED WITH CLEAN WATER, TO CREATE A MIXTURE CALLED WORT					
3							
10	OPERATING CONDITIONS						
11							
12	Temperature Inlet		25	°C			
13	Temperature Outlet		70	°C			
14	Quantity		1548	kg/batch			
15	Residence Time		60	min			
16	Pressure		1	bar			
17							
18	MATERIAL PROPERTIES				EQUIPMENT DETAILS:		
19							
20	Input Material Content				LOCATION	☑ INDOOR	☐ OUTDOOR
21							
22	Malt	Heat Capacity	2	kJ/kg.K	JACKETED	☑ YES	☐ NO
23		Density	700	kg/m3			
24					SIZE	2 X 15	hL
25	Water	Heat Capacity	4	kJ/kg.K			
26		Density	997	kg/m3			
27							

	NO	DATE	REVISION DESCRIPTION	BY	APVD
28	NO	DATE	REVISION DESCRIPTION	BY	APVD
29	1	Feb 1, 2022	Initial creation	AW	
30					
31					

THE UNIVERSITY OF BRITISH COLUMBIA

Hops boiler/ Whirlpool (V-102)

	DATA SHEET - BOILER/ WHIRLPOOL	Tank Tag Number
	UBC Engineering Ltd - Capstone Project Standard	**V-102**
PLANT FBIC Microbrewery	P&ID Number	PROJECT No.

Unit Name: Hops Boiler and Whirlpool Seperator

ISSUED FOR: PROPOSAL PURCHASE AS BUILT

SERVICE: Boiling of Wort and Separation of Spent Hops

OPERATING CONDITIONS

	MAX	NORM.	MIN.
FLUID TEMPERATURE - C	110	100	5

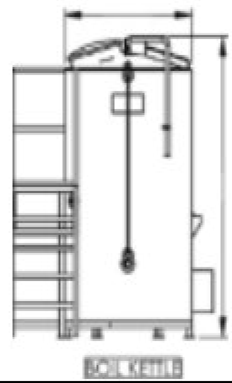
OPERATING VOLUMES - M3: 1.5

MATERIAL PROPERTIES

MATERIAL DESCRIPTION: Wort (Mixture of Malt and Water)

Hops

DESIGN FLUID DENSITY: 1060 KG/M3



VESSEL DETAILS

INDOOR OUTDOOR

- DESIGN CONDITIONS -

MAX DESIGN TEMPERATURE - C	800
MIN DESIGN TEMPERATURE - C	-190
MAX DESIGN PRESSURE - BARA	4
MIN. DESIGN PRESSURE - BARA	0

VESSEL GEOMETRY -

VESSEL POSITION:	VERTICAL
VOLUME - M3:	4.1
VESSEL DIAMETER - M:	1.42
VESSEL TAN/TAN LENGTH - M:	2.59
MATERIAL OF CONSTURCTION:	304 food-grade SS

NO.	DATE	REVISION DESCRIPTION	BY	APVD.
	Feb 2, 2022	For internal reference	SB	RP

Note for Appendix: The design condition temperatures are determined using the material of construction. The vessel height and diameter are taken from specifications provided by one of the vessel supplier found online, that met the capacity requirements. (Portland Kettle Works)

Heat Exchanger (E-100)

UBC	**DATA SHEET - HEAT EXCHANGER**	Exchanger Tag Number
	UBC Engineering Ltd. - Capstone Project Standard	E-100
PLANT:	P&ID Number 100	PROJECT No. P10

Unit Name: E Heat Exchanger

ISSUED FOR:	PROPOSAL	PURCHASE	AS BUILT
SERVICE:	Wort Cooler		

OPERATING CONDITIONS

	HOT SIDE		COLD SIDE	
PHASE	LIQUID		LIQUID	
FLUID FLOW - KG/BATCH	841		770	
INLET PRESSURE - BAR-A	1.0		1	
ALLOWABLE PRESS DROP - BAR	1.0		1.0	
FOULING RESISTANCE - M2 C / W	0.00015		0.00021	
	IN	OUT	IN	OUT
TEMPERATURE - C	95	20	20	85

FLUID PROPERTIES

	WORT		WATER	
FLUID DESCRIPTION	IN	OUT	IN	OUT
DENSITY - KG/M3	1040	1079	998	991
VISCOSITY - CP	0.44	0.67	0.889	0.333
SPECIFIC HEAT - KJ/KG C	3.9	3.9	4.2	4.2
LATENT HEAT - KJ/KG	N/A		N/A	

HEAT EXCHANGER DETAILS

INDOOR OUTDOOR

HEAT EXCHANGER TYPE: Plate Heat Exchanger

	HOT SIDE	COLD SIDE
MATERIAL OF CONSTRUCTION	Carbon Steel 316 L	Carbon Steel 316 L
DESIGN TEMPERATURE - C	150	150
DESIGN PRESSURE - BARG	10	10

NO.	DATE	REVISION DESCRIPTION	BY	APVD.
	Feb 1 2022	For Specification Sheet	TB	

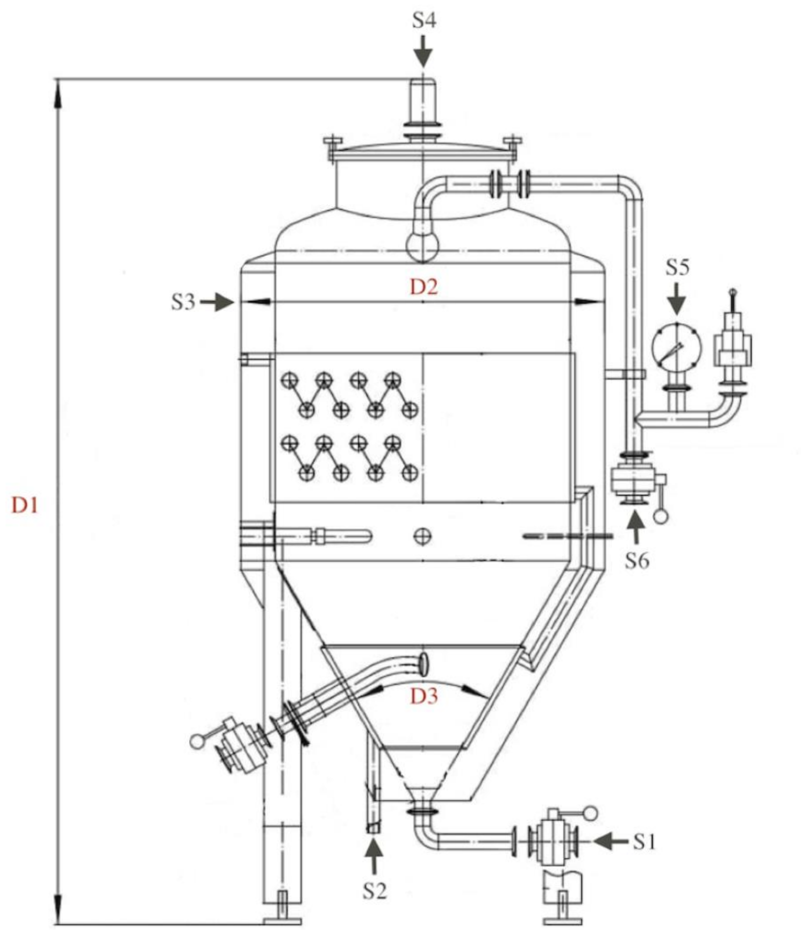
The heat exchanger which is chosen for the brewery is reseacrhed online and the main component of that heat exchanger is carbon steel ////// https://www.cpesystems.com/produc

Fermentation Tank (R-100)

	Data Sheet - (Reactor, Fermentor)	Reactor Tag
	UBC Engineering Ltd - Capstone Project Standard	R-101
Plant : Microbrewery	P&ID Number 101	Project N: 10, P10

Unit Name: Fermentor

1	ISSUED FOR:	Proposal [x]	Purchase	As Built [x]
2	SERVICE	Fermentation of Beer		
3	REACTOR TYPE			
4				
5	Type	Batch Reactor		
6				
7				
8	Jacketed	Yes		
9				
10	OPERATING CONDITIONS			
11				
12		15 to 20° Celsius depending on the brew		
13	Temperature			
14	Residence Time	2 to 8 weeks depending on desired beer type		
15				
16	MATERIAL PROPERTIES			
17				
18	Initial Liquid Content: %100WT Wort		Final Content	
19			Description: %98WT Beer, %2WT CO_2	
20	Density: 1040 kg/m³			
21				
22	Initial Solid Content: %100WT yeast		Density: 1060 kg/m³	
23	Density: 1095 kg/m³			
24	Reactor Details			
25				
26	INDOOR	OUTDOOR		
27				
28	Design Conditions			
29			Reactor Geometry	
30		40° Celsius	Reactor Volume	
31	Maximum Design Temperature			1200 Liters
32		0° Celsius	Reactor Outside Diameter	
33	Minimum Design Temperature			1.1 meters
34		3 atm	Conical Angle	
35	Maximum Design Pressure			60°
36		0 atm	Reactor Height	
37	Minimum Design Pressure			2.438 meters



D1	2.438 meters
D2	1.1 meters
D3	60 degrees

Part	Description
S1	Drain
S2	Glycol water inlet
S3	Glycol water outlet
S4	Safe valve
S5	Pressure Gauge
S6	CIP inlet

Bright Tank (V-103)

	DATA SHEET - TANK	Tank Tag Number
	UBC Engineering Ltd - Capstone Project Standard	**V-103**
PLANT: FBIC Microbrewery	P&ID Number	PROJECT No.

Unit Name: Bright Tank

1 ISSUED FOR: PROPOSAL PURCHASE AS BUILT

2 SERVICE: **Storage of final beer product**

3 **OPERATING CONDITIONS**

	MAX	NORM.	MIN.
FLUID TEMPERATURE - C	25	10	0

8 **MATERIAL PROPERTIES**

10 MATERIAL DESCRIPTION: **Final Beer Product**

12 DESIGN FLUID DENSITY; **1060 KG/M3**

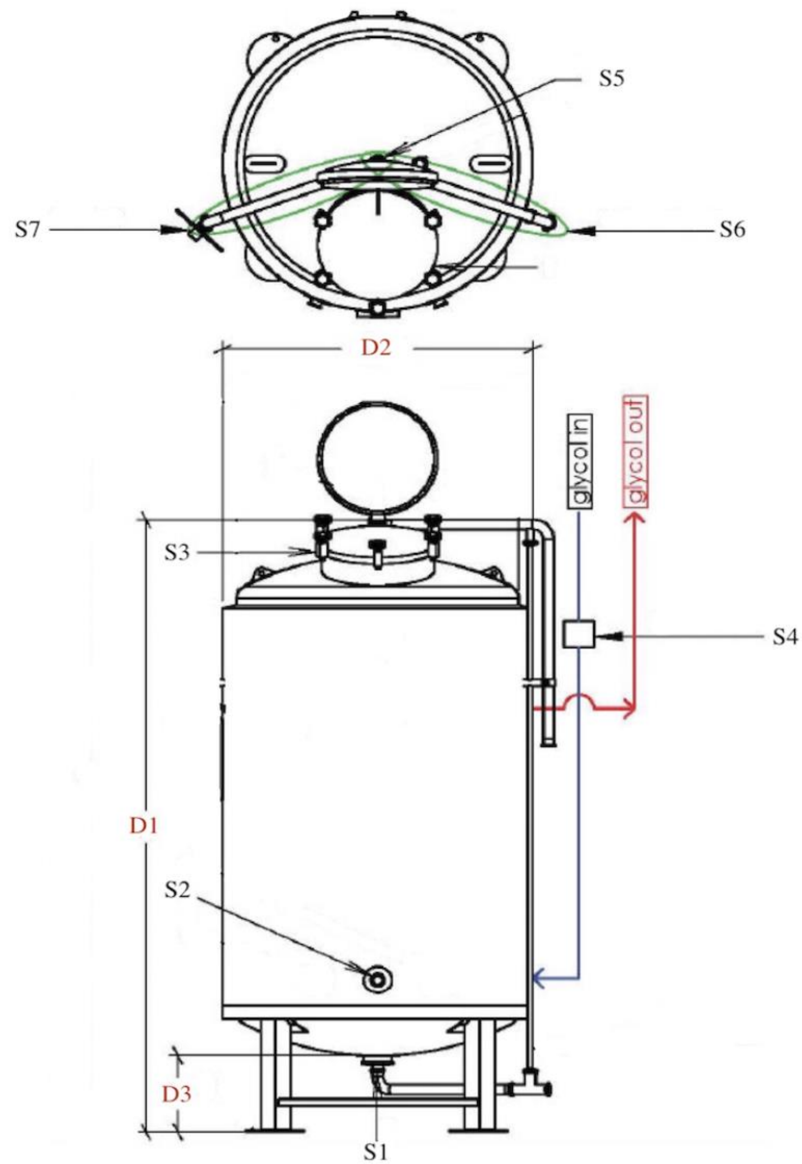
15 **TANK DETAILS**

16 INDOOR OUTDOOR

- DESIGN CONDITIONS -		TANK GEOMETRY -	
		TANK POSITION:	Vertical
		VOLUME - M3:	1.7
MAX DESIGN TEMPERATURE - C	800	ASPECT RATIO (HEIGHT/DIAMETER)	2.7
MIN DESIGN TEMPERATURE - C	-190		
MAX DESIGN PRESSURE - BARA	4	MATERIAL OF CONSTURCTION:	304 Food Grade SS
MIN. DESIGN PRESSURE - BARA	0		

NO.	DATE	REVISION DESCRIPTION	BY	APVD.
	Feb 1 2022	For quotation purposes	SB	RP

Note for Appendix: The design condition temperatures are determined using the material of construction. The vessel height and diameter are taken from specifications provided by one of the vessel supplier found online, that met the capacity requirements. (Portland Kettle Works)



D1	93 Inches
D2	10 Inches
D3	44 Inches

Part	Description
S1	Ultimate drain
S2	TC port
S3	Manway
S4	Valve
S5	CIP inlet
S6	CIP right arm
S7	CIP left arm

Centrifugal Pump (P-100)

	DATA SHEET- Pump P-100	Pump Tag Number
	P-10 - Capstone Project - FBIC Brewery design and optimization	**P-100**

Unit Name Centrifugal Pump

ISSUED FOR: PROPOSAL PURCHASE AS BUILT

SERVICE: **Water Effluent Pump**

OPERATING CONDITIONS

	MAX.	MIN.		
VOLTAGE :	460	230		V
Maximum Flow	4			L/s
NPSH AVAILABLE:	16.8			M
HORSEPOWER:	1			HP

FLUID PROPERTIES

FLUID DESCRIPTION: **Water with traces of malt**

	MAX.	NORMAL	MIN.	
PUMPING TEMP.:	75	70	60	°C
SPECIFIC GRAVITY:	1.055	1.022	0.99	
PRESSURE:	99	101	103	kPa-a
VISCOSITY:	0.61	0.91	1.31	cP

PUMP DETAILS

INDOOR OUTDOOR

PUMP TYPE: **Centrifugal Style Pump**

ELECTRICAL CLASSIFICATION:

CL.: ________ GR.: ________ DIV.: ________

NON HAZARDOUS

MATERIAL OF CONSTRUCTION: **Stainless Steel**

SPECIAL REMARKS: **None**

	DATE	REVISION DESCRITPTION		
	FEB 1 2022	FOR QUOTATION PURPOSES		

Note for Appendix: The design condition temperatures are determined using the material of construction. The pump operating condition range are taken from specifications provided by one of the vessel supplier found online, that met the capacity requirements.

APPENDIX D: HAZOP

RISK MATRIX

		FREQUENCY				
		Frequent – expected to occur	Probable – likely to occur in the next 5 yrs	Occasional – may occur within the life of facility	Rare – not anticipated to occur	Improbable
Consequence		**1**	**2**	**3**	**4**	**5**
Severe injury,Major Env. Damage,1 million $ +	**1**	H	H	S	M	L
Lost time accident, , Reportable Env. Event,$100k-$1Million	**2**	H	S	M	M	L
Medical treatment, $10k - $100k	**3**	S	M	M	L	L
Minor exposure, Onsite release, $1-$10k	**4**	M	M	L	L	L
localized spill, <$1k	**5**	M	L	L	L	L

The severity of the consequences has been modified within the scope of the project.

This analysis was done on the whole process as a single node.

PHA Worksheet

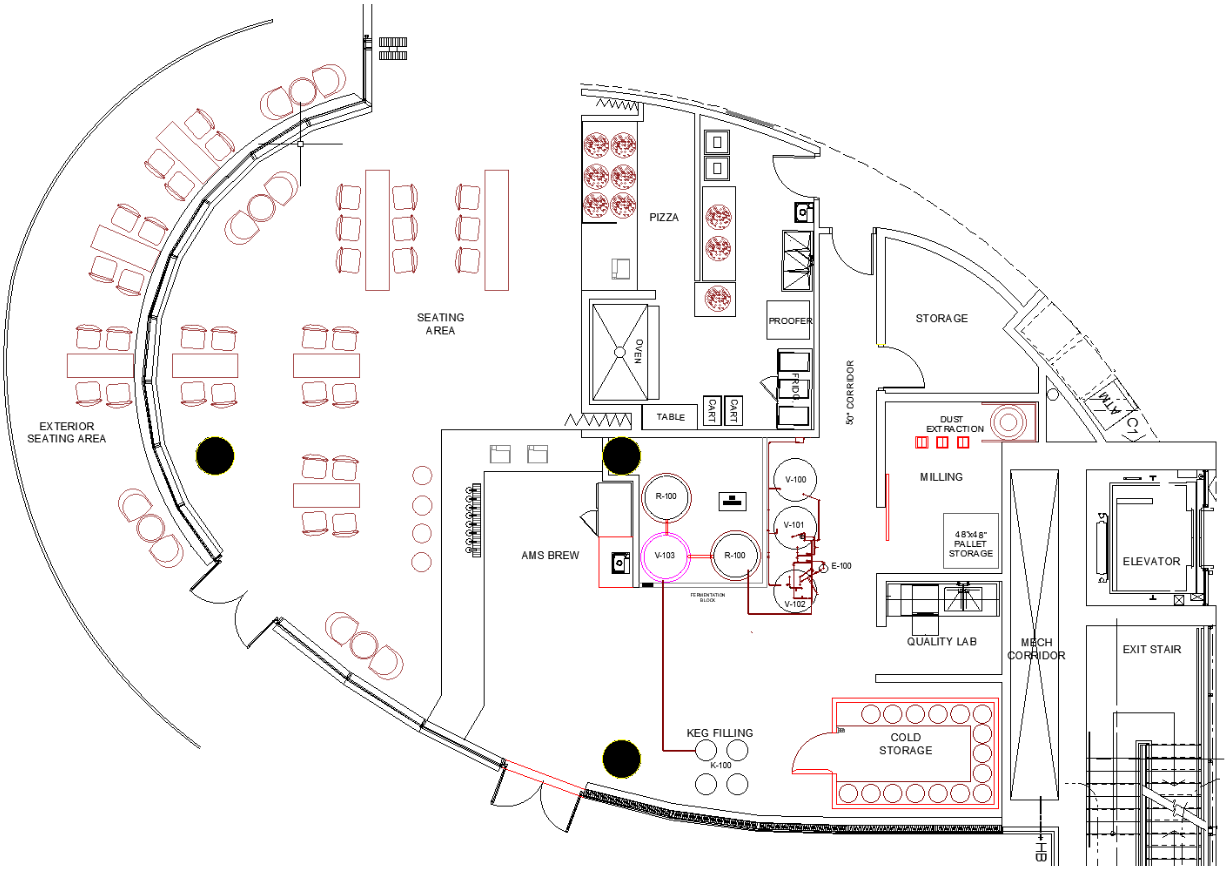
Node	**Node 1: Whole Process**
Reference Documents	
Design Intent Conditions / Parameters:	**DESIGN INTENT**: To produce beer **OPERATING CONDITIONS**: The hot side of the microbrewery (Mash/Lauter tun, Hops Boiler and Whirlpool, Hot water tank) operates at a temperature range of 70-100 degC, while the cold side of the microbrewery (Fermenter, Bright tank, Keg-filling station) operates at a temperature range of 4-25 degC. **PROCESS CONTROL**: . The temperature of the fermenter (R-100) and bright tank (V-103) are set by their respective controllers through a simple feedback loop. The controllers manipulate the flow of the glycol through the tanks' respective cooling jackets. **HUMAN INTERACTION**: There is no preventative maintenance required. The column is inpsected through the regular annual plant maintenance shutdowns. Final quality assurance is required to maintain an acceptable final product. **SAFE LIMITS**: The Fermenter (R-100) can operate between 10 degC and 20 degC without process upsets. **DESIGN CONDITIONS**: All equipment operates at 1 to 3 atm. The temperature varies for different equipment between 4 degC to 100 degC. **SAFETY DEVICES**: There are only temperature controllers in the process.

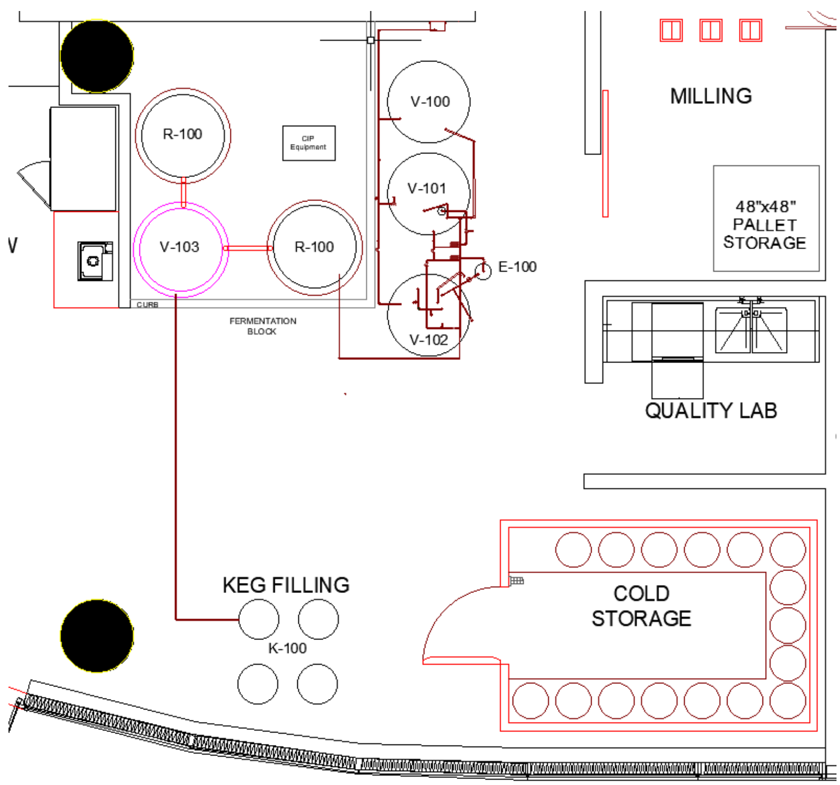
Deviation	Cause (Errors, Failures)	Consequence (without safeguards or operators)	Before Safeguards		Existing Safeguards (On P&ID or in place at facility)	After Safeguards			Recommendations / Comments	Responsibility	Final Recommendation / Solution
			Category	Severity		Category	Freq.	Risk Rank			
No/Less Flow	Pump(s) are not connected properly	Leaks from equipment	H&S	4	Locks on pipe ends	H&S	5	L	Extra seal to be added to the pipes that would lock in to prevent any leaks		Extra seal all the pipes
			FIN	4	Locks on pipe ends	FIN	5				
			REP			REP					
			ENV			ENV					
		Loss of beer	H&S	5	Isolated pipes	H&S	5	L	All the pipes from each equipment should be able to be isolated so that the loss of beer can be minimized		Isolate the pipes
			FIN	5	Drain valves	FIN	5				
			REP			REP					
			ENV			ENV					
		Cleaning required	H&S	5	The cleaning equipment required for the beer	H&S	5	L	Any leakage will require some cleaning and certain drainage which should be build in to the plant area.		Install drainage
			FIN	5		FIN	5				
			REP			REP					
			ENV			ENV					
High Temperature	Glycol is not pumped as much as it should be	The temperature of the fermenter increases	H&S	4	Thermometer attached and temperature log	H&S	5	L	If the temperature of reactor goes above 20 degree celcius for a prolonged time then the batch shoud be quality tested at several points to determine it's quality. Depending on the quality test results unfit amounts should be disposed of.		Quality test at several points
			FIN	3	Temperature controller	FIN	5				
			REP		Quality Control test (including taste test)	REP					
	E-100 malfunctioning		ENV	5		ENV	5				
		The temperature of the bright tank increases	H&S	4	Thermometer and temperature log attached	H&S	5	L	This would effect the quality of the beer however if this beer is not sold then reputation would be okay so every batch of beer should be test tasted before it can be solved.		Quality test every batch
			FIN	3	Temperature controller	FIN	5				
	Boiler burner set too high/malfunctioning		REP	3	Quality control	REP	5				
			ENV			ENV					
	Milling machine overheats	Milling machine shuts down causing fire	H&S	2	Have fire extinguisher	H&S	5	L	The dry grains should not be stored right next to milling machine so that no spark can reach to the storage to ignite everything		Isolate the dry grains storage
			FIN	2	Fire Alarm on site	FIN	5				
			REP	3		REP	5				
			ENV	4		ENV	5				
	Auger Clogs	Grain/dust spillage causing breathing hazard	H&S	4	HVAC system	H&S	4	L	Milling system should be check with smaller amounts before the whole batch is milled to be able to control this issue if it were to happen		Sample test the milling process
			FIN		PPE	FIN					
			REP		Milling system	REP					
			ENV	4		ENV	4				
	Chiller not working	Hops Boiler increased to a temperature higher than intended	H&S	5	Thermometer and temperature log attached	H&S	5	L	The flavor of the beer might be affected due to excess heat applied to the hops during this process and some water might also evaporate.		Quality control testing every batch
			FIN	5	Burner control included	FIN	5				
			REP			REP					

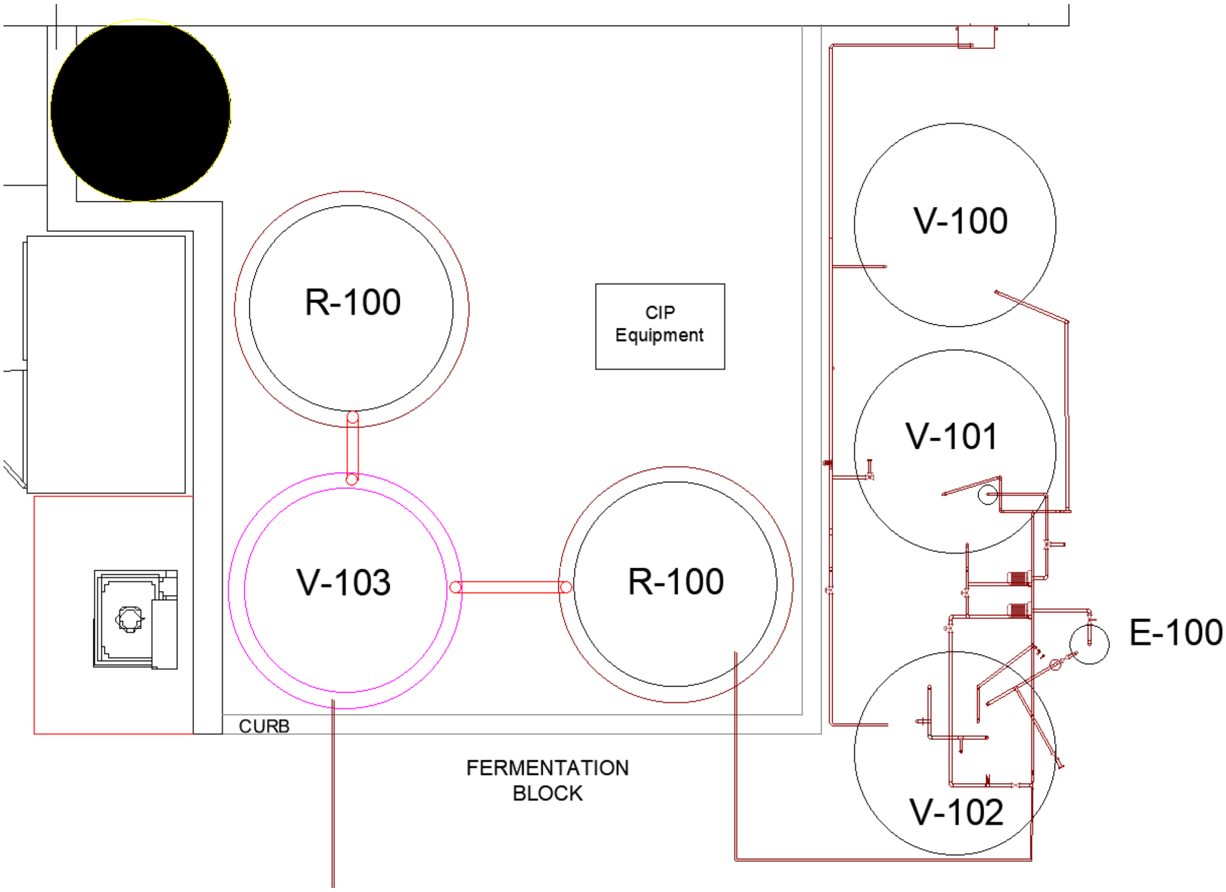
			ENV			ENV					
Lower Temperature	Chiller is providing more cooling than it should	The beer might not be fermented properly	H&S	5	Thermometer and temperature log attached	H&S	5	L	Taste of the beer might be affected since sugars won't fully be converted by yeast to alcohol , hence malted barley won't be fully used.		Quality control testing every batch
			FIN	3	Quality Control Testing	FIN	5				
			REP	3		REP	5				
			ENV			ENV					
	Hops Boiler is not being heated to the temperature it should	The bright tank might be cooled off than it should	H&S	5	Thermometer and temperature log attached	H&S	5	L			
			FIN	5	Quality Control Testing	FIN	5				
			REP	5		REP	5				
			ENV			ENV					
		Hops are not solving properly	H&S			H&S		L			
			FIN			FIN					
			REP	5	Quality Control Testing	REP	5				
			ENV			ENV					
Leak/Rupture	Failure of drain valves	The floor being flooded and the brewery is above the electrical room of the building	H&S	3	The curb drainage system is set to drain the	H&S	5	L	This consequence is very unlikely to happen as a massive rupture and blocked drainage system would have to happen at the same time while there are no operators close by. However it is also the costliest failure which can happen.		Inspect the drainage system frequently
			FIN	1	The layout of the brewery will be designed	FIN	5				
			REP	2	Quality Control of Drainage system with water	REP	5				
			ENV	4		ENV	5				
		The batch is completely lost	H&S			H&S		L			
			FIN	3	Same as above	FIN	5				
			REP			REP					
			ENV			ENV					
Misdirected/Reverse Flow	Pump is connected incorrectly	Batch contamination	H&S			H&S		L			
			FIN	3	Clear labels should be placed on piping	FIN	5				
			REP			REP					
			ENV			ENV					
	Redirection of pipes connected incorrectly	Batch contamination	H&S			H&S		L			
			FIN	3	Same as above	FIN	5				
			REP			REP					
			ENV			ENV					
	Pump failure	Batch contamination	H&S			H&S		L	This is unlikely to happen, given regular pump and valve maintenance. Additionally, having a backup pump can also reduce the likelihood of this happening		Frequent inspection and maintenance of pumping system
			FIN	3	Regular pump maintenance is required, install	FIN	4				
			REP			REP					
			ENV			ENV					
Higher Pressure	Not applicable for this project higher pressure is not reached during the process		H&S			H&S					
			FIN			FIN					
			REP			REP					
			ENV			ENV					
Lower Pressure	Not applicable to this process		H&S			H&S					
			FIN			FIN					
			REP			REP					
			ENV			ENV					
Higher Level	The only way this can be an issue if there was an error made by the operator		H&S			H&S					
			FIN			FIN					
			REP			REP					
			ENV			ENV					
Lower Level	The only way this can be an issue if there was an error made by the operator		H&S			H&S					
			FIN			FIN					
			REP			REP					
			ENV			ENV					
Wrong Composition	Not applicable to this process		H&S			H&S					
			FIN			FIN					
			REP			REP					
			ENV			ENV					
Wrong Reaction	Not applicable to this process		H&S			H&S					
			FIN			FIN					
			REP			REP					
			ENV			ENV					
Wrong Concentration	Grains not crushed properly	Wort out of spec disposed	H&S			H&S		L			
			FIN	4	Quality control testing	FIN	5				
			REP			REP					

			ENV			ENV					
	Excess amount of water is added during the lautering process	Beer out of spec sold	H&S			H&S		L			
			FIN			FIN					
			REP	3	Quality control testing	REP	5				
			ENV			ENV					
Sampling Hazards	There are no process errors associated with this type of hazards only user made ones		H&S			H&S					
			FIN			FIN					
			REP			REP					
			ENV			ENV					
Maintenance Hazards	There are no process errors associated with this type of hazards only user made ones		H&S			H&S					
			FIN			FIN					
			REP			REP					
			ENV			ENV					
Startup/Shutdown Hazards	Not applicable to this process		H&S			H&S					
			FIN			FIN					
			REP			REP					
			ENV			ENV					
Workplace Safety Hazards	High humidity prodcued by process	Slippery floors	H&S	3	Ventilation system	H&S	3	M	The brewing process produces a lot of humidity which can condense on floors and can cause a slipping hazard. Frequency of this can be decreased by air circulation. Wet signs		Install dehumidifiers
			FIN		PPE	FIN					
			REP			REP					
			ENV			ENV					
Flooding	Drainage system is clogged / full	Leaks and spillage accumulate, brewery is above the electrical room of the building	H&S	3	The curb drainage system is set to drain the	H&S	5	L			
			FIN	1	The layout of the brewery will be designed	FIN	5				
			REP	2	Quality Control of Drainage system with water	REP	5				
			ENV	4		ENV	5				
CIP Hazards	Exposure to CIP chemicals (caustic / acid)	Exposure to caustic /acid can cause health issues	H&S	3	PPE	H&S	5	L			
			FIN			FIN					
			REP			REP					
			ENV			ENV					
	CIP chemical residue remains after cleaning	Can be caused by improper rinsing, dead-leg pipes	H&S	1	Proper brewery CIP practices should be upheld,	H&S	5	L	It is unlikely for improper rinsing to be done during CIP, however piping should be designed with attention to detail.		Avoid dead-leg pipes in design process
			FIN	3		FIN	5				
			REP	1		REP	5				
			ENV	4		ENV	5				

APPENDIX E: PLANT LAYOUT


PIZZA
SEATING AREA
EXTERIOR SEATING AREA
OVEN
TABLE
CART
CART
PROOFER
FRIDG
50" CORRIDOR
STORAGE
DUST EXTRACTION
MILLING
48"x48" PALLET STORAGE
AMS BREW
R-100
V-103
R-100
V-100
V-101
V-102
E-100
QUALITY LAB
MECH CORRIDOR
ELEVATOR
EXIT STAIR
KEG FILLING
K-100
COLD STORAGE
ATM
C1
HB


R-100
CIP Equipment
V-100
V-101
V-103
R-100
E-100
V-102
CURB
FERMENTATION BLOCK
MILLING
48"x48" PALLET STORAGE
QUALITY LAB
KEG FILLING
K-100
COLD STORAGE


R-100
CIP
Equipment
V-100
V-101
V-103
R-100
E-100
CURB
FERMENTATION
BLOCK
V-102

APPENDIX F: ECONOMIC ANALYSIS

RAW MATERIALS

Description	Amount (kg)	Cost (CAD)
Yeast per kg	1	$3.02
Yeast per batch	10	$30.20
Yeast per month	40	$120.80
Yeast per year	**480**	**$1449.6**
Hops per kg	1	$22
Hops per month	5	$110
Hops per batch	20	$440
Hops per year	**240**	**$5280**
Malt per kg	1	$0.31
Malt per batch	285	$89.49
Malt per month	1140	$357.96
Malt per year	**13680**	**$4,295.52**
Total per batch		$229.69
Total per month		$918.76
Total per year		**$11,025.12**

Utilities

	Monthly Usage	Utility Costs ($)
Electrical (kW/hr)	1193	$145.60
Natural Gas (GJ)	13.64	$177.50
Water (L)	32000	$119.80
Total Monthly Cost		$443.00
Total Annual Cost		$5314.00

https://www.movingwaldo.com/daily-living/bc-utility-bills-how-much-does-utilities-cost/

Labor

Worker Title	No. of Workers	Pay $/hr	Total Annual Salary (125%)
Full-time Brewmaster	1	25	$60937.50
Part-time Brewmaster	1	16	$20800.00
Total	**2**		**$81738.00**

Revenue

	Beer Produced (L)	Beer Sold (L)	SP ($/L)	Revenue ($)
Per Batch	1000	950	8	$7600.00
Monthly	4000	3800	8	$30400.00
Annual	48000	45600	8	$364800.00

Group member contributions

Group Member Name	Contributions
Ali Wasti	Stream Table, Mass balance, Energy Balance, Equipment List, Economic Analysis, Start-Up/Shutdown Procedure, Recommendations, Appendix A
Haluk Kaan Kartal	Process Synthesis, Data Assembly, Equipment List, Environmental Analysis, Start-Up/Shutdown Procedure, Recommendations, Conclusion, Appendix B
Hassan Sinno	Introduction, PFD description, Executive Summary
Sarmad Ali	Process Synthesis, PFD, P&ID, Executive Summary, Start-Up/Shutdown Procedure, Economic Analysis, Appendix A
Tamer Baroud	Introduction, Market Analysis, Block Flow Diagram, Plant Layout, Appendix C, Appendix E, Appendix F
Vito Abednego	Process Synthesis, PFD, P&ID, Control Loops and Narrative, HAZOP Analysis, CIP Procedure, Appendix D
Michael Kosgei	HAZOP Analysis