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Design of a Standardized Brewery

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Design of a Standardized Brewery

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Abstract

Recently, craft brewing has gained popularity, and many startup craft breweries are being founded as a result. Our group was tasked to identify key factors that impact product consistency, model the brewery process on a simulation software ASPEN PLUS® to aid microbrewer's understanding of the chemistry of up-scaling operations, and to find the key elements of expansion. To accomplish these goals, we conducted further research into the craft brewery industry by consulting local micro/craft breweries to learn about companies' ideologies and to supplement our research. Once all this information was gathered, these factors would then be presented to our sponsors to consult with startup businesses, facilitating their growth, and providing preliminary information needed to create a brewing simulation if they choose to.

Acknowledgements

The completion of this project could not have been possible without assistance by our peers, mentors, and friends. Some aided us by providing guidance, while others gave us the resources required to complete this project. We would like to thank Professor Stephen J. Kmiotek for advising the project and supplying us with the resources to overcome obstacles we encountered. We would like to thank Cold One Engineering for entrusting us with the project. Lastly, we would like to thank the Chemical Engineering department at WPI for giving us the proper knowledge throughout our undergraduate career to tackle the task at hand, and those we will face as professional in the real world.

Executive Summary

The original purpose of this project was to assist our sponsor, Cold One Engineering, with the creation of a simulation model of the craft brewing process for the ultimate purpose of helping brewers create a consistent product. The findings of the project illustrate a necessity to identify challenges faced by breweries, production bottlenecks, and sources of deviance as a prerequisite for creating a simulation model. We conclude by offering two suggested courses of action going forward for our sponsor.

These two suggested courses of actions were found after researching more in depth about the brewery process more specifically the craft brewery process. To supplement our research on this topic, we visited some breweries across the state to investigate more about the process and learn about the real-world problems these companies face. We integrated this information into a simulation software called ASPEN PLUS® to represent the chemistry of the brewery process.

Breweries must face a few unique challenges that consultants should consider. Many craft brewers use repurposed buildings that dictate the floor plan and limits equipment size/location, hindering future expansion. Breweries often agree to multi-year contracts with suppliers, meaning plans drafted should work with existing equipment and contracts. Furthermore, many purchases/upgrades require large loans with long payback periods, posing a challenge to prioritize investments.

It is important to understand the bottlenecks that can limit beer production, which can make or break newer craft breweries. Ultimately, the number of fermenters limits a brewery's output due to being the longest step by far. In response, a brewery may hastily over purchase and be left with unused units (wasted investment), limited by another bottleneck. The secondary bottleneck would be the boiler, kettle, and mash-lauter-tun, which must be able to grow concurrently such that no expansion or upgrade is limited by the capacity of another piece. The decision to lease or purchase a packaging line (bottles, cans, kegs, etc..) is critical due to the options in operation flexibility, financial burden, quality control, and technical competence required; the conditions to purchase must be tailored for each brewery. In some cases, an existing floor plan can pose an operational bottleneck to expansion if not planned well beforehand.

Creating a consistent brew involves several variables; pertinent ones are described here. Sanitation/sterilization between batches is critical to keeping out biological contaminants that can alter taste or ruin a batch, and there are multiple ways to do so, each requiring proper training. Natural variation between, and even within, grain and hop varieties exist that should be accounted for in the recipe used. Hot wort from the kettle needs to be cooled quickly to prevent contaminants from getting a head start before the yeast, and to minimize dimethyl sulfide production. Yeast mutates during the fermentation step and may be reused a limited number of times. Timing and temperature control vary according to recipe, but much of it is based on open-loop and abstract taste testing, which has poor integration with full automation. Any time there is a transfer from one vessel to another is an opportunity for oxygen and bio-contaminants to be introduced, and a procedure should be made for each instance to reduce the risk. Climate control in storage and transportation is critical since it can alter or ruin a batch, costing the most money (as a late process error) and allows bad product to reach selves, impacting reputation.

We recommend two nonexclusive business pathways for Cold One Engineering. One is to seek out clients who are just starting out and offer a standardized brewery template that encompasses much of the technical and economic work, best practices, and offers business scale up plan. It can be complemented with an in-depth simulation model to take advantage of the reduction of unknown variables/variations across breweries. This method should save time and money long term, while being more likely to retain clients due to the integrated scale-up planning, along with close cooperation from the business's foundation. The other pathway is to make a broad simulation model template that is then tailored for each brewery. This is a more traditional consulting approach that leverages an existing market.

Chapter 1: Introduction

Our group was originally tasked by Cold One Engineering to assist in creating a software which would help microbrewers create a consistent product, expand their company, and provide cost and product estimations. These goals proved to be impractical at this stage and were ultimately changed to identify and document the key factors that affect a consistent product, model the basic brewery process on the simulation software ASPEN PLUS® to help our sponsors guide microbrewers understand the chemistry of scaling up, and to identify key factors for expansion. To accomplish these goals, we conducted further research into the craft brewery industry through literature review and visiting local craft microbrews to gather more information about the brewery process. Then, a bare bone model of the craft brewery process was created in the software ASPEN PLUS®. The real-world information along with a specific craft beer recipe was used to identify the parameters required by our simulation model. All other supplementary information, including business considerations, production bottlenecks, and sources of deviance, were reported separately for later integration into the model at our advisor's digression. The ultimate objective is to aid micro and craft breweries create a consistent product by leveraging an eventual simulation that integrates operational and business considerations.

Chapter 2: Background

2.1 Craft Brewery Process

2.1.1 Ingredients

Here, the overall craft-brewing process will be described. Note that this is a general process that can vary by producer and batch. The 4 main ingredients are water, barley/grains/cereals, hops, and yeast. Typically, utility water is filtered to purify it before use. If the source water is very soft, a brewer may add gypsum (calcium sulfate), Epsom salts (magnesium sulfate), calcium chloride, table salt (sodium chloride), and/or chalk (calcium carbonate). Magnesium, and particularly calcium, affect yeast metabolism, while bicarbonates alter pH.

The malted barley/grains are the source of starch for the sugar production, used in fermentation later. Malting refers to the process of allowing the cereals to germinate part way, then drying to stop the process. The purpose of this is to allow the enzymes that break down the endosperm starches to be released without much being consumed by the germination process. Typically, they soak in water for several days and are then drained, and dried. The cereal grain and sub varieties affect flavor, color, and aroma, as does the option of roasting, toasting, and/or smoking the grains. Adjuncts, non-germinated grains added separately, may also be added if additional starch is called for. It should be noted that most brewers buy malted-to-order barley due to the benefits of economics and required expertise coinciding with scale.

Hops release oils that provide some flavor and aroma, while inhibiting some spoiling bacteria. There is an incredibly wide variety of hops to choose from, and when they are added and for how long they are left to seep are all factors leveraged by recipes. The iconic bitterness from hops originates from the Alpha Acid resins, and International Bitterness Units (IBUs) is the standard used in calculations.

Yeast is the active culture that causes fermentation and is essential to the brew. They typically are in two categories: Top fermenting, which produces ale, and bottom fermenting, which produces lagers; top and bottom denotes whether the yeast floats or sinks. The yeast can be stored in dry form, which is easy to store and transport, or as a liquid, which enables a wider use of varieties and can obtain enhanced consistency. Cultures can be purchased (typically dried) or maintained in-house (though this is usually limited to larger brewers).

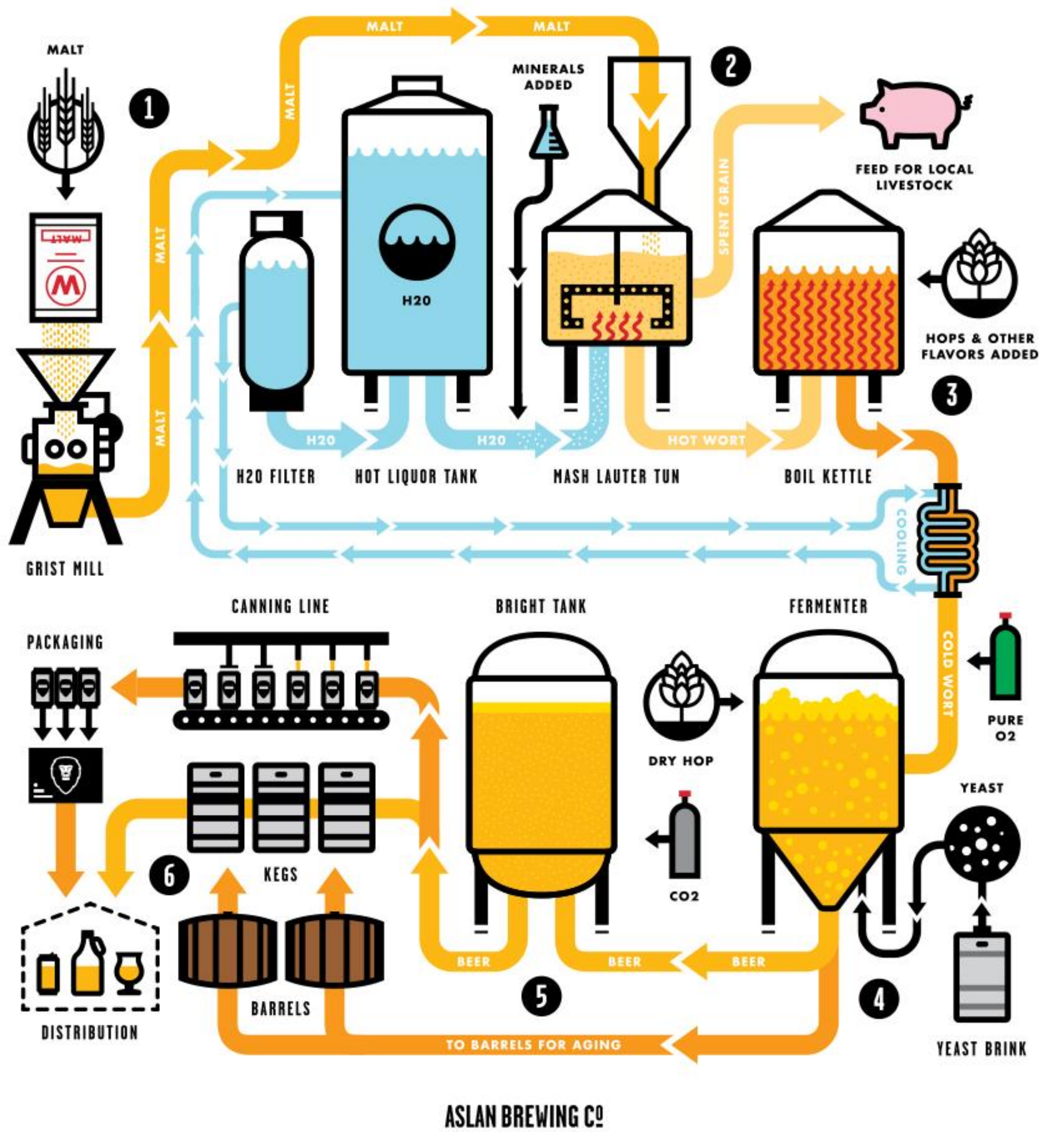

Figure 1: Craft Brewery Process

2.1.2 Mash

The first step in the brewing process is to produce the mash. The purpose of this step is to convert the starches in the grains into fermentable sugars. Beforehand, the kernels need to be crushed. Within limits, the finer they are broken, the more sugar can be obtained. However, if the grains are too small, water will not be able to permeate the grains, known as a stuck mash. Care must also be taken during processing to avoid a stuck run-off, which is when the water line is below the gain line, and the weight of the grains crush the bottom layer into an impermeable layer. These two “stuck” s are less of an issue if using a separate kettle for the mash. The grains are then put into a Mash-lauter-tun (or just a kettle) and soak in hot water, sprayed by the hydrator, to activate the various enzymes. The primary enzymes of interest are the Alpha and Beta Amylase enzymes, which work best at different temperature and pH ranges. Beta Amylase *-*(ideal range of 126-144F) is the heart of the process, as it snips segments of the starches into glucose. This process is greatly sped-up with the Alpha Amylase (ideal range of 149-153F), which cleaves the long starch segments, increasing the number of sites for the Beta enzyme to work. Limit dextrin’s are produced as a byproduct, which are starch segments with branching behavior enzymes cannot break down but are typically destroyed in the mashing process. Note that grain/sugar adjuncts may be added according to recipe.

Early in the mash, an acid rest may be performed by lowering the water temp in order to lower pH, a step typically done if the water used is very soft with no additives to counter it, or if the water chemistry is unknown. 15-30 minutes in a protein rest is typically done by reducing the temperature to 113-131F, which allows the various protein chains to break down. The time and temperatures involved in this step, along with almost all others in the brewing process, depend on the recipe used. For the mash process, the time spent soaking is a spectrum starting with a full (high starch) brew with ultimately low alcohol with short time frame, to the inverse with a high soak time. The temperature behavior of the mash process can be broadly be categorized as follows: Infusion is where there is a single temperature is held. Decoction is where boiling water is added, and periodically some water and grist is removed, brought to boiling, and re added to keep temperature up. This technique was standard when good temperature measurement was beyond practical means. Temperature Control is where there are consecutive temperature increases, best used with under-modified malts.

2.1.3 Lautering and Sparging

Next is the Lautering and Sparging steps. The purpose is to remove the sugars from the grain husks and retrieve the sugar water. It should be noted that this step may or may not be in the mash-lauter-tun, if a kettle was used for the mash (typical of very small brewing operations, such as homebrew), then this step uses a lauter unit. The temperature is first raised to around 170F to stop enzyme activity. In the lautering step, the unit is drained, and the liquid is poured over the mash to extract more sugar, while the husks themselves act as a filter to remove larger particulates. The following sparging step has the sugar-water drained, while fresh heated water pours over the gains to extract even more sugar, suppress enzymes further, and to prevent a stuck run-off.

2.1.4 Boil Kettle: Wort Production

The sweet sugar water is then transferred to the Boil Kettle. The purpose is to condense the sugar water into wort and to kill off any unwanted bacteria. Typically, a steam jacketed brew kettle is used to boil approximately 90 minutes. During that time, some hops are added at various stages for different effects. Boiling hops are added early, where the extracted oils add bitterness. Oils that contribute to flavor and aroma are volatile and boil off easily, so flavor hops are usually added around the last 15-minute mark, while aroma hops are added in the last few. There may be an oxygen control system, so that the yeast my grow but is not competed with by other bacteria. The wort produced can be concentrated to become malt, which with the addition of water can be used to brew. In this stage, other adjuncts, primarily for flavor and aroma, may be added per recipe.

2.1.5 Cooling Wort

The next stage is separation and cooling, the purpose of which is to remove undesired solids and prepare for fermentation. The wort is vortexed in the kettle, where the hops/solids, called turb, collects in the center, and is left to slow to a stop and solids settle at the bottom (flocculation). The clean wort is then quickly cooled to a proper temperature for the yeast. Rapid cooling is essential for several reasons: prolonged idle time increases the chance of contamination, existing biological contamination will have more time to grow before yeast is added, hot wort can produce dimethyl sulfides, and can react with oxygen to produce more off flavors, which both affect taste. The cooling is done often with a liquid-liquid heat exchanger, where the water used for cooling is used as pre-heated water for the next batch's mash (around 170F). This cooling water is transferring from a "cold" liquor tank to a "hot" one, which are only regular tanks with no alcohol, despite the name.

2.1.6 Fermentation

Now alcohol production via fermentation can begin. Ideal time and temperature vary according to recipe; for example, Ales typically need 2 weeks at 68F, while lagers need 6 weeks at 48F. There are two stages to fermentation: the primary stage has exponential growth of yeast from the ample supply of simple sugars, and foaming (krausen) from rigorous CO_2 production. In the secondary stage, heavy fats, proteins, and inactive yeast settle to the bottom of the tank, CO_2 production slows dramatically, and yeast levels fall as only heavier, complex starches remain for consumption. Some brewers may have separate tanks for these two stages, though this is not typical.

The CO_2 production causes the beer to partially self-carbonate, which has the secondary effect of inhibiting contaminate growth. The alcohol content can indirectly be be measured by identifying its specific gravity with a hydrometer. Alcohol content is one attribute that may be used to determine the stop time. A refractometer can measure the alcohol content directly while also being easier to calibrate and uses very little product. However, it often has a prohibitive up-front cost. Once fermentation is completed, it is cooled, sometimes to near freezing, to help settle the yeast and undesired proteins. From there, the beer is slowly pumped out (to avoid disturbing the settled material) and possibly filtered. Craft brewers often abstain from filtering, believing the quality control/consistency is not worth the change in taste, expense, and maintenance. Because the fermentation process produces heat, some form of cooling is necessary. This is often in the form of jacketed vessels with flowing coolant, namely water or ethylene glycol. Fermenters have a cone shaped bottom to collect yeast and other particulates that sink. The vessels are also sealed with one-way valves that let CO_2 escape while keeping oxygen and contaminates out, usually a water trap. The vessel needs to have extra space between the liquid level and vessel top (ullage) so that the foam (krausen) does not overflow. Furthermore, yeast may be recovered to start a new batch. Mutations limit the number of times this can be done to once or twice.

2.1.7 Brite Tank

The beer can then enter the Brite Tank, which is a vessel to add in extra CO2. Usually, canistered CO2 is purchased separately, and the gas is broken into smaller bubbles by a device, such as a bubbling stone, to conserve gas and time.

2.1.8 Packaging

The last step is to package the beer in cans, glasses, kegs, etc. Beyond ease of transportation, the containers keep out oxygen, sunlight, and stray contaminate that my alter the beer in shipment or storage. If the beer was not previously carbonated with the brite tank, it may be during the packaging process via priming, kraesening, or injection. Priming is when a water, sugar, and dry malt extract mixture is added to reactivate remaining yeast, producing some CO2. However, this comes with the risk of adding new flavors. Premade priming tablets can be purchased to be added to the bottles or batch and is usually used by homebrews rather than craft brew. Kraesening is where unfermented wort from earlier in the process (gyle) is added as it would in priming. This greatly reduces the chance of changing the taste, but the sugar content can vary, and the amount added should be adjusted accordingly. The last method is to simply inject pressurized CO2 while filling. The filling process for bottles, kegs, and cans are similar in procedure. The container is rinsed/disinfected, dried, flushed with CO2 to drive out air, partially pressurized with CO2 to suppress foaming, filled, and capped. Some systems may not pressurize CO2 and may opt to use a water jet to cause slight foaming, which helps push air out. In either case, the bottle is not filled to the brim, as some CO2 headspace helps keep the drink carbonated.

2.2 Craft Brewery Design methods

2.2.1 Floor Plan / building constraints and expansion.

Very few craft brewers have the upfront funds to build and design a building for operations, and often purchase or rent something pre-build and retrofit it as needed. As such, ideal arrangements of storage, equipment, office space, storefront, etc cannot be obtained, leading to unique operating flow challenges on case-by-case basis. For example, a building needs to consider future expansion, installation and movement of equipment (ie demolish and rebuild wall, equipment hatch), and loading dock access, as well as the movement of people and raw materials. This factor is more important for craft brewers since much of the work is not automated, hard piping is limited, and equipment and batch schedules are not set in stone.

2.2.2 Production bottlenecks

In terms of production, bottlenecks can ultimately make or break a brewery. Certain expenses must be paid off regularly while the money to do so is only earned by selling product. In terms of raw throughput, production is limited by the number of fermenters, as it’s the longest step by far in the series of batch processes. Simply buying more fermenters is the typical solution, however space, utility cooling, and expense dictates doing so when the business can. The second slowest would be the kettle, used to produce wort. Unlike fermenters, the utility heat is needed, and additional units or size upgrades and put strain on the boiler. If the boiler is not able to match the kettle’s demands, then the investment is lost until the utility us upgraded. Overall, when planning upgrades/expansions, be sure all related equipment/utilities will be able to handle the increase load.

2.2.3 Contract vs own can/bottle/keg lines

One of the larger business decisions is when to stop contracting a filling company and purchase a bottle/can/keg line. This is a huge financial investment, including operator and maintenance costs, but offers production flexibility via continuous availability, long term cost saving, direct quality control. The quality of the system can vary widely: method and level of sterilization (chlorine wash, ionized air, steam, UV, etc), degree of automation, throughput, maintenance needs, etc. The choice is largely a business-led and is expected to be treated as a long-term investment.

2.2.4 Scope of model

Due to the nature of business growth with time, and the consequential highly varied operating scales of craft brewers, the simulated model will not be the recreation of a specific brewery or recipe. Instead, it will be focused on creating an adaptable, scalable template design that identifies necessary variables, which should account for varying degrees of instrumentation and recipes.

2.3 ASPEN PLUS®

ASPEN PLUS® is a software package that allows the user to design and simulate a chemical engineering process without performing tedious calculations. ASPEN PLUS® will be used in this project, to simulate the craft/microbrewery process as seen in figure 1. ASPEN PLUS® was chosen due to the ability allow the user to pick and choose the components for a process model, rather than have a standard model you must choose from. This is useful because it provides flexibility to model the whole brewery process or focus on one equipment in the process. Another reason this software was chosen was because of familiarity since this software has been used before in other classes. Once the simulation model was built, the necessary parameters specified from a recipe would be input into the simulation before it could be run. The software would then output the results for each part of the process. ASPEN PLUS® was chosen to model the craft microbrewery process due to the familiarity with the software, along with flexibility and variety of the software. Other software could not be explored due to the limitation of WPI student licensing.

Chapter 3: Methods

3.1 Microbreweries interviewed

Two microbreweries were visited to gather more in detail information about real world practices. The first microbrewery that was visited was Wormtown, located in downtown Worcester, MA. Wormtown currently has 35 employees which work either in the tap room, sales, packaging, manager or the brewery “pit” room. Wormtown currently is located at 24,000 square feet facility in which a new canning lining was recently added. At this facility, they offer roughly around eight to beers on tap at one given time, which is standard for craft breweries since they pride themselves on offering variety. In 2017, Wormtown produced roughly 21,236 barrels of beer which were either distributed to locations across New England or sold locally in Worcester. The second microbrewery visited was Greater Good Imperial Brewing Company in

Worcester, MA Greater Good is currently leasing a facility in which the taproom is 2,500 square feet. They currently do not have a canning line and outsources this process to another company. Greater Good currently needs a way to monitor quality control when product is shipped on a truck in response to feedback from customers that their beers taste differently when bought at the taproom. Greater Good also desires to grow their own yeast in the future to ensure more quality control.

3.2 Variables affecting beer

Across the various configurations a brewery may have, certain universal variables will affect the beer. These include temperature, biological contaminants, oxygen, and light.

3.2.1 Temperature

For both storage and production, climate control, namely temperature, is essential. Greater Good has a climate-controlled storage area for holding grains and hops to help keep them fresh, as the humidity given off from the rest of the brewing process can, with sufficiently warm temperatures, foster bacteria and mold growth. Similarly, high temperatures can spoil beer via side reactions and bio-contaminants, which make refrigerated transportation ideal, but can be cost prohibitive for smaller breweries. Greater Good expressed concern that their product isn’t being contractually shipped in climate-controlled units and are interested in placing temperature probes in product cases to investigate this. The owner of Greater Good explicitly stated that their biggest issue with product consistency isn’t production, but rather transport of the finished product.

During production, fermentation produces heat which has to be managed. Overheating can denature enzymes, kill yeast, spur side reactions, and promote competing bacteria growth. This is the reason many brewers use jacketed reactors, but the coolant choice does matter. Greater Good uses water since it’s cheap and available but does not boast ideal thermodynamic properties for the temperature ranges needed. Due to this, Wormtown and Harpoon use ethylene glycol. In either case, the larger the fermenter, the higher the coolant flow rate needs to be due to the changing surface area to volume ratio. A solution could be to use numerous smaller fermenters, which offers greater control but does not change the coolant demand and takes up additional floorspace. Fermenter selection is essential in planning facility expansion since it impacts several other variables. Additionally, the rapid cooling of hot wort is essential in production for reasons stated earlier in the background.

3.2.2 Bio contaminants

Stray bacteria and yeast are a threat that extends beyond cleaning equipment between uses. Equipment can be cleaned and sterilized in a number of ways. Greater Good explained they have numerous cleaning solutions that can be used between batches, air-tight connections and a flush of CO2 before use, and a steam sterilizer for the bottling line. Wormtown uses ionized air for their bottling line and uses much the same tactics as Greater Good. Unfortunately, there is no way to determine the contamination level in real time, though lab samples could be performed if the brewery invested in one; Harpoon has one, and Wormtown is considering getting one. This usually requires hiring professional personnel, posing a barrier to smaller sized breweries.

3.2.3 Oxygen

Oxygen exposure can spur the growth of undesired bacteria or cause side reactions that can alter or spoil beer. From boil kettle stage onward, oxygen is an active contaminant concern. Pipes between units are flushed with CO2 before being used, as seen with Greater Goods' flexible tubing. one-way gas valves in fermenters prevent backflow into the vessel and are ubiquitous. We have also noted that once of the reasons brewers take so long to purchase a canning/bottling line is to save for a higher quality system that reliably keeps out oxygen and bio-contaminants out.

3.2.4 Light

The introduction of light to the finished beer can cause side reactions that can change the taste, or even spoil the beer entirely. This is universally recognized by brewers, who in response take appropriate steps to minimize exposure. A guided tour of Harpoon brewery emphasized its use of dark glass bottles, with large labels and paper carriers to cover the glass. Cans, kegs, and equipment used are opaque by default (ie stainless steel), passively eliminating the risk.

3.3 ASPEN PLUS® Simulation Model

To study the kinetics of a craft brewery ASPEN PLUS® simulation software was used to model the craft brewery process. Our simulation model for the craft brewery process consists of a kettle and fermenter as seen in the figure below.

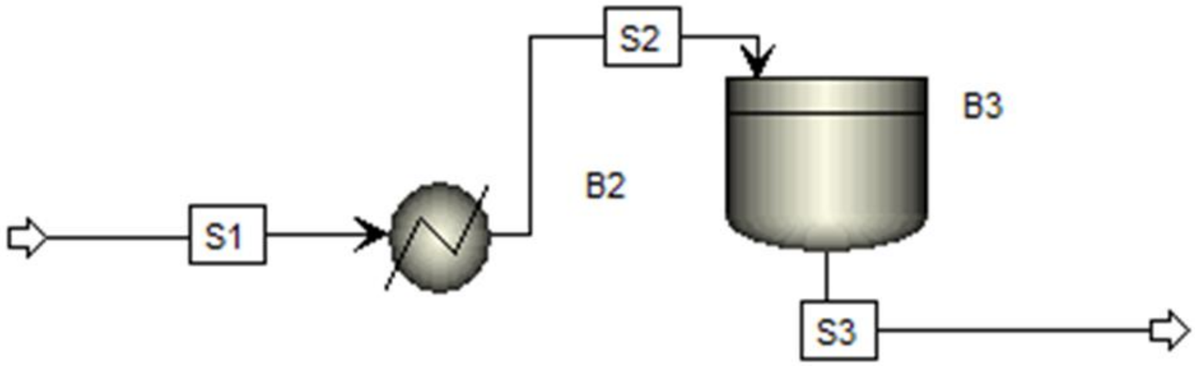

Figure 2: ASPEN PLUS® Simulation Model

The reason the model is incomplete is due to ASPEN PLUS®'s limitations. One major limitation of ASPEN PLUS® was that a lot of the omitted equipment was simply not in its database. Another limitation was that there was no easy way to model yeast kinetics. To model yeast kinetics, a separate input code file would have needed to be written, say in Matlab®, with the appropriate parameters. The software does not factor any human interaction, such as adding materials by hand. This is important since there are instances in which brewers add flavor additives to the beer manually (imprecise) and contaminates may be introduced. The last limitation of this software is that brewers may alter the original recipe by deciding for themselves when fermentation is complete. Brewers consider fermentation to be done when the material stops bubbling, which signifies that the carbonation is a range rather than one specific value of alcohol content, or by taste. The benefits of the software were that this software has been used in previous academic classes along with it gave us flexibility to model the process. The possibility of ASPEN PLUS® in future works could be using the project as a baseline and then creating a software to model the chemistry of the brewery process based on certain parameters. The aspen model we used considered the simple chemical reaction of sucrose turning into ethanol and carbon dioxide. This simulation model was run using the UNIQUAC model since many of the property models were not applicable for the brewery process. The three remaining models to choose from were UNIQUAC, UNIFAC and NRTL. Upon further research, it was found that the three models were very similar, therefore our group decided to go with UNIQUAC due to our familiarity with this property model. Each parameter for the streams and equipment differed due to the fact each recipe requires different inputs for each stream or equipment. An example of input parameters required can be seen in appendix D.

Chapter 4: Results

4.1 Bottlenecks aspects from interviews

While visiting the craft breweries, the interviewers helped identify key components that are taken into design considerations. When designing a brewery process, a craft brewer should consider fermenters since this process takes roughly a week based upon each recipe. The more fermenters a craft brewery can have will result in more production variety and more capacity for each craft beer. Unfortunately, companies cannot decide to buy one hundred 200-gallon fermenters and expect to produce a lot of craft beer because the reboiler and kettle limit this. The reboiler and kettle must be upgraded along with the fermenters to be able to process the same capacity as the brewer wants. This is sometimes overlooked by microbrewers which is worrisome since a kettle and reboiler costs significantly a lot more money than one fermenter. Another factor to consider in the long run is installing a bottling/canning line since a lot of microbrews outsource this process or do this manually themselves. This process sometimes takes a lot of time and energy because the cans or bottle must be sanitized by hand. This time could be focused on potentially preparing the next batch. The last area of concern throughout the process is quality and climate control.

4.2 Business Factors

The interview process informed us about business factors that should be taken into consideration. The first two business factors to be considered involve money. The first factor involves taking into consideration loan payoffs because this will be one factor that hinders you from upgrading. The other factor that hinders companies from upgrading is contracts with their suppliers for inputs. These contracts tend to be signed five years in advance with the suppliers which means companies would need to ensure that they have enough money to front the cost of a five-year contract. These two factors impact upgrades because the company will have to make sure to have enough money to pay off their current or upcoming debt along with make sure they are not taking too many risks which could result in the company losing money or going bankrupt. The last factor to consider involves the building the company decides to purchase because the owners will have to design their layout of their business. This could include where the tap room will be located, where the equipment to produce the beer will be located and any future expansion plans. The reason a layout needs to be created is because the equipment for the brew process needs to be placed by a crane through a hole in the roof. Therefore, if the owners do not leave enough space for future equipment, this could make it more difficult to move the equipment to a new location in the future. Also, if the company decides to expand the building then they must think if it feasible to expand or better to move to a new location.

4.3 Quality Control Issue

After interview the microbreweries, the most important factor to tackle throughout the brewery process is quality control because each microbrewery we talked to was very proud for creating a consistent product, but a big issue was that customers would note that getting a beer from tap was significantly different than one which was bought at a store. A major reason for the difference could have been that the quality control was not ensured throughout the shipping process. This can be combated by installing cheap temperature control sensors on some of the palettes to monitor the temperature of the beer. This helps brewers and owners ensure if the shipping company is providing adequate quality control for the breweries product as they promised. If that is not the case, the brewery could switch delivery companies to ensure adequate temperature or tell the delivery company about the issue and ask for a resolution to this issue. The microbreweries interviewed also mentioned that they might even stop selling beers at stores because the brewery company sometimes must pour the product down the drain which costs them money. Another factor to consider is mutation of yeast after a few uses. This of course results in higher cost because the yeast is roughly only used twice before thrown away to make sure the product is consistent. A way to ensure better control is to do some smaller scale test runs to figure out how many times the yeast can be used before it mutates and gives off a unique flavor. Another way to ensure the quality of the yeast and prevent it from mutating much is to have a lab which creates the yeast that is being used. These are two potential options, but it depends on the company and their technical background along with costs for each option. The last factor to combat quality control was that the process is semi-automatic for many microbrewers. A lot of the head brewers add components to the fermenter which cause the product to be exposed to the environment. This could affect the quality of the batch and the consistency of each batch. A suggestion to combat this would be to either make the process automatic or innovate the current equipment for these needs. If the process was made automatic then a brewer could tell a computer when to add a certain component, but the brewer could not taste the product to ensure it is the taste the beer should have. The other solution would be to see if chambers or valves could be installed to the equipment. These chambers would work in which the hoses or materials could be added or connected in these extra chambers. Once hose is connected it would create a seal to ensure minimal loss to environment would occur and material would be dumped into batch with desired flow rate. This could also be used for solid materials in which the chamber acts like a jar attached and closes from top once all material desired is added to this chamber. After this, the chamber would release all the material into the liquid. All these issues can be combated with many solutions but it all depends on the breweries needs and money.

4.4 Aspen Results

After further analysis of the brewery process along with the capabilities of the simulation model we deemed this software to be inadequate to properly model the microbrewery process since we would need to be able to compare our results to literature data. This could only be done if we were able to conduct experiments to measure these values based on an actual brewery operation. Another aspect learned from the interviews was some of the process is not fully automated in which a machine adds a certain ingredient at a certain time. This cannot be modeled in aspen well since the software requires a rigid framework to be run rather than be flexible and ask for ranges.

Chapter 5: Conclusion and Future Works

Our findings demonstrated that the more successful brewery companies have long term plans rather than short term plans. Therefore, we recommend for future startup breweries to come up with a plan for the next 50 years of the business with five-year goals. This plan should take into consideration the business factors and bottlenecks and be detailed as much as possible because the company will reach a point in which it starts expanding very quickly. If the company does not have a plan in place, they could get stuck in a circular loop in which they want to expand but do not have the resources to expand which results in the company staying at their size for a while.

Our recommendations for future work consist of two non-exclusive business pathways. One is to create a standardized template for new craft breweries to follow. This would encompass many technically challenging components of starting and operating a craft brewery. It may include equipment lists, floorplans, future expansion, cleaning procedures, general best practices, and any other technically-intensive critical information/guidance. A singular simulation model can be used with all clients since the plants will be standardized, eliminating several unknown variables in the process. As a result, the simulation model can be more in-depth and may be used for more precise estimations, troubleshooting, and allows indexing of experience accumulated across breweries. This business approach would be more likely to retain client's long term due to the assistance brewery expansion and early in-depth integration with operations. This is best suited for those who want to start a craft brewery and are in the beginning stages.

The other pathway is to create a broad simulation template that can be modified for each brewery. Expansion planning and advising would also be case-by-case, as it traditionally has been. This would be comparatively more expensive and time consuming but is offset by an existing market.

Bibliography

The Brewing Process. (n.d.). Retrieved April 03, 2019, from https://aslanbrewing.com/thebrewingprocess

Brewing. (2018, July 5). Retrieved January 13, 2019, from https://en.wikibooks.org/wiki/Brewing

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Appendix A: Greater Good Questions

1. What are your biggest issues with making a consistent product? How do you overcome these issues?
2. How do you account for variation of source materials? (grains, hops, water quality)
3. What control schemes do you use in the beer production system? I.e closed loop (PID-controls) vs open loop system (Adding by hand)
4. Any changes you would like to see in the future and why?
5. How do you limit oxygen levels in beer production?
6. How do you sanitize at every step? (Such as the equipment and bottles/cans)
7. Any plans for canning/bottling system?
8. What is your biggest challenge in making a quality product?
9. How do you know when fermentation is done?
10. Impact of filtration vs no filtration and how do you filter it?
11. Under what conditions would you consider pasteurizing?
12. What is the ideal number of fermentors per kettle?
13. What is the benefit of having a primary and secondary phase for fermentation?
14. Do you use warmed up water for next batch in heat exchanger? Or do you prioritize cooling off kettle and cool it as quick as possible?
15. How do you filter raw material water?
16. How do you choose which yeast to use? When do you know to use a new culture

Appendix B: Wormtown Questions

1. What are issues/bottlenecks?
2. What are you doing well?
3. Do you have enough instrumentation / controls to make consistent product?
4. Production per year?
5. Mixing finished batches to get consistency?
6. What do they purchase vs make themselves? Why?
7. Grain size distribution?
8. Differ from other brewers?
9. Additives?
10. How they filter finished product?
11. Different grains / malts alter product?

Appendix C: Useful Resources for Sponsors

1. https://interestingengineering.com/science-brewing-beer
2. https://www.equippedbrewer.com/production-and-operations/top-3-quality-control-methods-for-your-brewery
3. http://www.howtobrew.com/
4. https://www.beerbooks.com/cgi/ps4.cgi?action=enter&thispage=1305

Appendix D: ASPEN PLUS® Parameters

ASPEN Unit/Stream	Stream 1	Parameters	Fermentor 1	Parameters	Stream 2	Parameters	Fermentor 2	Parameters	Stream 3	Parameters	Stream 4	Parameters
Parameters Needed	Specifications		Specifications		Specifications		Specifications		Specifications		Specifications	
	Pressure		Constant Temperature		Pressure		Constant Temperature		Pressure		Pressure	
	Temperature		Reactor Pressure		Temperature		Reactor Pressure		Temperature		Temperature	
	Vapor Fraction		Catalyst Loading		Vapor Fraction		Catalyst Loading		Vapor Fraction		Vapor Fraction	
	Composition		Reactor Phase		Composition		Reactor Phase		Composition		Composition	
	Sucrose Flow rate		Operation Times		Sucrose Flow rate		Operation Times		Sucrose Flow rate		Sucrose Flow rate	
	Ethanol Flow Rate		Total Cycle Time		Ethanol Flow Rate		Total Cycle Time		Ethanol Flow Rate		Ethanol Flow Rate	
	Carbon Dioxide Flow Rate		Batch Feed Time		Carbon Dioxide Flow Rate		Batch Feed Time		Carbon Dioxide Flow Rate		Carbon Dioxide Flow Rate	
			Maximum calculation time				Maximum calculation time					
			Time interval between points				Time interval between points					
			Stop Criteria				Stop Criteria					
			Location	Reactor Vent Accumulator Vent			Location	Reactor Vent Accumulator Vent				
			Variable Type	Time Mole Fraction Mass Fraction Conversion Total Moles Total Mass Total Volume Temperatrure Pressure Vapor Fraction Vent mole flowrate Vent mass flowrate Prop-set Property			Variable Type	Time Mole Fraction Mass Fraction Conversion Total Moles Total Mass Total Volume Temperatrure Pressure Vapor Fraction Vent mole flowrate Vent mass flowrate Prop-set Property				
			Stop Value				Stop Value					
			Kinetics				Kinetics					
			Select Kinetic Reaction	Emulsion Free-rad General Ionic LLHW Powerlaw Segment-Bas Step-growth User Useracm Ziegelr-nat			Select Kinetic Reaction	Emulsion Free-rad General Ionic LLHW Powerlaw Segment-Bas Step-growth User Useracm Ziegelr-nat				

APPENDIX E: ASPEN PLUS® INPUT FILE

```
;Input Summary created by Aspen Plus Rel. 36.0 at 16:43:01 Wed Apr 24, 2019
;Directory R:\MQP_3  Filename R:\mqp.inp
;


DYNAMICS
    DYNAMICS RESULTS=ON

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

DEF-STREAMS CONVEN ALL

MODEL-OPTION

DATABANKS 'APV100 PURE36' / 'APV100 AQUEOUS' / 'APV100 SOLIDS' &
         / 'APV100 INORGANIC' / 'APESV100 AP-EOS' /  &
        'NISTV100 NIST-TRC' / NOASPENPCD

PROP-SOURCES 'APV100 PURE36' / 'APV100 AQUEOUS' /  &
        'APV100 SOLIDS' / 'APV100 INORGANIC' / 'APESV100 AP-EOS' &
         / 'NISTV100 NIST-TRC'

COMPONENTS
    SUCRO-01 C12H22O11 /
    ETHAN-01 C2H6O-2 /
    CARBO-01 CO2

SOLVE
```

```
    RUN-MODE MODE=SIM

FLOWSHEET
    BLOCK B3 IN=S2 OUT=S3
    BLOCK B2 IN=S1 OUT=S2

PROPERTIES UNIQUAC

STREAM S1
    SUBSTREAM MIXED TEMP=72. <F> PRES=12.54 <psig> FREE-WATER=NO  &
        NPHASE=1 PHASE=L
    MOLE-FLOW SUCRO-01 500. / ETHAN-01 0. / CARBO-01 0.

BLOCK B2 HEATER
```