Process Optimization of a Belgium Dubbel

The Worcester Dubbel

A Major Qualifying Project
Submitted to the faculty of
Worcester Polytechnic Institute
In partial fulfillment of the requirements for the
Chemical Engineering Bachelor of Science Degree

Sponsored By:
Purgatory Beer Company
670 Linwood Ave.
Whitinsville, MA 01588

Report Presented By:
Sarah Ewart
Timothy McDonald
Anika Stundtner

Advised By:
Stephen J. Kmiotek

Abstract
Purgatory Beer Company aims to “offer a wide range of styles, and constantly push limits to create unique and delicious new offerings” (Purgatory Beer Company, n.d.). Our team decided to add to their list of new offerings by refining the recipe and brewing process for a Belgium Dubbel. We conducted controlled homebrew experiments and varied the equipment, critical temperature timepoints, and the ingredients. We determined that the factors varied do have an effect on the quality of beer brewed. From our experiments, we recommend that Purgatory Brewery find similar ingredients from their bulk suppliers as used in Batch #10 and conduct their brewing process in a similar but adapted way to create the optimal Belgium Dubbel.

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Introduction

Craft breweries in the United States must maintain certain standards to qualify for the title, such as making less than 6 million barrels of product a year. These breweries are small brewers that commonly produce innovative beer (Brewers Association, 2020). Recently, the beer industry has shifted in favor of smaller brewers and consumers have become increasingly fascinated by the innovative beers.

To build off the growing demand for more unique beers, the focus of our project is a Belgium Dubbel. This beer is dark in color and has a malty sweetness with caramel and chocolate flavors. It has a medium to full body, with mild hop bitterness to balance out the sweet, but there are no lingering hop flavors present (Luna, 2017). This beer originated in Belgium, as the name suggests, and is well-paired with a bold cheese, flavorful meat, or chocolate. All around this beer is unique, and fits perfectly into the craft beer industry.

Purgatory Beer company, located in Whitinsville, MA, prioritizes crafting unique beers that do not follow the mainstream beer production industry. The company is co-owned by Brian Distefano and Kevin Mulvehill, who share a love for beer. There is a need to create a unique beer that is backed by science and can be produced with consistent quality. The beer produced will be easy to produce in their facility and the scientific analysis will be completed while preparing the optimal recipe.

The goal of this project is to refine the recipe and brewing process for a Belgium Dubbel that gives the most enjoyable flavor. Multiple processes will be varied in order to determine the optimal recipe. Modified variables include: sugar type, fermentation time, yeast type, and time during the brew when sugar is added. Additionally, the beer quality will be monitored through testing methods such as specific gravity, pH, and compound analysis. The composition of the beer will be analyzed to provide a greater understanding if components in the beer are creating desirable or undesirable flavors allowing the recipe to be modified to create a better tasting beer. The methods will determine the most optimal Belgium Dubbel recipe and production process. Considerations will be taken to modify the recipe for scale-up in the brewery and the information for the optimal Belgium Dubbel will be given to Purgatory Brewing Company.`

Background

Beer History and Popularity

Beer is a beverage enjoyed around the world and is a favorite among many alcohol drinkers. In fact, in a 2018 Gallup survey, 42% of Americans who drink alcohol preferred beer over other alcoholic beverages (Dugan, 2018). This surpasses the percentage of Americans who prefer liquor or wine. Thus, the market is abundant and has been for centuries.

Although there is some controversy as to who was the first to brew beer, there is written evidence of the brewing process documented by the Egyptians on papyrus scrolls around 5,000 B.C (Heartland brewery, n.d.). It is speculated that they used raw materials such as pomegranates, dates, or other herbs in the brewing process. Naturally, the process was modified and spread across the world as people moved and human civilization evolved.

The beer industry has now become a mutli-billion dollar business, bringing in approximately $116.0 billion dollars in sales a year (Brewers Association, 2020). Contributing to these sales are five large brewers including Anheuser-Busch Inbev, MillerCoors, Constellation, Heineken USA, and Boston Beer (America's Beer Distributors, 2020). However, the beer market is competitive and ever-changing as indicated by the more than 9% shift in sales to smaller brewers since 2009 (America's Beer Distributors, 2020).

Purgatory Beer Company

Purgatory Beer company, located in Whitinsville, MA, falls under the microbrewery category. A microbrewery can be defined as a brewery that produces less than 15,000 barrels of beer per year (Brewers Association, 2020). Since Brian Distefano and Kevin Mulvehill opened Purgatory in 2017, they too have experienced a growth in sales like many other smaller breweries. In general, craft breweries aim to preserve historical brewing styles, while adding their own spin on the recipes. Specifically, Purgatory aims to "offer a wide range of styles, and constantly push limits to create unique and delicious new offerings" (Purgatory Beer Company, n.d.). With this, our team decided to add to their list of new offerings by brewing a Belgium Dubbel.

How to Homebrew

The first step in brewing a beer is to acquire all the necessary equipment to conduct a brew and provide the correct containment for the fermentation process to occur. The equipment needed is as follows: boiling kettle, 6 gallon plastic bucket for fermentation, airlock with rubber gaskets, copper cooling coil, plastic tubing for syphoning, hydrometer, thermometer, nylon mesh grain bag or cheesecloth, bottles with airtight caps, and sanitizing solution. Once all the equipment is acquired, the next step is to purchase hops, grains, malts, sugars, and yeast. This step can vary dramatically depending on the type of beer desired.

After gathering all necessary equipment and raw material, the brewing process begins. The first step in this process is the mash. During this phase, the grain and malt go into a mesh bag and steep in water. When conducting a homebrew, one may use anywhere from 6 to 12 lbs of a mixture of grains and malts. The mash takes anywhere from 1 to 2 hours and there are many different methods for bringing the temperature up to a desired threshold of 170ºC. Some homebrewers will do a plateauing effect in which they will take certain periods of time to bring the mash up to predetermined temperatures. The overall time does not matter as well in terms of the length of the mash. 90% of the enzymes and sugars that can be extracted from the grain mixture are normally removed after an hour. However, the longer the mash, the more certainty there is that the highest extraction rate is achieved. The aqueous solution possesses a somewhat viscous property due to the extraction that occurs. This solution is the "wort" (Denny, 2009).

Once the mash has been completed the next step is to boil the wort.The reasoning behind this process is to remove or kill any impurities that may contaminate the wort and eventually the final product, the beer! These impurities consist of unwanted bacteria, insects, and undesired proteins that come off the grain. Before starting the boil, the grain bag is removed from the wort and in its place the bittering hops are added. The reasoning behind adding the hops to this phase instead of the mashing step is simple. When increasing the temperature of the wort the bittering hops release the acids that give the hops their key flavor. These acids transfer into the wort to further enhance the flavoring of the final product. The boiling process is recommended to be done over

the course of at least an hour and to have a rolling boil for the entire duration. One key element to pay attention to during this process is the rate at which the foam is rising inside of the kettle. Heat may have to be lowered at points and frequent stirring is recommended. The last final element of the boiling stage is the adding sugar and aroma hops. These two key ingredients are added during the last portion of the boil and play a key role in favoring the beer. The sugar also plays a significant part in the fermentation process as it is the nutrition for the yeast. Similarly to the amount and variety of grains that were used in the mash, the sugar is dependent on the type of beer being brewed. The aroma hops are also added during the last phase of the boil. They can be added at any time, but usually with 10 or fewer minutes remaining. The longer the aroma hops are left in the boil the stronger the aromatic flavor will be (Denny, 2009).

After completing the boiling process it is now time to cool down the sweet wort. During this step there is a high risk for bacteria to be introduced into the system. As the wort cools below the 160^{o}F threshold it is extremely vulnerable to contamination. To prevent this from occurring all equipment that comes into contact with the cooling sweet wort from this point on is required to be sanitized. This includes any thermometers, hydrometers, syphoning equipment, and fermentation unit. Additionally, the cooling unit is also sanitized. This is done, however, in the last 20 minutes of the boil by introducing the cooling unit to the boiling sweet wort. Once all equipment is sanitized the sweet wort may now be cooled (Denny, 2009).

To initiate the cooling process, the cooling coil is connected to running tap water, and then water flows through the coil, removing heat. The sweet wort is brought to a temperature range of 70^{o}F-80^{o}F and once this threshold is obtained, the cooling process is complete. The cooled solution is transferred to the fermentation unit for the final step in the process. Before transferring the solution, at this point a specific gravity reading is recorded. This ultimately helps to determine the final abv% content of the beer (Denny, 2009).

Once the sweet wort is transferred into the sanitized fermentor, the yeast is added to the mixture. This can be done by either using a liquid yeast or a dry yeast. If using a dry yeast one may have to activate the yeast or simply introduce the yeast in its dry form to the sweet wort. Either of the options will work for small scale fermentation. After an airtight lid and airlock with rubber gasket seals the system off from risk of contamination and oxygen. If either of these are introduced once the yeast has been added, the final product will have a vineragery sour taste which is unpleasant to the consumer. Once the yeast is introduced to the system, the fermentation process begins. Depending on the beer type, this stage can take anywhere for 3 weeks to more than 2 months (Denny, 2009).

Finally, the last step in how beer is made is the bottling process. This can be tedious if bottling beer individually by hand, but can be more efficient if completed in a keg. All the bottles, or keg, are thoroughly sanitized and prepared for the newly fermented beer. Air tight caps seal the bottles to allow 1 week of carbonation to occur within the new vessel. After this time has passed, the bottles are ready to be chilled, then served (Denny, 2009).

For our project specially, our team will be focusing on brewing a Belgium Dubbel. This is a darker beer that has a caramelized flavor, with grainy undertone, and is smooth to drink (Luna, 2017). A normal interpretation for a dark beer is heavy and creamy, but a Belgium Dubbel is the

opposite of this. For this reason, being unique, and not normally seen in microbreweries, our team proposed this beer to Purgatory Beer Company. Their mission is to stand out from the rest of the pack, and brew beers that are high quality and different from other microbreweries. A Belgium Dubbel can vary in ingredients, but for our project our team is anticipating using 2-Row and German Pilsner grains accompanied by Caramunich and Special B malts. This provides the necessary enzymes and dark base color to our Belgium Dubbel. For the sugaring agent our team is using Candi-Syrup D-90, which is a belgium candi-syrup commonly used in microbreweries and homebrew. For hops our team is using Perle for bittering and Saaz for aromatic. Finally, our team is using T-58 dry yeast for our fermentation phase. These ingredients are based on a homebrew recipe that was found online (Appendix 3). More specific details on the amount of raw material being used will be specified in Appendix 1.

Analyzing beer quality

Quality control and quality assurance practices are tools used in the brewery industry to monitor beer quality. Taking measurements such as specific gravity, pH, and international bitterness units (IBU) readings are common practices to monitor through the production process. Additionally, monitoring the yeast counts and viability in pitches both following difficult batches or routine monitoring are strong methods. It is uncommon for small craft breweries to pasteurize the final product. This makes quality control and assurance practices especially important to ensure the customer is receiving a quality product. One method to avoid bacteria growth is to complete micro readings on fermentation and brite tanks after they have been cleaned. Identifying anaerobic contamination can prevent a defective batch by washing the tank until receiving a result with no contamination. Bacteria growth, unwanted flavors, and inconsistent batches can damage the business's reputation (Crowell, 2015).

Additionally, the ethanol content must be measured to determine the beer characterization of the product. The methods breweries use to analyze ethanol content must be fast and easy in order to optimize the production process. Inexpensive and accessible methods are important in the industry, especially for small craft breweries with limited funds. Common methods used include: measuring density after distillation, gas chromatography analysis, measuring combined density and sound velocity, data based on enzyme driven catalytic reactions, and near-infrared spectroscopy (Engelhard et al., 2004).

Specific Gravity

The specific gravity of a beer is important because it can be used to measure the percent alcohol by volume (ABV). On average, beer ranges from 4 to 7 percent alcohol by volume (Monico, 2020). In the brewing process, the specific gravity is taken before and after the fermentation process using a hydrometer to take the measurements. The difference between the specific gravities, multiplied by a factor of 131.25, gives an approximate ABV (Homebrew Alcohol by Volume Calculator, n.d). For a Belgium Dubbel, we expect to get an alcohol percentage of around 5.9%.

Gas Chromatography

Gas chromatography is a tool to measure the quality of the product. While the main ingredients of beer are water, yeast, hops, and malt, volatile compounds can form during the production process. These volatile components create a spectrum where they have little to no impact on the

product to detrimental quality impacts. Volatile components form during yeast fermentation while the main component ethanol is produced. Secondary metabolites at low concentrations can form during fermentation. The resulting taste and aroma can have undesirable impacts depending on which compound is formed. The major types of compounds include: higher alcohols, esters, carbonyl compounds, and vicinal diketones (Olaniran et al., 2016).

Depending on the type, higher alcohols have positive or negative impacts on the flavor and aroma of the beer. Large quantities cause undesired and negative impacts on the products, while small quantities are desired and have a positive impact on the product. Isoamyl alcohol is a common higher alcohol that creates a heavier flavor in the product as the concentration of the compound increases. Isobutyl alcohol, another higher alcohol, negatively impacts the product when the concentration of this compound is larger than 20% of the total n-propanol, isoamyl alcohol, and isobutyl alcohol concentration totals (Olaniran et al., 2016).

Esters are produced during yeast fermentation. Esters are volatile components that have the largest impact on the beer's aroma. In small concentrations, esters provide a pleasant and full-bodied note to the beer. However, in large quantities esters can create an undesired synthetic fruity impact on the product. For example, isoamyl acetate creates a banana aroma and ethyl octanoate tastes of sour apple. If a beer has undesirable taste or aroma, a gas chromatograph analysis should occur to measure the amount and type of volatile organic components of the beer. Additionally, the common types of volatile compounds have known causes. If identified, the brewery can determine the unwanted compound and change the process to prevent it from forming again (Olaniran et al., 2016).

Sensory Training

While the quality assurance and control methods mentioned above are important to create a clean and desirable product, methods that monitor the beer flavors are critical to run a successful operation. Sensory analysis is a quality control method that uses taste to monitor beer during production (Simpson, 2016). Sensory analysis utilizes taste and smell senses. Experienced tastors block out other senses such as appearance to prevent bias while tasting (Bickham, 2020). Sensory tasters identify and rate the intensity of flavors in the beer. Sensory tasters take training courses to learn how to develop flavor perception. Product should be monitored via sensory analysis to prevent low quality or defective batches from being released. Additionally, sensory analysis can be used with gas chromatography to identify flavor instability, microbiological issues, isolated production incidents, and for process improvement (Simpson, 2016). *Figure 1* below identifies the flavor groups and specific flavors found in each category (Bonham, 2016).

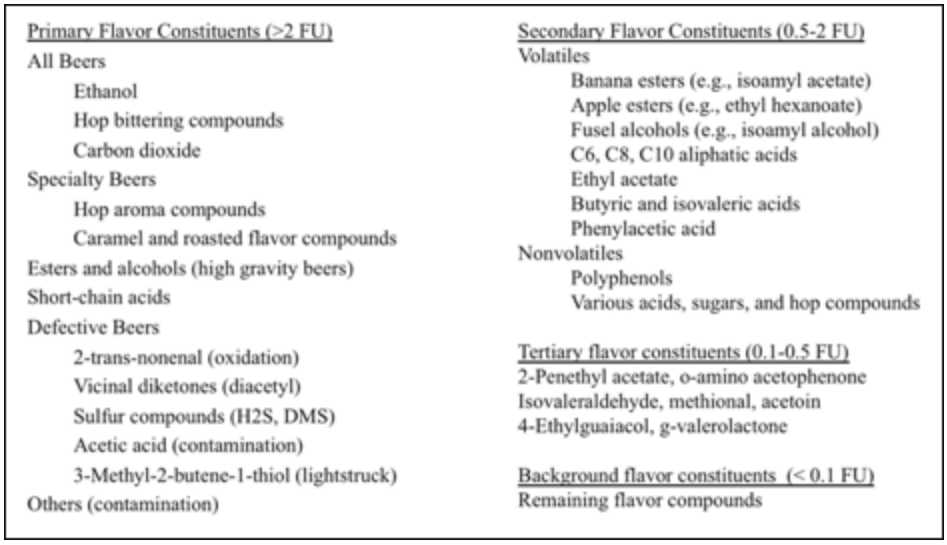

Figure 1. Meilgaard Thresholds chart (Bonham, 2016)

Anton-Paar Alcolyzer DMA 4500
The Anton-Paar Alcolyzer DMA 4500 is a machine at the University of New Hampshire Brewing Science Laboratory that measures a variety of properties of the sample.

Density and calories will be measured with this machine. Density is the mass per unit volume of the sample. Calories are the measure of energy per sample. This machine measures the percent alcohol in a given volume. This is the alcohol by volume measurement.

The real degree of fermentation is the amount of sugar in the wort that ferments into alcohol through fermentation. A sweet beer has more residual sugar from the wort in the final product. Beers with higher degrees of fermentation are a lighter and drier beer than one with a smaller real degree of fermentation. Beers with lower percentages have a syrup feeling and are sweet (Chlup, n.d.).

Methodology
The goal of this project was to refine the recipe and brewing process for a Belgium Dubbel that gives the most enjoyable flavor for Purgatory Brewing Company. Our team outlined four objectives in order to achieve our goal.

1. Determine the most efficient way to increase alcohol content by varying the type of strainer used to increase mass transfer.
2. Determine the critical temperature timepoints for enzyme extraction prior to mashout by varying the amount of time at each temperature.
3. Experiment with process variation to determine what yielded the highest alcohol content.
4. Determine the optimal flavor by comparing gas chromatograms from professionally made Belgium Dubbels to our homebrew batches.
5. Analyze the samples via Anton-Paar Alcolyzer DMA 4500 at the University of New Hampshire Brewing Science Laboratory.

Brewing Process
Each batch followed a similar recipe and ingredients list adapted from MoreBeer!'s information on brewing a Belgium Dubbel (MoreBeer!, 2018). The batch ingredients can be seen in Appendix 2. Each batch varied slightly from the original recipe.

Production also varied between batches. The procedure was varied following each brew in order to determine the optimal batch.

Equipment
To hold the grain during the brewing process, three variations of a strainer were tested. The first strainer was a cheesecloth strainer that sat in the kettle's metal insert. The second and third strainers were iterations of a ¼ inch wire mesh frame.

Pictures of the wire mesh strainers are shown in *Figure 2*, *Figure 3*, and *Figure 4*. The first iteration of the wire mesh strainer was created using one sheet of mesh. The wire mesh surrounded the metal insert and was held together by wire.

Figure 2. First iteration of the wire mesh strainer

The second iteration of the wire mesh strainer was created using two pieces of mesh. One piece of mesh formed the outside walls and the other formed the bottom of the strainer. Again, this was held together by wire.

Figure 3. Second iteration of the wire mesh strainer

Note that the metal insert was not utilized in the second iteration of the wire mesh strainer, as shown in *Figure 4*.

Figure 4. Second iteration of the wire mesh strainer in the kettle

Time vs. Temperature

During each brew temperature vs. time data was recorded in order to ensure a temperature control could be maintained within each batch. Variance occurred in the amount of time spent at certain temperatures between trails. This data was collected to generate time vs. temperature graphs to then help determine the best temperature stepping method to be used. Enzyme exactration occurs mainly at 150^{o}F and operates between a window of 140^{o}F - 160^{o}F before stopping at 170^{o}F at mash out.

Specific Gravity

A hydrometer was used to measure the specific gravity of the beer. This measurement was taken twice for every batch, at two different time points. First, our team obtained an initial specific gravity value after the sweet wort was cooled, but before adding yeast. Second, our team obtained a final specific gravity value after the beer had fermented for two weeks. If after two

weeks, the specific gravity had dropped at least 75% from the initial reading the beer was bottled (Warren, n.d.).

The formula used to obtain the Alcohol By Volume (ABV) is shown in *Equation 1* below. Here, OG is the original specific gravity and FG is the final specific gravity. 131.25 is a standard correction factor. Note that this is only an approximation. As the alcohol content of beer increases, this approximation becomes less accurate.

$$ABV = (OG - FG) * 131.25 \quad (1)$$

To collect and measure these two samples, a sanitized siphon was used to transfer the beer from the fermenter to the hydrometer tube, at both time points. Our team ensured the hydrometer tube was filled to the brim. Then, the hydrometer was carefully placed into the tube as shown in *Figure 5*.

Figure 5. Specific Gravity Reading of 1.086 for Batch #9

Once the hydrometer settled, the specific gravity was read at the last line visible to the team. An example of this is shown in *Figure 5*. Here, the initial specific gravity was measured to be 1.086.

Gas Chromatography

A gas chromatograph was used to test batch samples. The results showed which components were found in the product—both undesirable and desirable. Four professionally made Belgium Dubbels were tested as control variables and compared to the batches produced in this MQP. Three bottles were randomly selected from each batch and then brought to Goddard Hall for testing. Only one sample from the three bottles was tested due to the shear volume of sampling that was being performed at Goddard Hall. This provided a completely random sample per batch to remove any bias that there may have been. The results were compared to previously identified component spikes. This allowed for flavor constituent identification, one method to identify the quality of the beer and decide which was the most optimal batch.

To run the GC-MS, 1uL injection volume was utilized for all samples. Samples were taken as-is and injected at an injection temperature of 290ºC in split mode with a 25 to 1 split ratio. The column oven temperature was set to 30ºC and was ramped to 200ºC at a rate of 2ºC per minute until it reached 200ºC and was held for 5 minutes. MS analysis was completed with an ion source temp of 200ºC and a scan speed of 1666. This test method was per Heather Leclerc (Appendix 4).

Anton-Paar Alcolyzer DMA 4500 Testing
The final tests completed were with the help of the University of New Hampshire Brewing Science Laboratory. This lab has an Anton-Paar Alcolyzer DMA 4500 machine. This testing was carried out by Cheryl Parker and due to COVID we were unable to assist in testing. This testing determined the alcohol content, real degree of fermentation, calories, density, and real extract.

Results & Discussion
In order to refine the recipe and brewing process for a Belgium Dubbel, we collected data during the homebrew process and after the batch was done fermenting. We also did background research prior to beginning the homebrew process. The results of our experiments are outlined in the following sections.

Objective 1
Our first objective was to determine the most efficient way to increase alcohol content by varying the type of strainer used.

To find if there was any correlation between alcohol content and the type of strainer used, we graphed specific gravity versus the batch number and noted the type of strainer used in the legend. Batches #1-#4 used a cheesecloth strainer. Batch #5 used the first iteration of the wire mesh strainer, as shown in *Figure 2*. Batches #6-#10 used the second iteration of the wire mesh strainer, as shown in *Figure 3* and *Figure 4*.

Batches #1-#4 had a specific gravity ranging from 1.014 to 1.026. Batch #5 had a specific gravity of 1.046. Batches #6-#10 had a specific gravity ranging from 1.062 to 1.086. *Figure 6* displays these results.

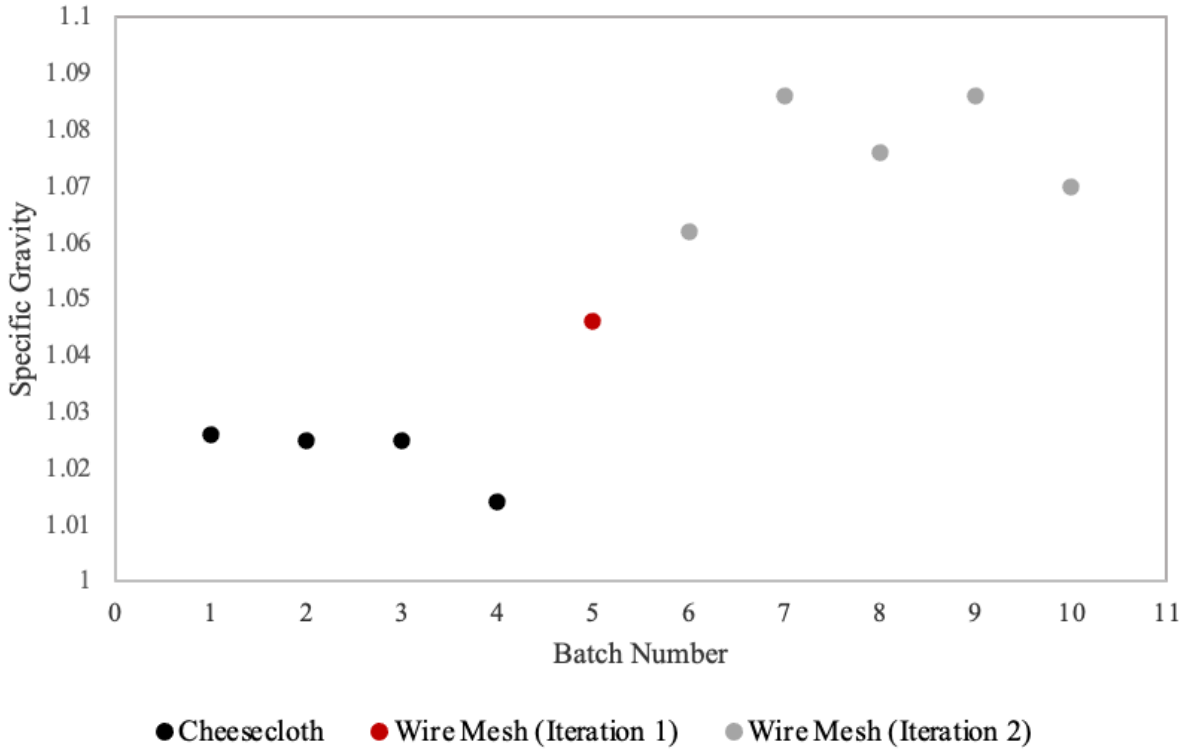

Figure 6. Specific Gravity vs. Batch Number

Notably, the first iteration of the wire mesh strainer showed a 0.0235 point increase in specific gravity compared to the cheesecloth strainer (*Table 1*). The second iteration of the wire mesh strainer also showed an increase in specific gravity in comparison to the first iteration. It showed a 0.0300 point increase.

Table 1. Average specific gravity according to strainer type.

Strainer Type	Average Specific Gravity
Cheesecloth	1.0225
Wire Mesh (Iteration 1)	1.046
Wire Mesh (Iteration 2)	1.076

Specific gravity is "a measurement of the density of liquid relative to pure water" (Warren, n.d.). The specific gravities presented in *Figure 6* are the original gravities and were taken prior to fermentation. A higher original gravity means a higher density, and likely more sugar has been extracted from the grain. A higher sugar content in the wort gives the yeast more opportunities to convert the sugar extracted to alcohol and carbon dioxide during fermentation. Ultimately, this leads to a higher alcohol content. Based on this logic, the second iteration of the wire mesh produced the highest specific gravity and alcohol content.

One reason why the second iteration of the wire mesh strainer had the highest average specific gravity was likely because there was increased mass transfer between the grain and the water. In Batches #1-#4 the cheesecloth tightly surrounded the grain. This left no opportunity for mixing as well as limited the mass transfer and extraction from the grain.

The wire mesh strainer was a turning point in our project. It allowed for manual mixing of the grain throughout the process. It also provided a larger surface area for the grain to come in contact with the water. Both of these factors contributed to a higher original specific gravity reading. This is shown in *Figure 7*.

Figure 7. Second iteration of the wire mesh strainer during the brewing process

Objective 2
Our second objective was to determine the critical temperature timepoints for enzyme extraction prior to mashout by varying the amount of time at each temperature.

Initially the group did not perform temperature stepping when conducting batch trials. This procedure was followed for Batch #1 and Batch #2, which can be observed on *Figure 8*. Due to this we did not achieve high levels of enzyme extraction due to reaching mash out, of 170^{o}F, too quickly. This was noted and we then adjusted our temperature stepping to be maintained at 150^{o}F for 60 minutes. This was first attempted in Batch #3, however, there were issues with controlling the temperature due to the electric oven that we were using as a heat source. Temperature fluctuation occurred and we surpassed the mash out threshold of 170^{o}F, but attempted to salvage the batch by bringing it back down. This did not succeed as enzyme extension had already been put to a halt.

In Brew #4, we made the decision to further increase the amount of temperature stepping. This decision was made based on two factors. The first being was how we had difficulty stabilizing the temperature at 150^{o}F when increasing the temperature. The second was that we knew enzyme extraction mainly occurs between 140^{o}F and 170^{o}F, so to increase the total solids in our wort we wanted to increase the window for extraction. In Batch #4, we conducted temperature stepping at 140^{o}F for 15 minutes, 150^{o}F for 60 minutes, and 160^{o}F for 15 minutes. It was recommended to us by Timmy Runnette, who is an avide homebrewer. He has noted during his homebrews that

80% total enzyme extraction occurs within 30 minutes of being at 150°F. He recommended that if we wanted to ensure 90%-95% total extraction, we should stabilize the temperature at 150°F for 45 minutes to an hour. After completing this batch we did not see the anticipated results of a higher specific gravity, but instead received a lower value. This prompted us to investigate our mixing, which was discussed in Objective 1.

After adjusting our mixing procedure and continuing with temperature stepping, we saw a large increase in the specific gravity that was recorded off of each batch. Our first decent batch occurred at Batch #6 when we received a specific gravity of 1.062. This utilized both proper mixing and temperature stepping. We then moved into our last four batches with a proven method for enzyme extraction that would help us achieve a higher specific gravity, thus resulting in higher alcohol contents. This data can be seen in *Figure 6* with the highest specific gravity of 1.086 from Batch #7 and Batch #9, which showed repeatability in our procedure and further solidified the decisions we made as correct.

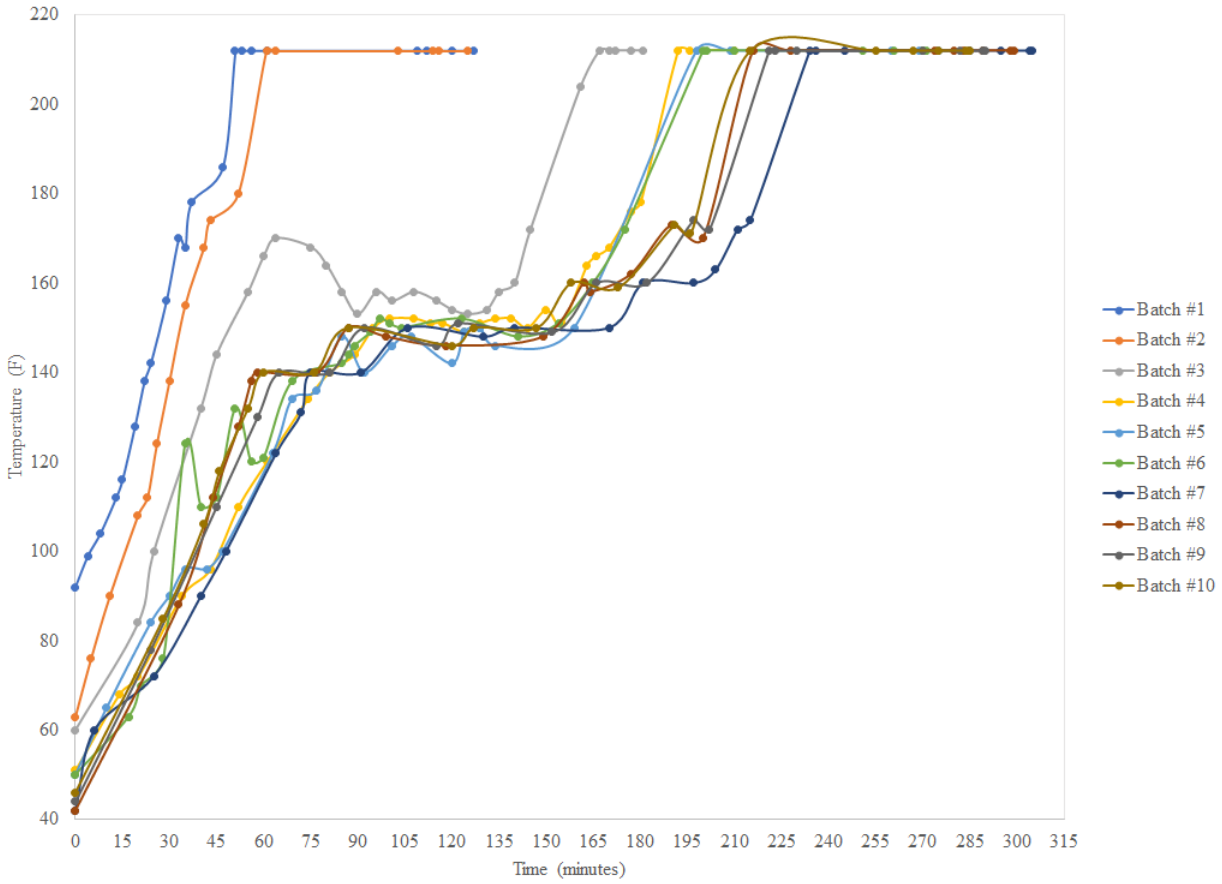

Figure 8. Temperature vs. Time Data from Batches

Objective 3
Our third objective was to experiment with process variation to determine what yielded the highest alcohol content.

Particularly, we were interested in determining if the type of sugar had an effect on the alcohol content. To find if there was any correlation between alcohol content and the type of sugar used, we graphed density (g/cm^3) versus the alcohol content (% v/v) and noted the type of sugar used on the graph. Only Batches #7-#10 are included on the graph because these batches were submitted to the University of New Hampshire Brewing Science Laboratory. The alcohol content measured for these batches is credible and compared to a calibration standard. This is more accurate than using *Equation 1*, the ABV approximation.

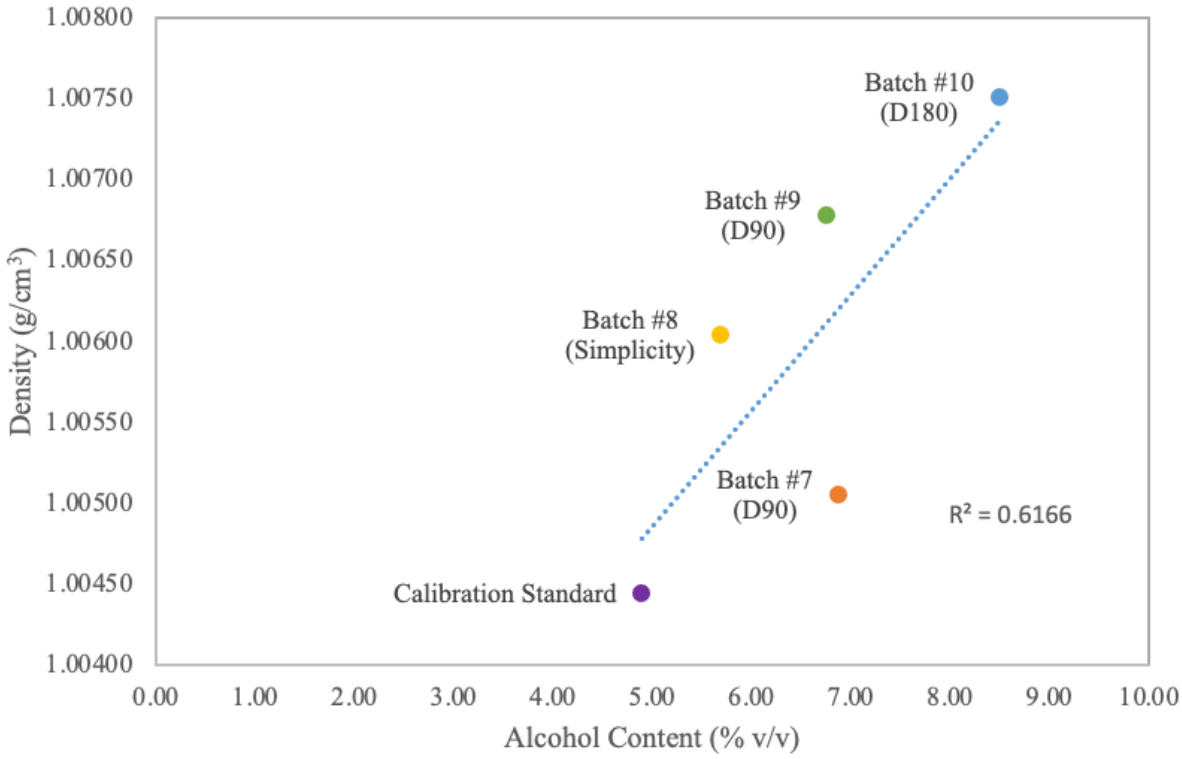

Figure 9. Density (g/cm^3) vs. Alcohol Content (% v/v)

Batch #10 used 8oz of D180 Candi Syrup and 1 pound of table sugar to account for the difference in color that D180 would provide, but matching the same sugar content by approximation. Batch #7 and Batch #9 used D90 Candi Syrup to prove that we could achieve consistency in our batches with varying available hops and yeast. Batch #8 used Simplicity Candi Syrup to vary the color, as well as, to vary the flavor that a lighter colored candied sugar would bring. These sugar choices varied the flavor and color, but more significantly changed the alcohol content.

D180 Candi Syrup produced the highest alcohol content, 8.50%. This was likely due to the pound of table sugar added to the wort. With a higher sugar content, more sugar can be converted into alcohol and carbon dioxide, as previously stated.

The alcohol content also increased as density increased. This showed a positive linear relationship with an R^2 value of 0.6166. Note that an R^2 value of 1 indicates a perfect linear fit. This relationship was unexpected. We predicted that the density would decrease with increasing alcohol content because the yeast consumes more sugar, leaving a less dense solution. It is possible that the batches with higher alcohol contents needed more time to ferment. In this case, the yeast would not have consumed all the sugar at the time of bottling and thus the solution would be more dense.

An additional factor to consider when comparing this data is the method for introducing the sugar to the wort. If there is a constant heat source still causing the wort to boil, there is a high likelihood some of the sugar will burn on the bottom of the brew pot. To combat this we removed the brew pot from the heat source to help prevent sugar from burning. We are not certain that a large amount of sugar was burned, but this is also a factor that must be considered.

Objective 4

Our fourth objective was to determine the optimal flavor by comparing gas chromatograms from professionally made Belgium Dubbel batches to our homebrew batches.

Figure 10 and *Figure 11* below compare the relative intensity data found from gas chromatography. The figure on the left shows the first three batches made. There are many spikes in this chart, but with minimal distinction to identify significant peaks. The chart on the right shows the final four batches brewed. This chart shows significant improvement from the first batches. The peaks are stronger, more defined, and there are more of them. This shows the process improvements were successful producing both more and stronger compounds.

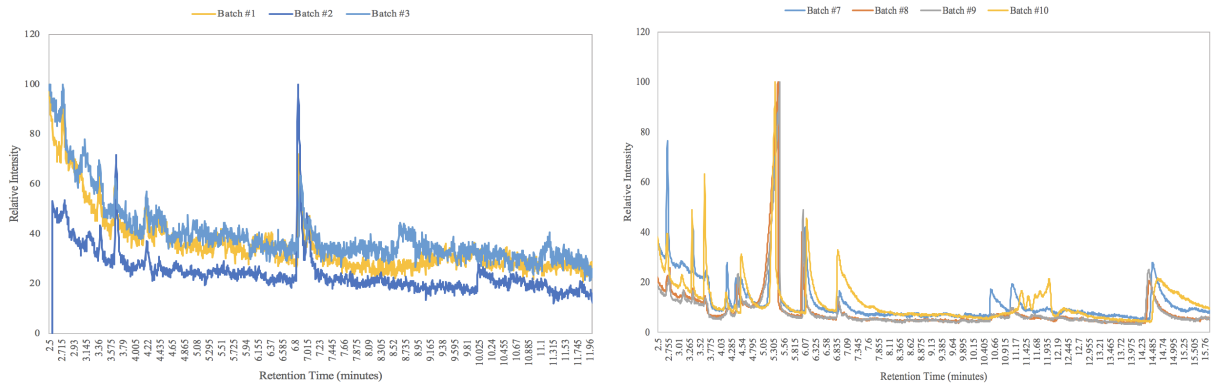

Figure 10. Batch #1- Batch #3 Relative Intensity Data (Left), **Figure 11.** Batch #7 - Batch #10 Relative Intensity Data (Right)

Figure 12 shows the professionally made control samples and Batch #7 - Batch #10. The chart displays an overlay of all samples for a comparison. *Figure 13* displays just Batch #7 - Batch #10 for a more detailed view of the peak strength. The professionally made beer has less defined peaks than any of the home brew batches. *Table 2* and *Table 3* provide a detailed breakdown on

the compounds found within the home brew batches. There are numerous undesirable compounds found in the homebrew batches, so not all of the spikes are beneficial. However, the flavor compounds remain more defined in the homebrew batches.

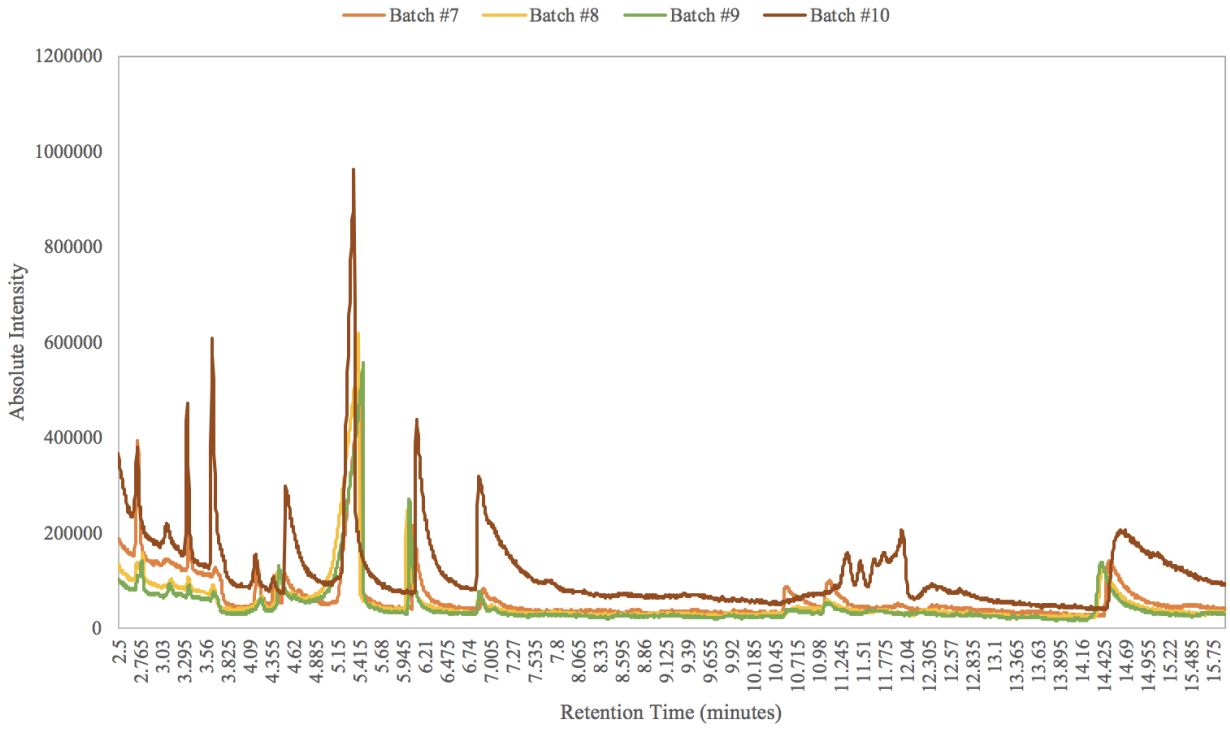

Figure 12. Absolute Intensity Data of Control Samples and Batch #7 - Batch #10

Batch #10 specifically has the strongest peak intensity of any batch in *Figure 12* and *Figure 13*. Batch #8 and Batch #9 are very similar in peak intensity and occurrence. In *Table 2* and *Table 3*, Batch #8 and Batch #9 show identical peak occurrence. The absolute intensity varied minimally, but the identical compounds were identified.

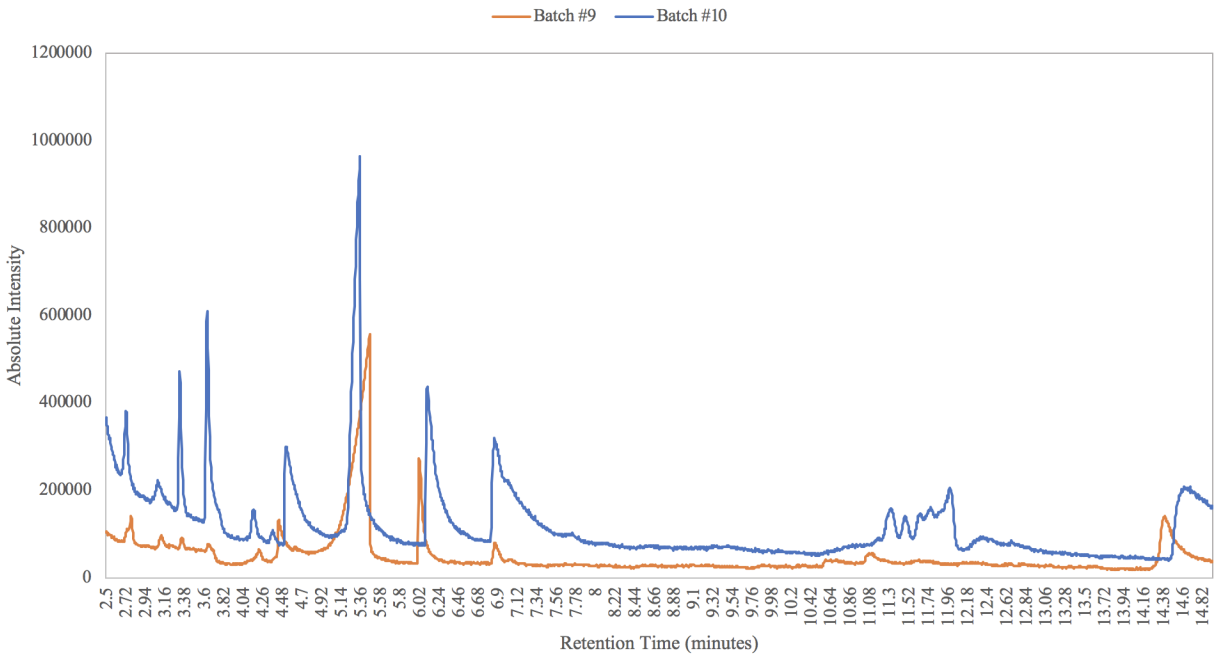

Figure 13. Absolute Intensity Data over Gas Chromatography Retention Time of Batch #9 - Batch #10

Table 2 displays the desired compounds in beer and which batch contained it in the Gas Chromatography data. The compounds in this table are desired compounds that positively benefit the flavor of the beer. Every batch contained ethyl acetate, ethanol, and isoamylacetate. Isoamyl alcohol and *β*-Phenylethanol were identified in multiple batches. Octanoic acid was not identified in any batch. Ethyl acetate is a flavor compound that over a threshold negatively impacts the flavor, but it benefits the flavor prior to that point (Olaniran et al., 2017).

Table 2. Desired Compounds Identified through Gas Chromatography Absolute Intensity Chart

Compound	Batch #7	Batch #8	Batch #9	Batch #10
Ethyl Acetate	X	X	X	X
Ethanol	X	X	X	X
Isoamylacetate	X	X	X	X
Isoamyl alcohol	X			X
Octanoic Acid				
β-Phenylethanol	X	X	X	

Table 3 displays the undesired compounds found. No unwanted flavor was found unanimously in all four batches. Batch #8 and Batch #9 contained the lowest unwanted flavor compound frequency, but these batches also had the weakest peak intensity. Batch #7 contained four

unwanted flavor compounds and Batch #10 had five unwanted compounds. Batch #7 had weaker peaks and less frequent spike occurrence than Batch #10, so having fewer flavor compounds was expected. The unwanted flavor compounds can be beneficial to the flavor of the beer until they reach a flavor threshold. However, the flavor threshold is lower for these compounds compared to ethyl acetate. This is why they are unwanted flavor compounds.

Table 3. Unwanted Compounds Identified through Gas Chromatography Absolute Intensity Chart

Compound	Batch #7	Batch #8	Batch #9	Batch #10
Isobutyl Acetate	X			X
Ethyl Caprylate/Acetic Acid	X	X	X	
Isobutanol		X	X	X
Ethyl Caproate	X			X
n-Octanol				
n-propanol	X			X
Capric Acid				X
Unidentified Acid				

Batches #8 and #9 contained less undesirable compounds than Batch #10, but the final batch showed peaks with higher intensity. The flavor profile and compounds in Batch #10 were significantly more defined as seen in *Figure 14*. Due to the weaker flavor profile shown by the peak intensity, Batch #10 is a stronger batch than the similar middle batches.

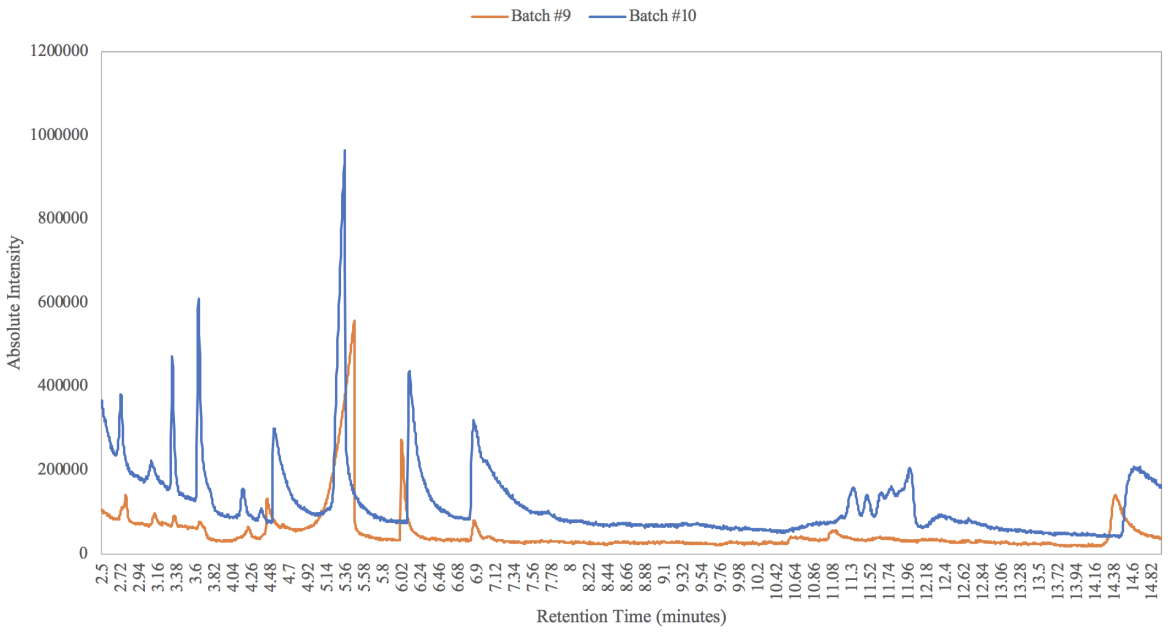

Figure 14. Comparison of Absolute Intensity of Peak Strength for Batch #9 and Batch #10

Objective 5
Our fifth objective was to analyze the samples via Anton-Paar Alcolyzer DMA 4500 at the University of New Hampshire Brewing Science Laboratory.

Objective 3 began to look at the results from the Anton-Paar Alcolyzer DMA 4500 (Appendix 5). *Table 4* below details the results from the University of New Hampshire Brewing Science Laboratory. The alcohol content significantly varied. The gas chromatograph showed Batch #8 and Batch #9 to be similar, but the alcohol content is very different. Batch #8 has a 5.69% ABV and Batch #9 has a 6.76% ABV. However, the batches had similar density and real degree of fermentation values. Batch #6 had the lowest ABV of 5.69% while Batch #10 had the highest of 8.50%.

Batch #7 had the highest real degree of fermentation, but the lowest density of all the batches. This batch also had the second highest ABV of 6.88%, Batch #8 also had the lowest real degree of fermentation. Batch #10 had the largest density and second highest real degree of fermentation.

Table 4. Anton-Paar Alcolyzer DMA 4500 Results

Data	Batch #7	Batch #8	Batch #9	Batch #10
ABV	6.88%	5.69%	6.76%	8.50%
Density	1.00505	1.00604	1.00678	1.00751
Real Degree of Fermentation	72.62%	69.40%	70.39%	72.04%

Conclusion and Recommendations

The findings in this report showed that Batch #10 is the ideal Belgium Dubbel for this project. This batch was a result of improved mass transfer practices. The mesh wire method used yielded an average specific gravity of 1.072 which is larger than the two earlier methods. Proper temperature stepping also assisted in creating this batch. This batch also used D180 syrup with table sugar. This sugar created the batch with the highest ABV. A large real degree of fermentation was found where 72.04% of the sugar in the wort was fermented. The gas chromatography results showed clean, distinct, and strong peaks of desired components.

Based on the results of this project, we recommend Purgatory Brewery find similar ingredients from their bulk suppliers as used in Batch #10 to create the optimal Belgium Dubbel. There will be differences since the ingredients will be different. A belgium yeast and belgium grains should be used since it is a belgium beer. Using hops with similar alpha acids, 2.8% and 7.8%, will provide a similar level of bitterness as the ones used in this project. A dark sugar should be used with a combination of the brewery's preferred sugar.

Adapting the optimal home brew process to match brewery equipment will allow for a similar beer to be produced. Trial and error might be needed when adapting home brew processes to the brewery equipment. Due to project limitations the beer produced was not carbonated. Purgatory Brewery should carbonate the beer with their current carbonation methods, likely a carbonation stone before packaging.

The packaging method used in this project was significantly different than how the brewery will package. Use the preferred packaging method already in place at the brewery.

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Appendices

Appendix 1. *Ingredients Chart*

Table 5. Ingredients used in each batch (MoreBeer!, 2018)

	MoreBeer! Recipe	**Batch #1**	**Batch #2**	**Batch #3**	**Batch #4**	**Batch #5**
Grain	2-Row German Pilsner Candi-Syrup D-90 Caramunich Special B	8lb Swaen Ale Malt 4lb Swaen Pilsner Malt 0.25lb Weyermann CaraMunich 0.25lb Chateau Special B	8lb Briess 2 Row Brewers Malt 4lb Swaen Pilsner Malt 0.25lb Weyermann CaraMunich 0.25lb Chateau Special B	8lb Briess 2 Row Brewers Malt 4lb Swaen Pilsner Malt 0.25lb Weyermann CaraMunich 0.25lb Chateau Special B	8lb Briess 2 Row Brewers Malt 4lb Swaen Pilsner Malt 0.25lb Weyermann CaraMunich 0.25lb Chateau Special B	8lb Briess 2 Row Brewers Malt 4lb Swaen Pilsner Malt 0.25lb Weyermann CaraMunich 0.25lb Chateau Special B
Yeast	Fermentis Safbrew T-58 (Dry)	2 Packs Fermentis SafBrew T2 (ale yeast)	2 Packs Fermentis SafBrew T1	2 Packs Fermentis SafBrew T1	2 Packs Abbey Ale Liquid Yeast	2 Packs Fermentis SafBrew T1
Hops	Perle Saaz	1 oz Perle Pellets (Alpha=7.8%) 1 oz Czech Saaz Pellets (Alpha=2.8%)	1 oz Perle Pellets (Alpha=7.8%) 1 oz Czech Saaz Pellets (Alpha=2.8%)	1 oz Perle Pellets (Alpha=7.8%) 1 oz Czech Saaz Pellets (Alpha=2.8%)	1 oz Perle Pellets (Alpha=7.8%) 1 oz Czech Saaz Pellets (Alpha=2.8%)	1 oz Perle Pellets (Alpha=7.8%) 1 oz Czech Saaz Pellets (Alpha=2.8%)
Sugar	None	Belgium Candi Syrup D90	Belgium Candi Syrup Simplicity	Belgium Candi Syrup D90	Belgium Candi Syrup D90	Belgium Candi Syrup Simplicity
Misc	1 oz. White Labs Yeast nutrient	1Tbsp Yeast Nutrient	1Tbsp Yeast Nutrient	1Tbsp Yeast Nutrient	1Tbsp Yeast Nutrient	1Tbsp Yeast Nutrient

Table 6. Ingredients used in each batch (MoreBeer!, 2018)

	Batch #6	**Batch #7**	**Batch #8**	**Batch #9**	**Batch #10**
Grain	8lb Briess 2 Row Brewers Malt 4lb Swaen Pilsner Malt 0.25lb Weyermann CaraMunich 0.25lb Chateau Special B	10lb Briess 2 Row Brewers Malt 4lb Swaen Pilsner Malt 0.25lb Weyerman CaraMunich 0.25lb Chateau Special B	8lb Briess 2 Row Brewers Malt 4lb Swaen Pilsner Malt 0.25lb Weyermann CaraMunich 0.25lb Chateau Special B	8lb Briess 2 Row Brewers Malt 4lb Swaen Pilsner Malt 0.25lb Weyermann CaraMunich 0.25lb Chateau Special B	8lb Briess 2 Row Brewers Malt 4lb Swaen Pilsner Malt 0.25lb Weyermann CaraMunich 0.25lb Chateau Special B
Yeast	2 Packs Abbey Ale Liquid Yeast	2 Packs Abbey Ale Liquid Yeast	2 Packs Abbey Ale Liquid Yeast	2 Packs Wyeast Belgium Abbey II Yeast	2 Packs Wyeast Belgium Abbey II Yeast
Hops	1 oz Perle Pellets (Alpha=7.8%) 1 oz Czech Saaz Pellets (Alpha=2.8%)	1 oz Perle Pellets (Alpha=7.8%) 1 oz Czech Saaz Pellets (Alpha=2.8%)	2 - 1 oz Perle Pellets (Alpha=7.8%)	1 oz Perle Pellets (Alpha=7.8%) 1 oz Czech Saaz Pellets (Alpha=2.8%)	1 oz Perle Pellets (Alpha=7.8%) 1 oz Czech Saaz Pellets (Alpha=2.8%)
Sugar	Belgium Candi Syrup D90	Belgium Candi Syrup D90	Simplicity syrup	Belgium Candi Syrup D90	Belgium Candi Syrup D180
Misc	1Tbsp Yeast Nutrient	1Tbsp Yeast Nutrient	1Tbsp Yeast Nutrient	1Tbsp Yeast Nutrient	1Tbsp Yeast Nutrient

Appendix 2. *MoreBeer! Recipe Sheet*

BELGIAN DUBBEL

SUGGESTED YEAST
White labs: WLP500 Monastery
Wyeast: 1214 Belgian Abbey
Imperial: B48 Triple Double
Fermentis Dry: Safbrew S-33

EXTRACT (KIT260)

6 lbs German Pilsner
2 lbs Light DME
1 lb Candi Syrup D-90

SPECIALTY MALTS

4 oz Caramunich
4 oz Special B

ALL-GRAIN (KIT560)

8 lbs 2-Row Pale
4 lbs German Pilsner
1 lb Candi Syrup D-90

SPECIALTY MALTS

4 oz Caramunich
4 oz Special B

HOPS

1 oz Perle – Boil 60 min
1 oz Saaz – Boil last 1 min

OTHER ADDITIONS

Clarifier – Boil last 5 min

BELGIAN DUBBEL

RECIPE TIPS

For the all-grain version, the suggested mash temperature is 151°F. Add the Candi Syrup during the last 10 minutes of the boil. We recommend a fermentation temperature in the 68°F range.

NOTES MY RATING: 1 2 3 4 5

TASTING DATE: _____

APPEARANCE _____

AROMA _____

TASTE _____

OVERALL _____

REVIEW THIS KIT ON MOREBEER.COM

BEER STATS

EST. ORIGINAL GRAVITY
1.059–63

ACTUAL O.G. ☐

SRM: 15–16

IBU'S: 12

EST. ABV %: 6

ACTUAL ABV %: ☐

DATE BREWED: ☐

NOTES:

NEED HELP?

SEARCH

BELGIAN DUBBEL KIT on MoreBeer.com to see detailed brewing instructions & descriptions

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&
Over 125 Videos at morebeer.com/videos

BREW DAY QUESTIONS?

Our friendly staff are ready to help!

GIVE US A CALL
800-600-0033
OR EMAIL US 24/7
info@morebeer.com

RECORD KEEPING

DATE BREWED _____

GALLONS IN FERMENTER _____

ORIGINAL GRAVITY _____

TEMP OF WORT AT PITCH _____

LAG TIME _____

FERMENTATION TEMP _____

DAYS IN FERMENTER _____

FINAL GRAVITY _____

YEAST STRAIN _____

FOR ALL GRAIN BREWERS

STRIKE WATER TEMP _____

MASH TEMP _____

BREWING CALCULATORS morebeer.com/calc

Use our free on-line Brewing Calculators to calculate Alcohol %, Boil Off %, Hydrometer Correction, & More!

Appendix 3. MoreBeer! Brewing Instructions

Extract Brewing Instructions

www.MoreBeer.com
1-800-600-0033

These are the step-by-step instructions for brewing MoreBeer! Malt Extract Ingredient Kits using either the *Partial-Boil* or *Full-Boil* method of brewing.

Necessary Equipment and Supplies:

1. MoreBeer! Personal Brewery Starter System
2. MoreBeer! Malt Extract Ingredient Kit
3. A kettle that will boil a minimum of 3 gallons. Usually a 5 gallon (20 qt) kettle is the minimum.
4. Approximately (48)12 oz or (24) 22 oz non-twist, pry-off style beer bottles.
5. Re-usable nylon mesh bags for steeping grain and hops.

Steps:

____ **1.** Getting Ready: Fill your carboy or plastic bucket fermenter with 5 gallons of water and draw a line at the 5 gallon mark with a permanent marker. Continue to fill to the rim and add 1 oz of sanitizer. You will need to fill your bottling bucket or another bucket with a sanitizing solution for sanitizing additional equipment later in the process. If using liquid yeast, take the yeast out of the refrigerator to allow it to warm to room temperature. If using dry yeast please follow step 13 at that time.

____ **2.** If you are using a 5 gallon kettle, add 2–3 gallons of water to your kettle. If using a 7.5 gallon, or larger, kettle fill with 6 gallons of water. Place kettle on stove and turn on heat.

____ **3.** Take your cracked flavoring grains (such as crystal, chocolate, roasted barley, black patent malts, etc.) and put them into a large nylon mesh bag. Put the bag into the heating water and remove when the water reaches 170°F, allowing about 30 minutes to do so. If you reach 170°F in less than 30 minutes, turn the heat off and let the grains steep until a total of 30 minutes has passed.

____ **4.** Remove the grain bag and continue to heat the water to a boil. Turn the heat off and stir in, so it does not burn on the bottom, the liquid malt extract, dried malt extract (DME), dextrin powder, sugar and/or lactose as called for in the recipe. This solution is now called sweet wort (pronounced wert.) ***Note: Do not add the 4 oz, white bag of corn sugar; the sugar will be used two weeks from now during the bottling process.***

____ **5.** Turn the heat back up and bring to a boil. Stay near your kettle! When your wort begins to boil, you will notice foam starting to rise. You need to be there to turn down the heat. When the foam drops, reapply heat and proceed to boil.

____ **6.** Add your bittering hops. Put the hops in a fine mesh nylon bag if available. If you do not have a bag add them directly to the boil. Boil for 60 minutes.

____ **7.** You now need to sanitize any equipment that might come in contact with the beer once it drops below 160°F. This list includes a lid (if you are using a plastic bucket fermenter), an airlock, funnel, thermometer, hydrometer sample taker, all stoppers, and anything else that will come in contact with the cooling wort. Put all this equipment into the sanitizing solution that you made earlier in step 1.

____ **8.** With 20 minutes left to the end of your boil, sanitize your wort chiller (for larger kettles) by placing chiller into the boiling wort.

____ **9.** With 5 minutes left in the boil, add the Whirlfloc tablet. Read addendum ***4** for info on Whirlfloc.

____ **10.** Add your hops according to the recipe, with 10, 5, or 1 minute(s) left in the boil. Use fine mesh nylon hop bags if available.

____ **11.** Cooling hot wort if using a **5 gallon kettle, doing a Partial-Boil**: *(if doing full-boil skip to section 11)*

A) You need to create a method for cooling your wort to around 130°F. For example, you can put the pot, with the **lid on**, in your sink and run tap water around it. Or you can put the pot in an ice water bath in your sink. If your pot is too big for the sink, you can use the bathtub.

B) While the kettle is cooling, empty the sanitizing solution out of your fermenting vessel and fill it with 2 gallons of cold water and/or ice. If using ice, use store bought so you won't transfer flavors acquired from your freezer. Remember that when using water from your tap and/or ice your beer is subjected to whatever level of contamination is in the water to begin with. That may be a little or it may be none. For more info read addendum ***2B & 2D**.

D) When the temperature reaches 130°F, transfer the wort into your fermenter (that you previously added 2 gallons of cool water/ice to) and top up to 5 gallons with cold water and/or ice. Do not attempt to strain during this transfer. For more information see addendum ***1.**

____ **12.** Cooling hot wort if using a **7.5 gallon, or larger, kettle, doing a Full-Boil:**

Hook up your wort chiller to tap water and slowly turn on. Be careful as the water leaving the wort chiller will be close to 200°F for the first few minutes.

When using a MoreBeer! wort chiller you will not need to use a thermometer to check temperature. 30 minutes after the kettle started cooling, feel the outside of the kettle with your hand. You will feel a cool layer on the bottom and a hot layer on top. When the cool layer reaches the top and the entire exterior of the kettle is a cool uniform temperature you can be assured the wort temperature is very close to the tap water temperature and you are ready to transfer wort into fermenter. **Do not attempt** to strain the wort during this transfer ***1.**

____ **13.** Once the wort is into the fermenter, cover the opening with

a lid (plastic bucket) or solid stopper (carboy). If the temperature dropped to between 70–80˚F, proceed to step 13, if not you will have to do additional cooling.

____ **14.** If using dry yeast you will want to re-hydrate the yeast in accordance with the directions on the packet. If no directions are printed on packet, add dry yeast to 4 oz of warm (86–92˚F) water for 15 minutes. If using liquid yeast there is no need to do anything at this time.

____ **15.** Take a hydrometer reading and mark it down on the recipe sheet. If using buckets utilize the spigot to get a sample. If using a carboy utilize the sample-taker to get a sample. Do not return your sample to the rest of the wort. You take a hydrometer reading to determine how much sugar is in the sweet wort.

____ **16.** Add the yeast. For an advanced tip on why and how to add oxygen at this step on your future batches, read addendum ***2C**.

____ **17.** If brewing an ale, ideally keep your fermenter in a dark spot and at a room temperature between 65–70˚F. Fermentation varies with individual conditions, but normally it starts in about 1–2 days and finishes in about 3–7 days. If you are doing a lager read addendum ***3**.

____ **18.** After approximately 14 days, allowing seven for fermentation and seven for settling, the beer is ready to be bottled or kegged.

Bottling:

____ **19.** You will need to sanitize about 2 cases of re-cappable bottles. You can either wash your bottles with a sanitizing solution and drain them upside down (this is where a bottle tree is worth its weight in gold) or run previously cleaned bottles through your dishwasher on hot wash and dry with no soap. If you are using dirty bottles, you must scrub the inside with a bottle brush first. Do not wash labeled bottles in your dishwasher, as pieces of labels will come off.

____ **20.** If you need to move your fermenter to be able to siphon, move it a few hours, or even a day, ahead of time so that the yeast and sediment, called 'trub', can settle.

____ **21.** Sanitize your bottling bucket, siphon hose, racking tube (w/carboys only), bottle filler, spoon, hydrometer, and bottle caps with a sanitizing solution.

____ **22.** In a small pot mix the 4 oz corn sugar packet and two cups of water. Boil for 5 minutes.

____ **23.** Take a final gravity hydrometer reading and record it on the recipe/log sheet.

____ **24.** Siphon your beer from the fermenting vessel into the bottling bucket being careful not to splash. Air is now the enemy. Dissolving air into the beer at this point causes premature staling via oxidation. After there is 2 inches of beer in the bottom of the bucket gently stir in the boiled corn sugar. The dissolved sugar will ferment in the bottle, making natural carbonation.

____ **25.** To prevent airborne bacteria from falling in, cover the bottling bucket. Aluminum foil or loose fitting saran wrap is perfect. We don't recommend attaching a bucket lid because these are so tight they can create a vacuum in the bucket as you drain out the beer.

____ **26.** Take the 5' of 3/8"siphoning hose and attach one end to the spigot on the bottling bucket and one end to the bottle filler. Fill the bottles to the top and remove the filler, leaving about 1" of headspace. Place a cap on top of each bottle. You can choose to cap the bottles as you go or you can fill all of the bottles first and then cap them all at once.

____ **27.** Leave the bottles at room temperature for at least 2 weeks to carbonate. Colder temperatures, 65˚F or below, will require additional time for carbonation. You can drink the beer after 2 weeks, or when carbonation is present, however your beer will improve significantly with additional aging in either the refrigerator (ideal) or at room temperature. The refrigerator, or a cool spot, is really beneficial for long-term aging (months). Beers with higher alcohol contents and higher bittering rates will need to age longer.

Addendums:

***1** While transferring from kettle to fermenter there is no need to strain the wort. Use fine mesh hop bags to retain most of the vegetable matter from the hops.

***2** Beginning brewers often ask what they can do to increase quality and consistency while saving time. Here are our top three biggest differences.

A. Use liquid yeast as the difference in quality when compared to dry yeast is noticeable.

B. Consider doing a full-boil if you are currently doing a partial-boil. You get a better flavor (less carmelization and more utilization from hops), less chance of contamination (no added water at end), and you save a great deal of time. When you upgrade to using a kettle of this size it often means getting a wort chiller and a stand-alone burner because your stove top will probably not have the power to boil 6 gallons of wort. Our large, Heavy-Duty *MoreBeer!* Kettles also come with a valve and spigot allowing you to transfer the wort into your fermenter without having to pour or siphon.

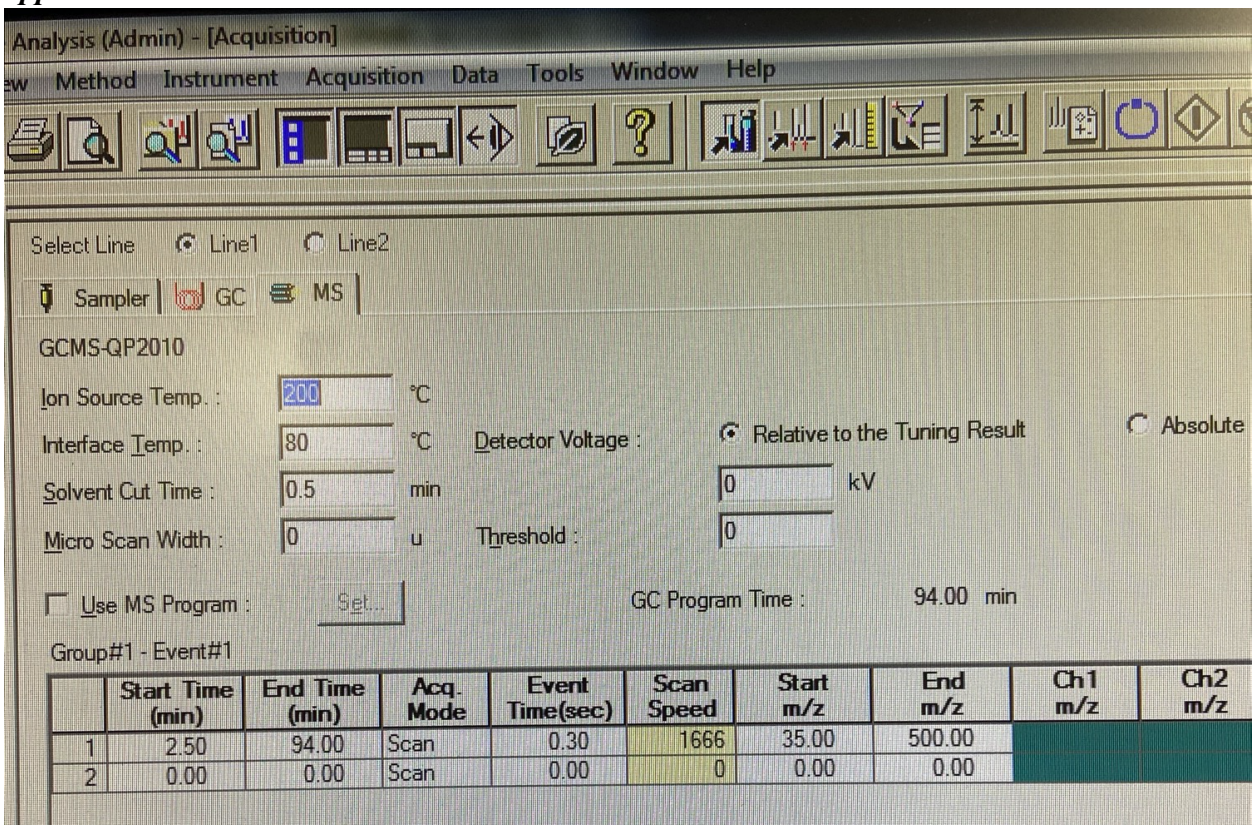
C. Use our oxygenation or filtered aeration kit to provide your wort with pure clean oxygen. The yeast uses the oxygen to create healthy cells, which translates into better beer and less fermentation problems.

D. Remove Chlorine from your brewing water. Filter your water with a carbon filter (FIL32) or use another filtered water source.

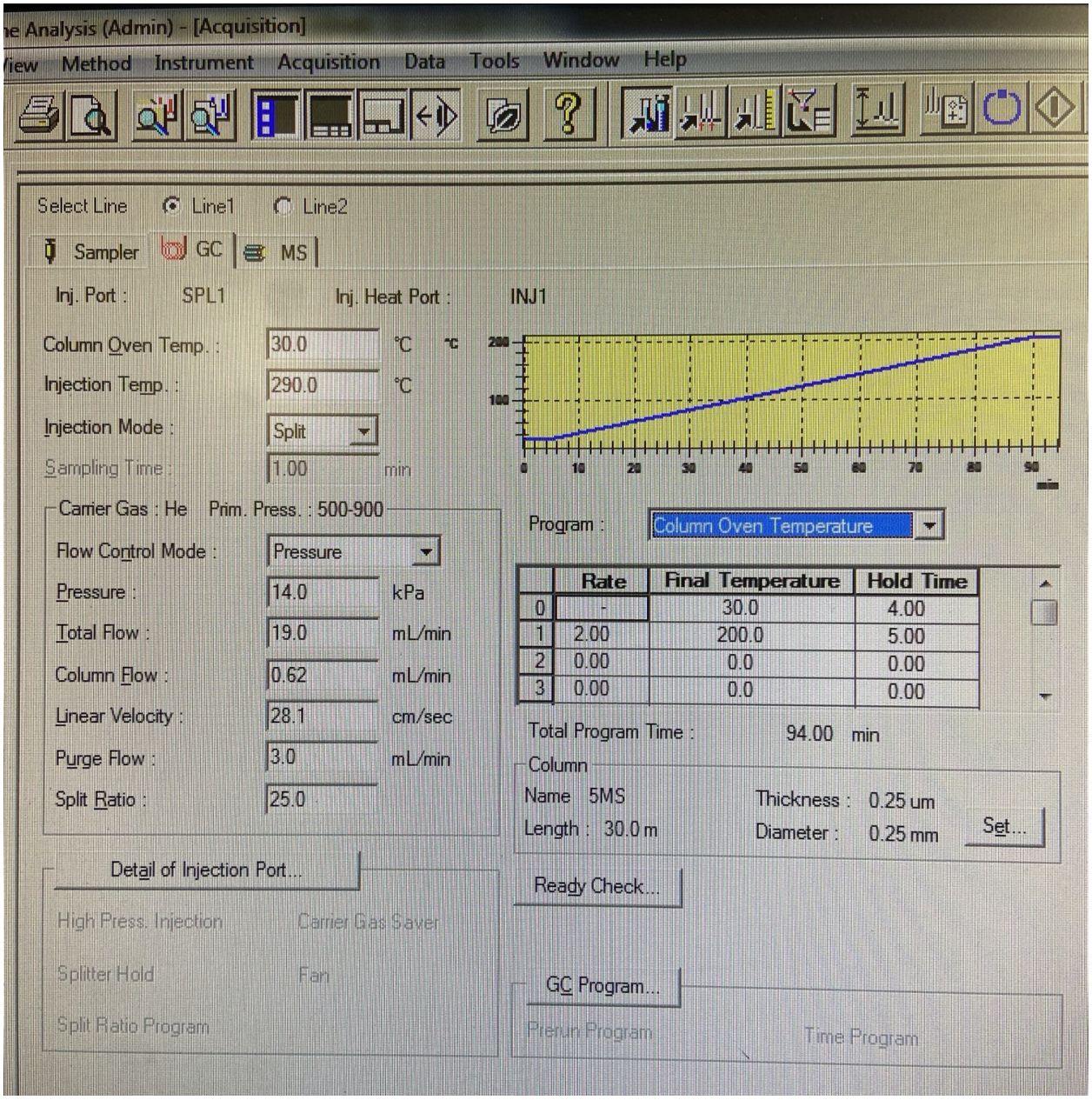
***3** We recommend that the beginning brewer start with ales, as they are easier to make. Lagers require a fermentation temperature between 48–58˚F, the addition of more yeast up front, and a 3-week fermentation time. With some experience and additional reading (see our paper online about Brewing Lager Beers) they can be successfully brewed at home.

***4** Whirlfloc is a natural product made from seaweed. It helps to clear your beer by attaching to protein molecules which then become heavy and fall out of solution.

Appendix 4. *GC-MS Method*



	Start Time (min)	End Time (min)	Acq. Mode	Event Time(sec)	Scan Speed	Start m/z	End m/z	Ch1 m/z	Ch2 m/z
1	2.50	94.00	Scan	0.30	1666	35.00	500.00		
2	0.00	0.00	Scan	0.00	0	0.00	0.00		


e Analysis (Admin) - [Acquisition]
iew Method Instrument Acquisition Data Tools Window Help
Select Line Line1 Line2
Sampler GC MS
Inj. Port : SPL1
Inj. Heat Port : INJ1
Column Oven Temp. : 30.0 °C
Injection Temp. : 290.0 °C
Injection Mode : Split
Sampling Time : 1.00 min
Carrier Gas : He Prim. Press. : 500-900
Flow Control Mode : Pressure
Pressure : 14.0 kPa
Total Flow : 19.0 mL/min
Column Flow : 0.62 mL/min
Linear Velocity : 28.1 cm/sec
Purge Flow : 3.0 mL/min
Split Ratio : 25.0
Detail of Injection Port...
High Press. Injection
Carrier Gas Saver
Splitter Hold
Fan
Split Ratio Program
Program : Column Oven Temperature
Rate
Final Temperature
Hold Time
0 - 30.0 4.00
1 2.00 200.0 5.00
2 0.00 0.0 0.00
3 0.00 0.0 0.00
Total Program Time : 94.00 min
Column
Name 5MS
Length : 30.0 m
Thickness : 0.25 um
Diameter : 0.25 mm
Set...
Ready Check...
GC Program...
Prerun Program
Time Program

Appendix 5. *University of New Hampshire Brewing Science Laboratory Results*

Alcolyzer Beer: Known Concentration Check

Unique Sample Id	Date	Time	Sample Name	Density Condition	Alcohol (% v/v)	Density	Ethanol AOAC 60 °F (% v/v)
			-	-	%v/v	g/cm³	% v/v
122	4/5/21	10:52:28 AM	calibration std	valid	10.21	0.98455	10.10

Alcolyzer Beer: BEER

Unique Sample Id	Date	Time	Sample Name	Density Condition	Alcohol (% v/v)	Density	Alcohol (% w/w)
			-	-	%v/v	g/cm³	%w/w
123	4/5/21	10:58:09 AM	check std	valid	4.90	1.00444	3.85
124	4/5/21	11:14:24 AM	Sample 1	valid	6.88	1.00505	5.40
125	4/5/21	11:20:59 AM	Sample 2	valid	5.69	1.00604	4.47
126	4/5/21	11:31:00 AM	Sample 3	valid	6.76	1.00678	5.30
127	4/5/21	11:36:51 AM	Sample 4	valid	8.50	1.00751	6.66

Density	Ethanol AOAC 60 °F (% v/v)
g/cm³	% v/v
0.98455	10.10

Density	Alcohol (% w/w)	Er (real extract) (% w/w)	Ea (app. extract) (% w/w)	p (original extract) (% w/w)	RDF (real deg. of ferm.)	Calories (kJ/100 mL)	Note the units!
g/cm³	%w/w	%w/w	%w/w	%Plato	%	kJ/100ml	
1.00444	3.85	3.39	1.61	10.90	70.09	163.28	
1.00505	5.40	4.21	1.76	14.54	72.62	220.91	
1.00604	4.47	4.07	2.02	12.69	69.40	191.71	
1.00678	5.30	4.60	2.21	14.72	70.39	224.15	
1.00751	6.66	5.34	2.39	17.83	72.04	275.23	