Quantifying the Effects of Barley Milling on the Clarity of Beer Products

A Major Qualifying Project Report
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Abstract

The goal of this project was to help Wachusett Brewing Company increase beer clarity. Phase one involved the optimization of a six roller mill to produce a grist with a desirable husk volume above 400cc / 100g. Phase two entailed correlating husk volume to lauter tun runoff clarity. A husk volume of 455cc / 100g was achieved with mill settings of 1.65 mm, 0.9 mm, and 0.6 mm. Additionally, the results from phase one indicated that the second roller gap has the greatest impact on husk volume. In phase two, the optimized mill settings of 1.65mm, 0.9mm, and 0.8mm was found to decrease the quantity of haze forming compounds by 43%. As a tradeoff, lautering time increased by 26 minutes.

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1. Introduction

Beer clarity is one of the best first impressions for the quality of craft beer. Each consumer has a different opinion about what the appearance of beer should be, but beer haze is at the front of the debate for beer advocates. Hazy beer is a common practice for craft breweries nowadays. Unfiltered beers, which are hazy in nature, are very popular amongst beer enthusiasts. Some craft brewers even disregard filtration processes altogether since it discounts beer artisans' hard work and can alter the taste.

Despite this trend, bright beer is on the rise. Bright beers have a clear appearance with minimal beer haze. Bright beers are almost always filtered, which goes against a lot of craft breweries' ideology. However, in some cases, filtration isn't enough to eliminate beer haze. Chill haze, for example, is a type of beer haze that can't be removed using standard filtration processes. Instead, other parts of the beer process can be optimized to increase beer clarity. In particular, the barley milling and lauter tun processes.

The lauter tun process is the first chance to remove haze-inducing compounds in beer without filtering. Lauter tuns use grain beds made out of milled grains to filter out proteins and polyphenols, two haze-inducing compounds, from the beer. Incorrect operation of the lauter tun can allow undesirable compounds to be absorbed into the wort during boiling. Then, weeks or months after bottling, the compounds undergo a chemical reaction and settle out of the beer. Customer complaints of hazy beer and sediment in the bottom of the bottle have inspired Wachusett Brewing Company to pursue the production of bright beers even though bright craft beers are less common. The clarity of lauter tun runoff has a direct relationship with bright beer. The effectiveness of the lauter tun process, however, is dependent upon the operation of the grain mill.

Within the past two years, Wachusett Brewing Company has acquired a new six roller mill to help increase their annual volume production of beer. Six roller mills are also proven to produce better quality grist for use in the lauter tun. However, the addition of the new mill has not shown any improvements in the clarity of their beer that they expected. Wachusett Brewing Company has determined that the mill must be optimized to produce a better quality grist.

The project was completed in two phases. Phase one is to optimize the mill by changing different operating parameters to produce a desired husk volume and weight distribution of milled barley. Phase two involves evaluating the outcomes of phase one by examining the clarity of the lauter tun runoff. The beer chosen to be analyzed is Wachusett Blueberry Ale.

2. Background

In this section, the causes of beer turbidity are discussed in further detail. Different parts of the beer making process, including the milling and the lauter filtration processes, are examined to show their role in haze formation. The current setup of Wachusett Brewing Company is also examined.

2.1 Beer Clarity and Turbidity

The clarity of beer is a source of debate amongst beer advocates. Some people prefer their beer to be "bright" and very clear whereas some people believe beer should be hazy. Some craft breweries in particular believe that haze gives the beer a more robust appearance. This may be true, but there are several drawbacks to hazy beer such as suspended solids and sediment that appears at the bottom of the bottle. As a result, many microbreweries, like Wachusett Brewing Company, have decided to shift away from hazy beers. However, removing haze in beer can be a difficult process, since haze can be caused by many different phenomena.

Turbidity can be defined as the cloudiness or haziness in a liquid caused by a large number of individual particles. It can be measured visually or with a turbidity meter called Nephelometers. There are many causes of turbidity in beer including age and origin of malt, proteins binding with polyphenols, and yeast management. Turbidity in beer can also be caused by insoluble or semi-soluble particulate matter which are small enough to form a colloidal suspension in beer. These particles can be generated anytime throughout the beer process[18].

Beer turbidity and haze can be classified into three groups: cold break haze, age-related haze and leftover solids. When beer is cooled after it is packaged, cold break haze may occur, which is the result of polyphenols and proteins bonding non-covalently due to the increase of intermolecular forces. More often called chill haze, cold break haze is not permanent since the solids dissolve at temperatures above 40F. The polyphenols and proteins that cause chill haze are found in barley and hops, two of the essential ingredients of beer, making it difficult to remedy chill haze. A picture of chill haze can be seen in Figure 2.1. The beer on the left is "bright" and the beer on the right has chill haze.

Figure 2.1: *Bright Beer (Left) Compared to Beer with Chill Haze (Right)*[2]

If a beer is left unopened for an extended period of time, age-related haze can occur, which is caused by permanent polar bonds between polyphenols and proteins. Both cold break and age-related haze cause beer fog, but they don't necessarily produce sediment or suspended solids in the beer. Leftover solids from hops and malt can increase beer turbidity and actually leave visible sediment at the bottom of the bottle as seen in Figure 2.2.

Figure 2.2*: Suspended Solids in a Beer Bottle*[12]

2.2 Brewing Process

The brewing process for craft breweries can be considered universal. It is rarely the same for different companies but it can be generalized into a simple nine step process. All beer contains the same four ingredients: water, malted grains, hops, and yeast. The next paragraph describes the nine different steps. The nine different steps are milling, mashing, lautering, boiling, whirlpooling, cooling, fermenting, maturing and filtering. A picture of the process can be seen in Figure 2.3.

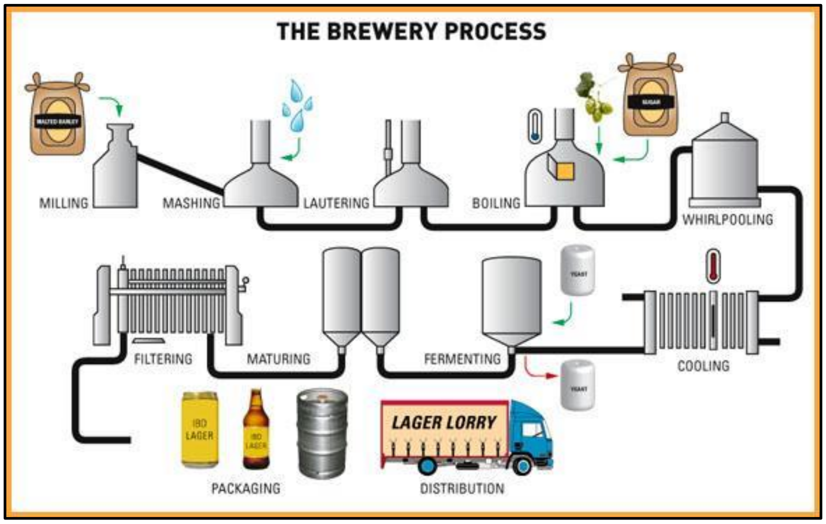

***Figure 2.3**: Beer Production Process*[16]

In the first step, the malted grains are crushed in a milling machine. The grains provide the necessary sugars for fermentation. The product of the milling process is called the grist. The second step in the process is called mashing. In the mashing process, the grist from the first step is transported to the mash tun and then mixed with heated water. This is where the fermentable sugars in the grist are transferred to the water. The product of the masher, called wort, is then moved to the lauter tun. Lautering separates the wort from the grain husks and any other large solids in the grist. The wort then enters the kettle, where it is boiled to a desired temperature. In the kettle, hops are added for flavor. After the hops are added and the wort is done boiling, the product of the kettle moves to the whirlpool. The goal of whirlpooling is to create a clear liquid by removing malt and hop particles from the wort. The wort is spun in the whirlpool until all the solids crash out of solution due to centrifugal forces. The product of the whirlpool needs to be cooled before fermentation can begin. After being cooled, the liquid moves to a vessel where yeast is added. Yeast converts sugar into alcohol and releases carbon dioxide. This is where most of the flavor comes from. The fermentation process takes time, so the beer is left to mature in maturing tanks for the second to last step. As a last step, some breweries filter their beer to give an added level of clarity. Other breweries bottle their beers right away[16].

2.3 Sources of Beer Turbidity in the Brewing Process

Beer turbidity can be caused by a variety of different problems in the beer process. In this report, the focus is limited to the milling and lauter tun filtration processes. Ideal operation of these two pieces of equipment is essential to reduce the turbidity of beer.

First, the way that barley is milled at the beginning of the brewing process can be an initial source of beer turbidity. The product from the mill, called grist, must be a certain size, texture, and have a desirable husk volume to ensure ideal brewing conditions further downstream in the process. There are plenty of sources of operational error during the milling process that can affect the quality of the grist. For example, an incorrect roller gap can affect the particle size and husk volume of the grist. It is crucial that the husk, bran, endosperm, and embryo of the barley are separated from each other. Poor separation can create large particles and damaged husks that are troublesome in later processes.

Next, correct lauter tun operation is necessary to produce a “bright” beer. The wort from the mash tun is brought to the lauter tun where it encounters a separation process, called sparging. Hot water separates the sugars from the grains and extracts of the milled barley. The product of the lauter tun is called the sweet wort, or the lauter tun runoff. If incorrect temperatures of water are used to sparge, the sweet wort clarity can be effected. Also, excessive raking or pressures applied can cause separation to be negatively affected. More specifically, grain extracts may pass through the false bottom if raking is done incorrectly. Lastly, if lauter plates are damaged, warped, or incorrectly re-laid, the sweet wort product may not be as clear as expected.

Clear lauter tun run-off is essential for the production of “bright” beer. Poor sparging processes leave grain extracts in the lauter tun runoff, ultimately increasing the concentration of haze forming compounds. If all of the grains aren’t separated from the wort in the lauter tun, the chance of leftover solids in the final product increases.

2.4 The Mill

Wachusett Brewing Company uses a Buhler Group six roller milling machine to grind and separate the grain components. The goal of the milling process is to open the grain and separate it into three distinct parts: husk, flour and grits. The grain is separated as to keep the husks intact but also grind the endosperm into flour. Six roller mills allow for further grinding of the grist, compared to two and four roller mills. Six roller mills also provide more protection for the husk.

The mill at Wachusett Brewing Company consists of a feed roller and three pairs of rollers. The feed roller is used to spread the grain across the length of the rollers. The first pair of rollers is designed to loosen the husks. Next, the second set of rollers are designed to separate the husk and endosperm. After passing through the first two sets of rollers, the barley enters the sifting process. There are two sieves in the mill: the first sieve has a mesh size of 2 mm and the second one has a 1 mm mesh size. The husks are typically larger than 2 mm, so they are caught on the first sieve and are allowed to bypass the third set of rollers and go straight through to the lower surge hopper. The flour is smaller than 1 mm and bypasses the third set of rollers as well. The grits, or the material greater than 1 mm and less than 2 mm, continues onto the third set of rollers to be ground further before joining the flour and husks in the lower surge hopper. A schematic of a six roller mill is shown below in Figure 2.4.

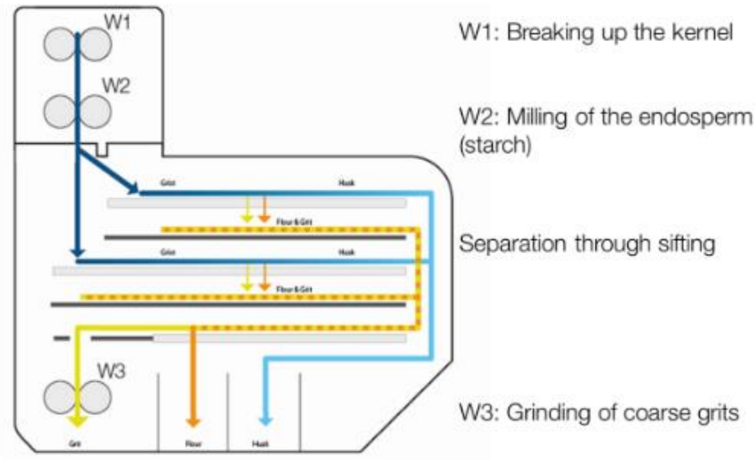

Figure 2.4*: Six Roller Mill Schematic*

The Buhler Group roller mill at Wachusett Brewing Company also has two sampling ports that allow technicians to analyze the freshly milled barley before sending it to the mash tun. The first port is located right below the first set of rollers. This port allows technicians to analyze how well the first set of rollers are loosening the husk from the endosperm. The second sampling port is located at the bottom of the mill after the barley has been sifted and milled. The Buhler Group roller mill separates the milled barley into three different groups (flour, coarse grits and husk). The sampling tool catches and separates these three groups for quick visual analysis of the milling process.

The gaps between the rollers can be changed electronically using a controller connected to the mill. The controller can change the gaps between the rollers by increments of 0.01 mm, which allows for precise milling of barley. Currently, Wachusett Brewing Company mills barley for their Wachusett Blueberry Ale with the first roller gap set to 1.65 mm, the second gap set to 1.3 mm, and the third roller gap set to 0.88 mm. Conversely, after talking with Roger Scheel, a representative from Buhler Group, the recommended mill settings are 1.6 mm, 0.9 mm, and 0.5 mm for moderate loading of the lauter tun. Wachusett Brewing Company claims that a coarser grind of barley works best in their lauter tun process, therefore the brewmasters at Wachusett Brewing Company prefer to operate the milling machine with larger roller gaps.

2.5 Composition of Milled Barley

The composition of the milled barley is important to produce clear beer because it determines how well the sweet wort is filtered through the lauter grain bed. To prevent beer turbidity downstream, brewers have an "ideal" grind for their grist in their respective brewery. Usually, this grind is determined by trial and error. To quantify the composition of the grist, a sieve analysis can be used.

The particle size distribution of a grist can be quantified through a sieve analysis. The goal of the sieve analysis is to determine the quantity of different sized particles by sifting the mill output through a series of sieves. The sieves are stacked upon one another and shaken for a set amount of time. Each sieve has a different mesh size, so different parts of the grain are caught on different stages. At the end of the analysis, the composition, by weight, of different sized particles can be determined.

A common sieve set in the US is recommended by the American Society of Brewing Chemists. The sieves used are characterized by numbers. The most common sieves used are #10, #14, #18, #30, #60, and #100. The composition of the grist can be broken down into weight fractions on each sieve tray. The fractions, found in Table 2.1, are recommended by Buhler Group.

***Table 2.1**: Grist Composition Breakdown by Sieve*

Sieve	Mass Percentage
Sieve #10	~ 0%
Sieve #14	18-25%
Sieve #18	< 10%
Sieve #30	35%
Sieve #60	21%
Sieve #100	7%
Pan	< 12-15%

As seen above, the majority of the grist should be present on the #30 sieve. This is because if the grist contains too many small particles, it may cause the lauter tun to clog, which can ruin an entire batch of beer. An important indication of a good grind is the collection of intact husks on the #14 screen. The husks are important for a good lauter tun process so it is vital that the husks stay intact during milling.

Lastly, the lauter tun cannot function correctly without a high husk volume of milled barley. The milled barley needs to allow for wort to pass through the false bottom of the lauter tun but it also needs to act as a filtration membrane. The ability of the liquid to pass through the membrane is a function of the milled barley's husk volume. Husk volume is defined as the volume of husk for a given weight of 100 grams. In general, high husk volumes are desired. This means that the milled barley is light and occupies a large volume for a given weight of 100 grams. In the lauter tun filtration process, high husk volumes reduce the chance of barley particles sticking together and clogging the lauter tun. In the beer producing world, milled barley bulk densities above 500 cc / 100 g are considered to be okay, 750 cc / 100 g is good, and 900 cc / 100g is extraordinary.

Wachusett Brewing Company's current weight distribution for their mill settings of 1.65 mm, 1.3 mm and 0.88 mm is not as expected in Table 2.1. This is partially due to the uniqueness of Wachusett Brewing Company's brewing process but also a result of their milling process. A current weight distribution of milled barley for Wachusett Blueberry Ale is shown below in Figure 2.5.

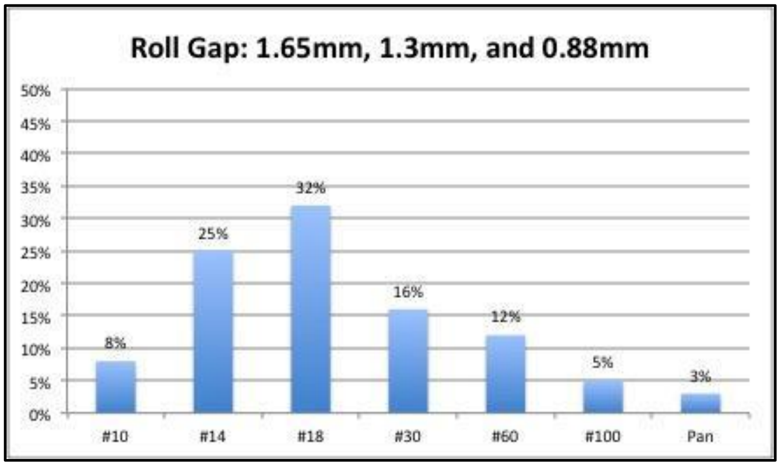

***Figure 2.5**: Weight Distribution of Milled Barley (1.6 mm, 1.3mm, and 0.88mm)*

In an effort to improve their process, Wachusett Brewing Company has identified an expectation for milled barley that they believe will increase beer clarity in their brewing process. Buhler Group also has a recommendation for a weight distribution that has been shown to achieve a high husk volume at other breweries. The two weight distribution graphs are shown in Figure 2.6 and Figure 2.7.

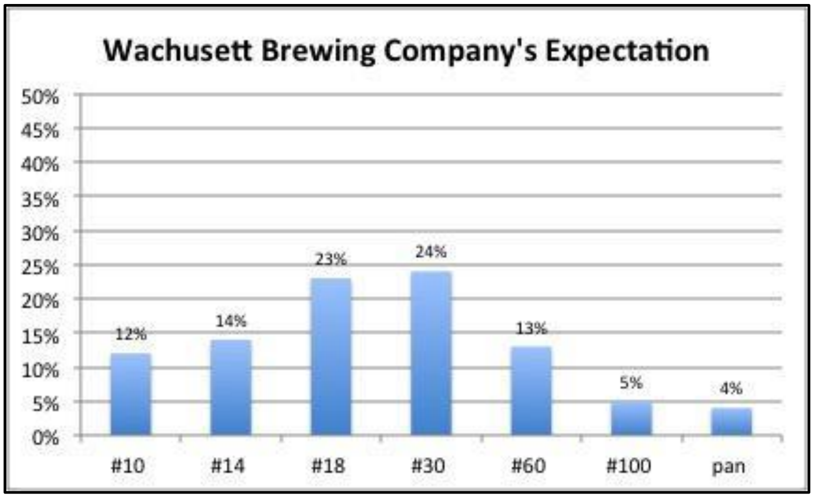

Figure 2.6*: Wachusett Brewing Company Weight Distribution Expectation Graph*

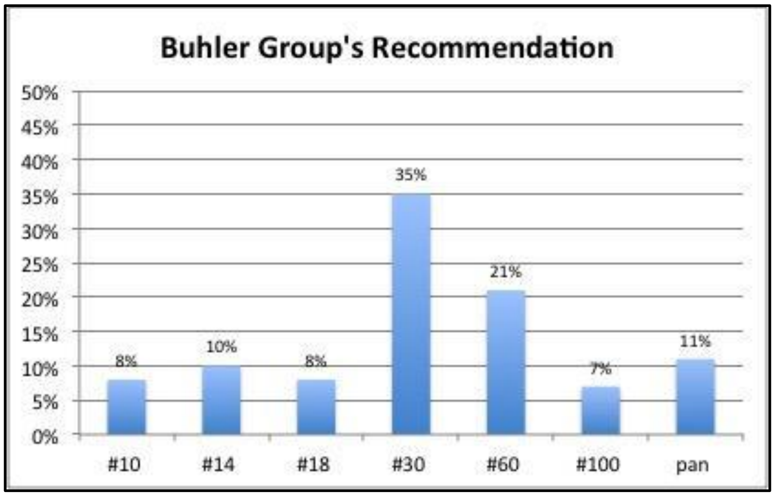

Figure 2.7*: Buhler Group Recommended Weight Distribution Graph*

Looking at the two graphs, Buhler Group’s recommendation is slightly different than Wachusett Brewing Company’s expectation. The main differences between Wachusett Brewing Company’s expectation and Buhler Group’s recommendation is the reduction of weight on the #18 screen. Buhler Group’s recommendation is much finer than Wachusett Brewing Company’s, however both graphs agree that the largest presence of barley should be on the #30 screen. The current roller gaps of 1.65 mm, 1.3 mm, and 0.88 mm do not achieve this.

2.6 Quantifying Beer Clarity

Haze is the general term to describe the opacity of beer, however not all haze is visible. Haze that is visible is known as turbidity. Turbidity can be measured using nephelometers (more commonly called turbidity meters). Figure 2.8 shows the design of a generic turbidity meter. At one end there is a light source and on the other end there is a light detector.

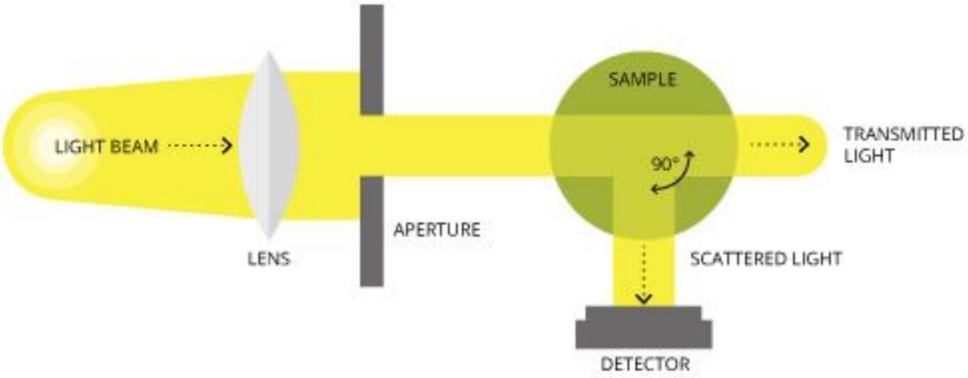

Figure 2.8*: Schematic of How Nephelometers Work*[15]

The concept of the nephelometer, like the one shown in Figure 2.8, is to use a lens to shine light through a sample liquid and calculate the amount of light transmitted and deflected. In a clear liquid with no particles present in solution, the source light will pass straight through the sample media with little deflection and a high transmittance. However, if particles are present in solution that deflect light, then the scattered light will pass through to the light detector and a low transmittance reading will result. The more light detectors present at different angles from the sample liquid the more accurate the result will be. Turbidity meters show the digital results in units of FTU's. FTU stands for Formazin Turbidity Units.

Wachusett Brewing Company measures beer turbidity in two different ways. One way is to use a turbidity meter in the lab like the one shown in Figure 2.8. To use the turbidity meter in the lab, a sample of beer is taken from the kettle before boil up and then analyzed at room temperature. Since the unboiled wort tends to be very hazy, a better indication of beer clarity can be achieved using a turbidity meter on the lauter tun. The turbidity meter on the lauter tun measures the clarity of the runoff automatically during lautering. The turbidity meter on the lauter tun measures the absorbance of light with a wavelength of 730 nm and uses that information to calculate the concentration of haze inducing compounds in the beer in Concentration Units (CU's).

3. Methodology

This chapter includes all of the methods used to collect and analyze the data necessary to complete the project. The project was organized into two separate phases as described below:

- Phase 1: Optimize mill settings and produce high husk volume
- Phase 2: Correlate optimized mill settings to lauter tun runoff clarity

To accomplish Phase 1, the mill was operated with different roller gap settings and grain samples were taken. The samples of each roller gap setting were sifted through a six-tier ASBC sieve deck. After the sieve analysis was performed, samples of grain husk were taken and used to calculate husk volume. In Phase 2 of the project, a full batch of grain for Wachusett Blueberry Ale was milled at the optimized roller gap settings determined in Phase 1 and lauter tun runoff data was collected. The lauter tun runoff was tested for clarity by use of a turbidity meter.

3.1 Design of Experiments

A Design of Experiments takes a statistical approach to analyzing data. It allows for the least amount of runs to be completed while providing the most data analysis. The design of the DOE used in the experimentation was a two level factorial with center points, studying two factors. The first step in creating a DOE, is to determine the two factors, or parameters to be studied. The first roller was chosen because it has a high impact on the husk volume, a parameter Wachusett Brewing Company desired to increase. Buhler Group also suggested to maximize the weight percent of the grain on #30 and #60 sieves, which was hypothesized to be controlled by the second roller gap. Based on these two objectives, the first and second roller gaps were the chosen factors to be studied.

After choosing the factors, the levels at which the factors were to be studied needed to be determined. An important consideration for determining the levels was how the grain progresses through the mill. Each consecutive roller gap should be tighter than the preceding one to further grind the grain as it advances through the mill. Therefore the third roller gap should be smaller than the second, and the second roller gap should be smaller than the first. Secondly, the levels were determined using data of previous runs Wachusett had tested prior to our experiments. The range of roller gap spacings tested by Wachusett Brewing Company are tabulated in Table 3.1.

Table 3.1*: Roller Gap Spacing Tested by Wachusett Brewing Company*

Roller Gap	Ranges Tested
1st Roller Gap	1.7 mm - 1.2 mm
2nd Roller Gap	1.4 mm - 0.6 mm
3rd Roller Gap	0.9 mm - 0.4 mm

The trials run by Wachusett Brewing Company tested multiple types of grains. However, the type of grain can impact how the roller gaps are optimized. Thus, the ranges Wachusett Brewing Company tested were used only as a baseline to test a single grain type. Using the baseline established by Wachusett Brewing Company in combination with the knowledge of the progression of the grain in the mill, the high and the low levels for each factor were determined in Table 3.2:

Table 3.2*: Ranges of Roller Gaps Tested*

Factor	High Point	Low Point
1st Roller Gap	1.7 mm	1.2 mm
2nd Roller Gap	1.1 mm	0.7 mm

The DOE used in this project can only study two factors, therefore, the 3rd roller gap was held constant. Looking at the roller gaps tested by Wachusett Brewing Company, the third roller gap was chosen to be 0.6 mm since it was close to middle of the values tested.

After the factors and levels for the DOE were identified, Minitab, a statistical software used for data analysis, was used to make a run plan to test the ranges of roller gaps. The run plan was created to test the high and low levels of each factor against each other as well as test a centerpoint in order to discover curvature in trends. Minitab created a series of runs used in the barley milling experiments of this project (Table3.3).

***Table 3.3**: First Design of Experiments Roller Gap Settings*

Run Order	1st Roller Gap (mm)	2nd Roller Gap (mm)	3rd Roller Gap (mm)
1	1.7	0.7	0.6
2	1.7	1.1	0.6
3	1.45	0.9	0.6
4	1.2	1.1	0.6
5	1.2	0.7	0.6

After the completion of the first DOE, the results were analyzed to help create another set of ranges to test. The first DOE created a scope of data that was too large to identify small trends. Therefore the focus of the second DOE was narrowed to smaller ranges of roller gaps, which can be seen in Table 3.4. The first roller gap was varied between 1.7 mm and 1.5 mm and the second roller dap was varied between 0.9 mm and 0.7 mm.

***Table 3.4**: Second Design of Experiments Roller Gap Settings*

Run Order	1st Roller Gap (mm)	2nd Roller Gap (mm)	3rd Roller Gap (mm)
1	1.7	0.7	0.6
2	1.7	0.9	0.6
3	1.6	0.8	0.6
4	1.5	0.7	0.6
5	1.5	0.9	0.6

3.2 Sieve Analysis

To begin the sieve analysis, the grist must be collected from the Buhler Group milling machine. Samples from the mill were taken when the mill was operating at full load, or after grinding for about two minutes. The clean sampler was inserted into the mill at the lowest sample port, in the closed position, and rotated to the open position for about four seconds. This allowed for an even catch of the grist across the sampler. The sampler was carefully removed from the mill and the collected grist was then transferred to a sample bucket.

The ASBC (#10, #14, #18, #30, #60, #100, and pan) sieves were utilized throughout the analysis. The sieves were stacked in order from top (largest mesh opening) to bottom (smallest mesh opening). The sieves were previously weighed by Wachusett Brewing Company and an excel template was utilized for data collection. The data collection template used can be seen in Appendix A. To begin the sifting procedure, the collected grist sample was poured onto the top sieve. Next, the cover of the top sieve was placed into position and the sieves were agitated for approximately three minutes. The procedure for agitating the sieves was given by Wachusett Brewing Company. The sieves were passed back and forth between hands for a total of 150 times. After sifting, each individual sieve was weighed to determine the amount of grist on each sieve by subtracting the weight of the clean sieve in the excel template.

Finally, the husk volume was calculated to determine how well the husk was separated from the endosperm in the mill. A clean graduated cylinder was weighed and filled with grain from the #10 and #14 sieve. The weight and volume of the material were then recorded. The volume fraction, in terms of milliliters per 100 grams, was found by the following equation,

$$Husk\ Volume = \frac{100g}{(weight\ of\ grain)} * (volume\ of\ grain)$$

3.3 Optimization of the Mill

After completion of the two DOE’s, a final test was performed to determine the optimal settings of the mill. The final test was an independent second roller analysis that was used to determine the effect the second rollers on husk volume. To isolate the effect of the second roller gap, the first and third roller gaps were held constant. The two DOE’s concluded that the highest husk volumes were encountered when the first roller gap was set to either 1.7 mm or 1.6 mm. To back up this finding, the team took samples of grain from the first sample port right below the first set of rollers and inspected the husk for damage. Table 3.5 represents the range of roller gaps for this test.

Table 3.5*: Second Roller Gap Settings*

Run Order	2nd Roller Gap (mm)
1	1.1
2	1.0
3	0.9
4	0.8
5	0.7
6	1.3

The range for the second roller gap varied between 1.1 mm and 0.7 mm. The final run, run 6 in Table 3.5, was completed to mimic Wachusett Brewing Company's mill settings. This allowed the team to calculate Wachusett Brewing Company's current husk volume. After finishing this test, Phase 1 of the project was complete.

3.4 Lauter Tun Runoff Clarity

In order to evaluate the results from the first phase of the project, the team wanted to determine if the new grind increased beer clarity. As mentioned before, lauter tun runoff can be correlated with a clear final product, so the team changed focus from the milling process to the lauter tun process. To be consistent, the team decided to choose one beer to analyze: Wachusett Blueberry Ale.

To start, a full batch of Cargill 2-Row malt and white wheat for Blueberry Ale were ground using the optimized mill settings the team identified in Phase 1. After mashing, the wort was sent to the lauter tun for separation. The brewers followed the standard lauter tun SOP that Wachusett Brewing Company specified to help eliminate other variables that could affect beer clarity. Throughout the lauter tun process, samples of the lauter tun runoff were analyzed for clarity using a turbidity meter. The batch's overall turbidity was measured using a benchtop turbidity meter in the lab before the wort was boiled in the kettle.

In order to get a baseline for the clarity of Wachusett Blueberry Ale, the brewers also brewed a batch of Blueberry Ale using grain milled at their standard mill settings. The clarity of the runoff was found in a similar manner using the turbidity meter on the lauter tun and also using a benchtop turbidity meter in the lab. This information allowed the team to determine whether or not the new settings improved clarity. To reduce batch variability, it was ideal to brew both batches of beer on the same day using the same grain. Similarly, the team preferred to have the same brewer oversee both batches. However, due to work shifts, the two batches were brewed by two different brewers.

For each batch, the lauter tun runoff volumetric flowrate and runoff turbidity in concentration units (CU's) were recorded. The position and speed of the rakes in the lauter tun were also recorded even though their significance were not analyzed in this report. Both brewers provided notes about the lauter tun process such as runoff stops and starts, bed cuts, and transfers. Manipulating the lauter data allowed the team to determine if the clarity of the beer was improved and if the process efficiency was impacted.

To quantify if the new mill settings increased the clarity of the beer, the amount of haze forming compounds in the runoff needed to be determined. Since the lauter tun process Excel spreadsheet indicated the flow rate and turbidity of the runoff at different time intervals, the instantaneous flow rate of haze forming compounds was found by multiplying the runoff flow rate by the turbidity in concentration units. However, the instantaneous value of the flow rate of haze forming compounds was not helpful in determining the overall clarity of the runoff since the turbidity of the runoff changed frequently during lautering. To determine the overall clarity of the runoff, the value of the runoff flow rate times the turbidity in concentration units was plotted versus the time elapsed during runoff. Since the flow rate and turbidity readings were recorded at sporadic time intervals, the flow rate and turbidity were assumed to remain constant between recordings. Therefore the value of runoff flow rate times turbidity in concentration units changed in a step wise fashion. With the graph completed, the overall batch clarity was quantified as the integral of the graph from the start to end of lautering. The final value was in the units of gal*CU which indicated the quantity of haze forming compounds present in solution. The percent change in haze forming compounds between the two batches of Wachusett Blueberry Ale was found and used to determine to what degree the new mill settings increased/decreased lauter tun runoff clarity.

4. Results & Discussion

The results obtained from the design of experiments, independent second roller analysis, and lauter tun runoff clarity tests were used to determine an optimal mill setting for Wachusett Brewing Company. The results are broken into the two phases of the project. The result from Phase 1 was an optimized mill roller gap setting that achieved a higher husk volume than currently achieved at Wachusett Brewing Company. The result from Phase 2 was a turbidity analysis from two batches of Wachusett Blueberry Ale: one using Wachusett Brewing Company's standard mill settings and another using the optimized mill settings from Phase 1 of this project.

4.1 Phase 1: Optimal Roller Spacings

4.1.1 First Design of Experiments

The goal of the first design of experiments was to test how the first and second roller gap affect husk volume. Using Minitab, contour graphs were plotted to visually represent the impact of the first and second roller gaps on husk volume, as shown in Figure 4.1. A high husk volume is desired, which is represented by darker shades of green in the contour plot.

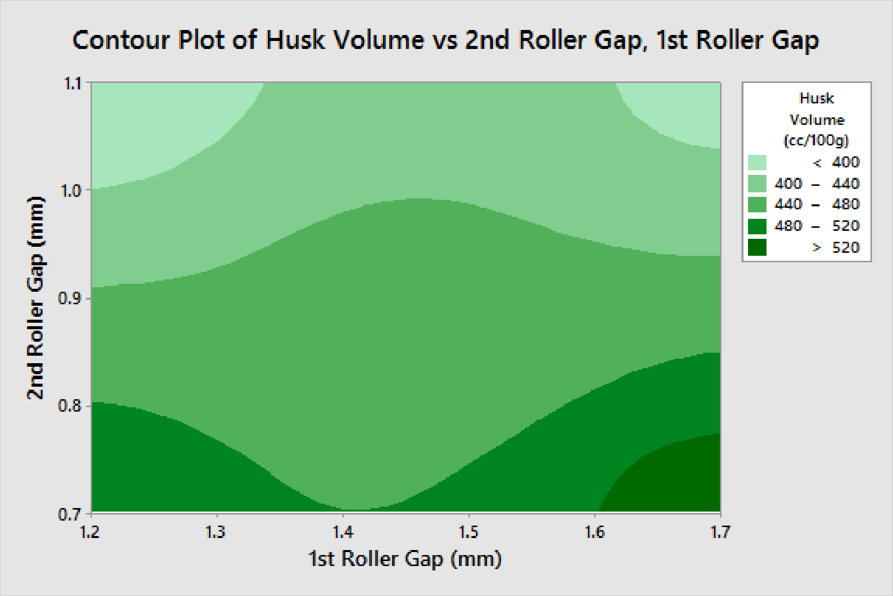

Figure 4.1: *Contour Plot of the Effect of the 1st and 2nd Roller Gaps on Husk Volume*

The contour plot in Figure 4.1 indicates that the first roller gap had less of an effect on the husk volume than the second roller gap, as there is less variance in the husk volume along the x-axis. From the first DOE, it can be concluded that anywhere between 1.2 mm and 1.7 mm yielded a good husk volume for the first roller gap. However, husk volume appears to decrease from 1.2 mm until reaching a minimum at 1.4 mm. From there, husk volume appears to rise steadily to a maximum at 1.7 mm, where a husk volume of 520cc / 100g was achieved. From this data, there is a potential trend that a wider first roller gap produces higher husk volumes. However, with so few data points, the trend identified in the first DOE needs to be studied more in order to further provide evidence for this theory.

In conjunction with the contour plot, a Pareto Chart of Effects was created using Minitab to show which factors had the greatest impact on husk volume, shown in Figure 4.2. The Pareto Chart and Contour Graph both suggest that the second roller gap had a larger impact on the husk volume. The Pareto Chart in Figure 4.2 also suggests that changing both the first and second roller gaps simultaneously has a minimal effect.

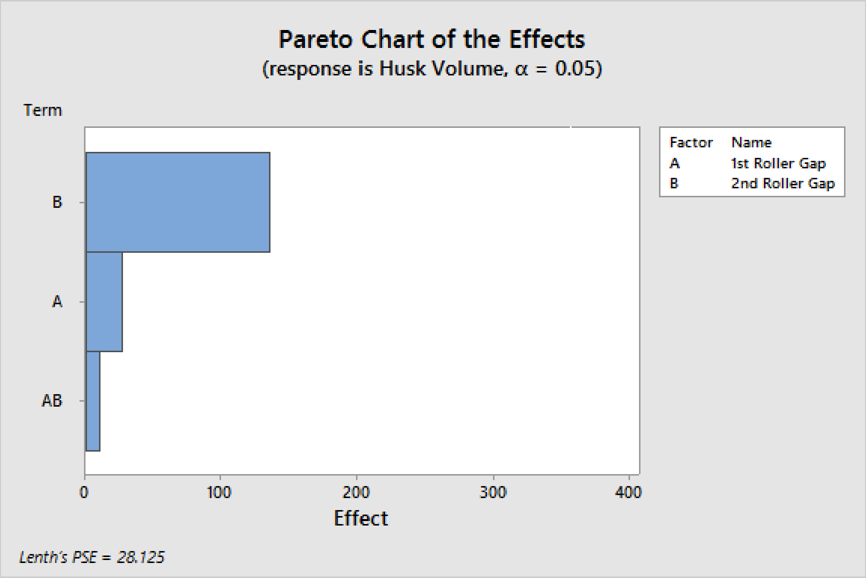

***Figure 4.2**: Pareto Chart of Factors that Impact Husk Volume*

4.1.2 Second Design of Experiments

The objective for the second DOE was to test a smaller region of roll gaps to confirm the trends determined from the first DOE. The trends from the first DOE indicated that resultant husk volumes were highest with a first roller gap between 1.5 mm and 1.7 mm and a second roller gap between 0.7 mm and 0.9 mm. Therefore the team decided to test this region in order to clarify where the ideal roller spacings were. Figure 4.3 shows the region tested in the previous contour plot from the first DOE.

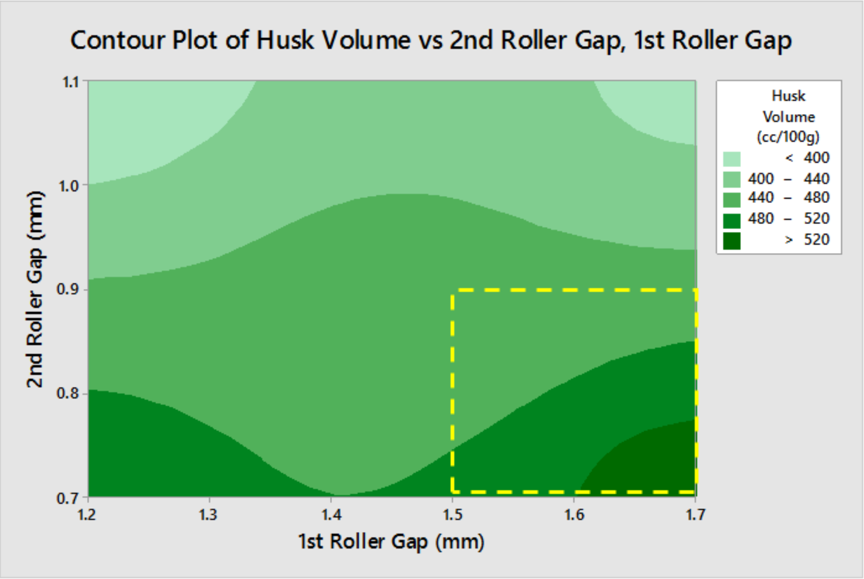

Figure 4.3: *Region to be Tested for the Second Design of Experiments*

Even though a spike in husk volume was found with a first roller gap between 1.2 mm and 1.4 mm, these points were excluded from additional testing. A first roller gap from 1.2 mm to 1.4 mm damages the husk which is undesirable for lauter tun processes. The Minitab contour plot generated from the second DOE can be seen in Figure 4.4.

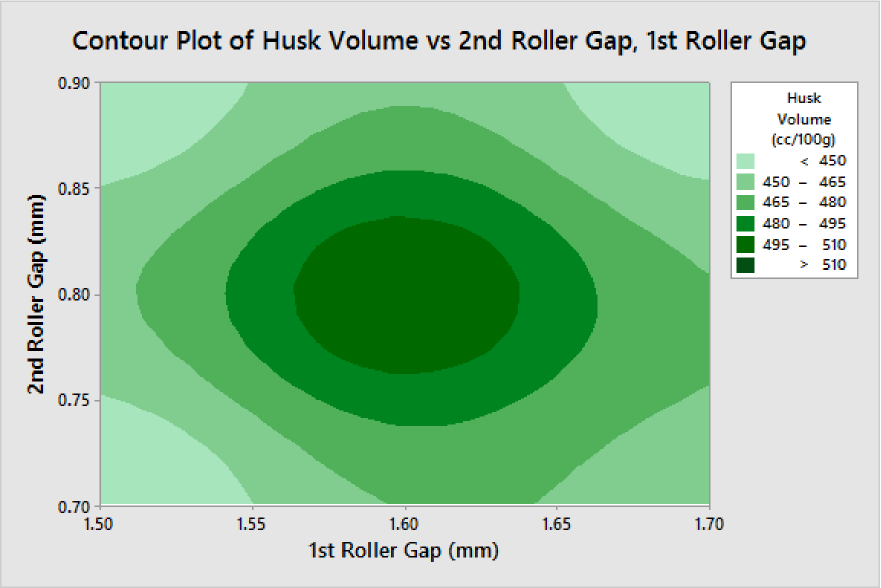

Figure 4.4: *Second Design of Experiments Contour Plot*

First off, it is important to note that the values for husk volume from the two DOE's cannot be compared, only the trends can be. This is because the lot of grain used in both experiments was different and therefore the resulting husk volume could be potentially different. Nonetheless, the trends provided the team with enough information to make some valuable conclusions regarding the mill. As expected, the second DOE supported the finding from the first DOE. The maximum husk volume was determined to be at a first roller gap of 1.6 mm and a second roller gap of 0.8 mm. Figure 4.4 also continued to prove that the second roller gap had a more significant impact on husk volume. Even though the data from the second DOE was more refined than the first, the team decided that a third experiment needed to be completed to better understand the dependence of husk volume on the second roller gap. But first, the next step was to determine the ideal first roller gap.

4.1.3 First Roller Gap Setting Visuals

To determine what the ideal first roller gap was, the team took pictures of the milled grain from the first sample port on the mill, which is located directly under the first set of rollers. The first set of rollers is designed to loosen the husk around the grain but not damage it. Visual inspection of the photos in Figure 4.5 allowed the team to decide that the ideal roller spacing is 1.65 mm.

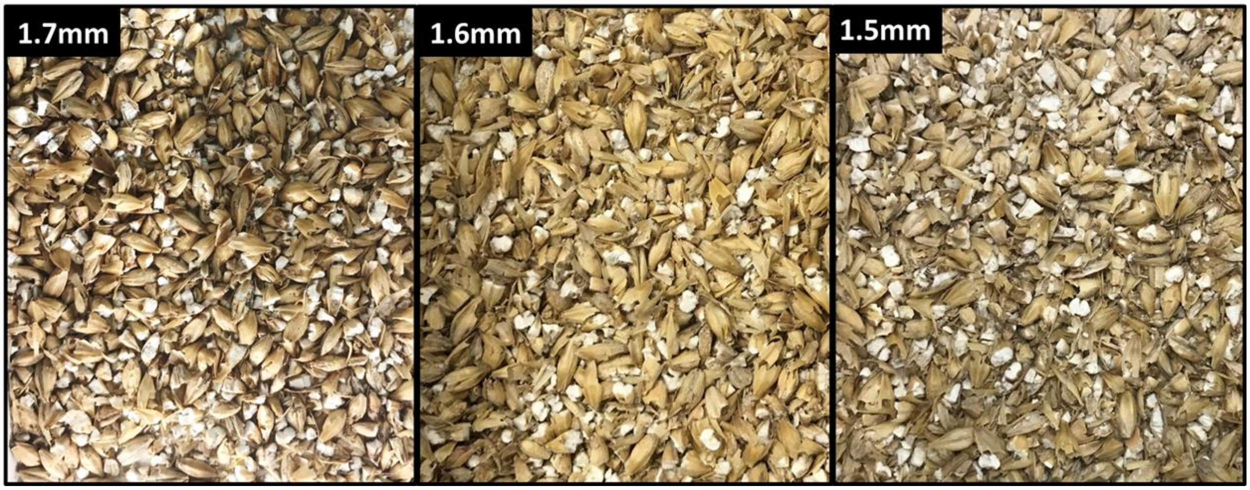

Figure 4.5*: First Roller Husk Sample Pictures*

In the pictures above, the white bits are endosperm. Endosperm shouldn't be exposed after the first set of rollers. The husk should also still be attached to the grain, but in the photo on the right, husk was removed and damaged by the first set of rollers. Damaged husk is not optimal for lauter tun processes. A roller gap of 1.7 mm failed to loosen the husk at all. Looking at the photo from the 1.6 mm roller gap, it is clear that some husk started to be removed from the grain. Therefore the team decided that the best first roller spacing was 1.65 mm.

4.1.4 Independent Second Roller Analysis

The objective for the independent second roller analysis was to determine the dependence of the second roller gap on husk volume. To do so, the team collected data by keeping the first and third roller gap constant and varying the second roller gap. The first and third roller gaps were kept at 1.65 mm and 0.6 mm, respectively, while the second roller gap was varied between 0.7 mm and

1.1 mm. An additional run was completed with the second roller gap at 1.3 mm to determine the husk volume of Wachusett Brewing Company's current milling process. Figure 4.6 below shows the established correlation between the second roller gap and husk volume.

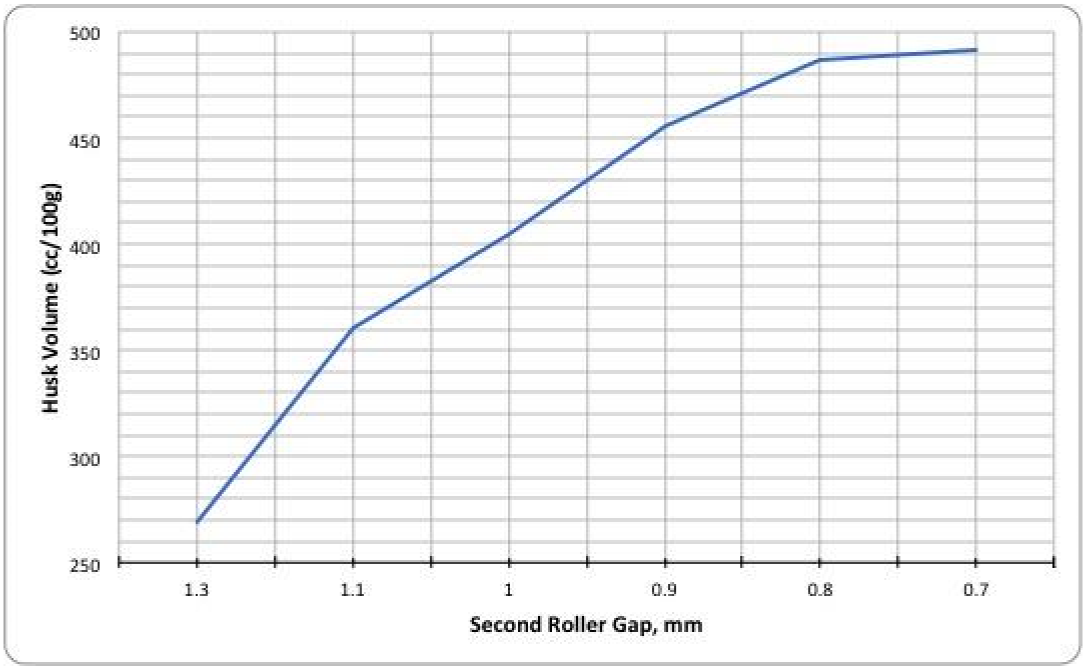

***Figure 4.6**: Husk Volume Dependence on 2nd Roller*

As mentioned earlier, the husk volume values in this analysis cannot be compared to other data collection tests in the project. The trend observed was a reduction in second roller gap spacing from 1.3 mm to 0.7 mm resulted in an increasing husk volume. From Figure 4.6, a second roller gap of 0.7 mm produced the highest overall husk volume.

4.1.5 Determining the Optimal Mill Settings

To determine the optimal mill settings for Wachusett Brewing Company, weight distribution graphs were created and compared to Wachusett Brewing Company's and Buhler Group's recommendations. The graphs display the percent of the total weight of ground barley on each sieve after the sifting. Both Wachusett Brewing Company's and Buhler Group's recommendations for weight distribution are presented for a second time in Figure 4.7 for ease of comparison.

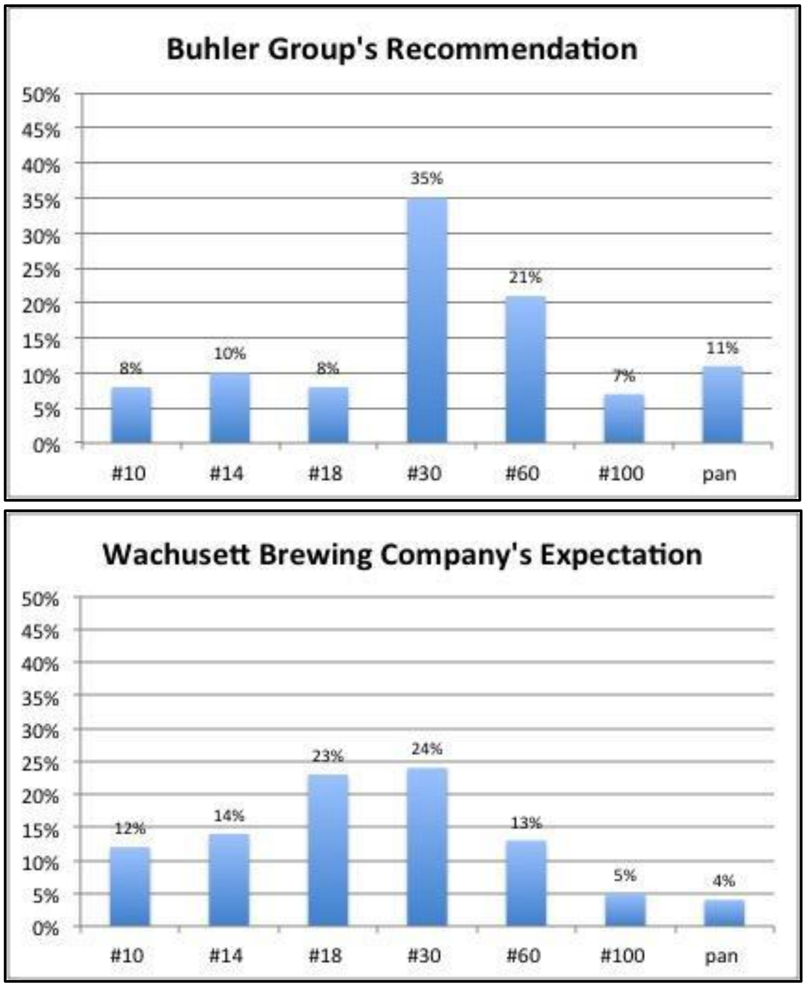

Figure 4.7*: Mill Composition Recommendations and Expectations*

Out of the five runs completed in the independent second roller analysis, Runs 3 and 5 were deemed most favorable. The weight distributions for Runs 3 and 5 are shown in Figures 4.8 and 4.9, respectively. These two runs were deemed most favorable because of the similarity to both Wachusett Brewing Company's expectation and Buhler Group's recommendation.

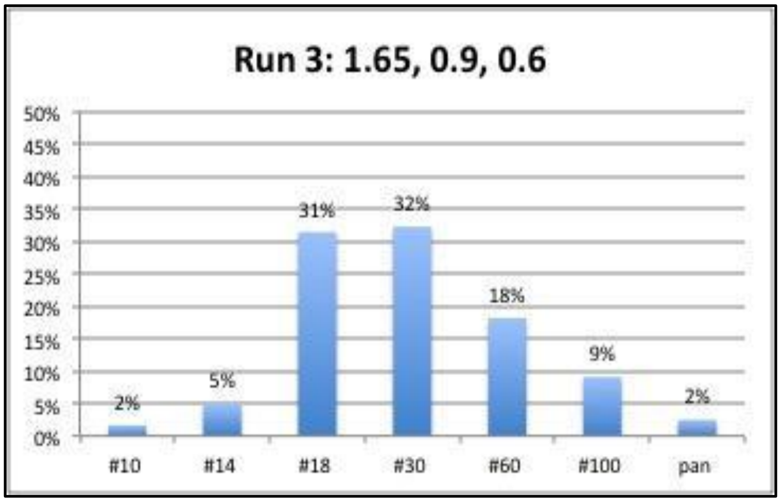

Figure 4.8*: Run 3 Barley Weight Distribution Graph*

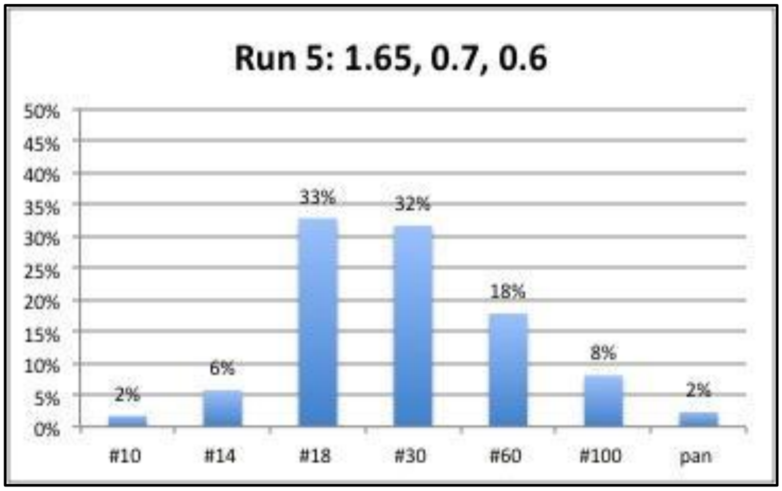

Figure 4.9*: Run 5 Barley Weight Distribution Graph*

Taking into consideration the expectations and recommendations from Wachusett Brewing Company and Buhler Group, Run 3 was chosen over Run 5. Even though the resulting husk volume was higher for Run 5 (490 cc/100g) than Run 3 (455 cc/100g) the team chose Run 3 for two reasons. The first reason was because the weight percent on the #30 screen was highest overall in Run 3 and the second was because of Wachusett Brewing Company's unique brewing process. Wachusett Brewing Company has made it clear that a coarser grind works better in their lauter process. Wachusett Brewing Company claims that a coarser grind allows for a quicker runoff in their lauter tun, allowing them to mash every two hours. As a result, brewmasters at Wachusett Brewing Company did not want to run the mill with a third roller gap smaller than 0.8 mm. Using the mill settings in Run 3, allows for the third set of rollers to be set at 0.8 mm, creating a coarser grist. To finalize the comparison between Wachusett Brewing Company's expectations and Buhler Group's recommendations and the team's optimal mill settings, Figure 4.10 was made.

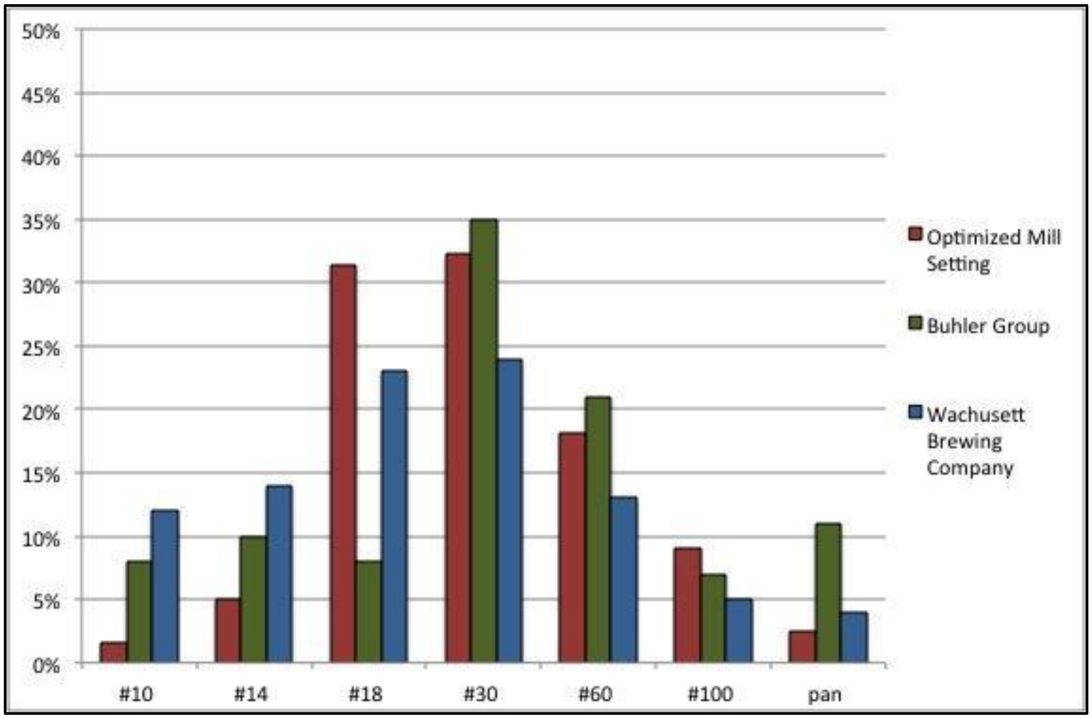

***Figure 4.10**: Comparison of Weight Distributions*

The optimal mill settings determined in this report have desirable characteristics for both company's recommendations. For example, the weight percent of barley on the #30 and #60 screens is nearly the same for the optimal settings and Wachusett Brewing Company's expectation. The optimal mill settings also reduce the weight percent of barley in the pan, which indicates a coarser grind. Comparing to Buhler Group's recommendation, the optimal mill settings achieve a desirable amount of barley on the #18 screen. The weight percents on the #10 and #14 screen seem to be very different than both Wachusett Brewing Company and Buhler Group. The team attributes this inconsistency to the light weight of the husk and the high weight percent of grain on the #18 screen. The husk is a small portion of the total weight of the barley grain, therefore it is expected that the weight percents should be very small. It seems unrealistic that the husk on the #10 screen can be higher than 10% like Buhler Group recommends. Additionally, Wachusett Brewing Company was concerned that the low weight percent on the #10 and #14 screens indicated that the husk was being pulverized and accumulated on a smaller screen. To alleviate this concern, Figure 4.11 shows pictures of the #10, #14, and #18 screens after sifting. The roller gaps for this trial were 1.7 mm, 0.7 mm, and 0.6 mm.

***Figure 4.11**: Sieve #10, #14, and #18 with Roller Gaps 1.7 mm, 0.7 mm, and 0.6 mm*

Looking at the husks on the #10 screen, there is a slight amount of damage to the husks. The husks were not completely intact but most were in half. The #14 screen contains more husk that was further ground, however the husk was still large enough to contribute to increased husk volume. Finally, the #18 screen had a decent amount of ground husk that was unfavorable. The husk on the #18 screen increased the weight percent of the screen to too high of a magnitude. Despite this, ground husk on the #18 screen is to be expected. Figure 4.12 below shows pictures from Buhler Group of the #10 and #18 screens from their milling process.

***Figure 4.12**: Buhler Group Pictures of the #10 and #14 Screens After Sifting*
(Photo provided by Roger Scheel)

The husks in Figure 4.12 on the #18 screen look very similar to the husks on the #18 screen in Figure 4.11. However, the quantity of ground husk is less. The #10 screen in Figure 4.12 also has fully intact husks. Ideally, the optimal mill settings should produce husks similar to those in Figure 4.12. It is possible that the condition of the grain before it enters the milling machine has an effect on the quality of the husks after milling. Wachusett Brewing Company stores their grain in silos outside of their brewery and uses an auger to carry the grain from the silos across the length of the brewery to the milling machine. The transfer from the silos to the milling machine using the auger could potentially damage the husks before the grain enters the milling machine. If the husk is loosened before entering the milling machine, the husk would be more prone to detaching from the endosperm and being ground up by the rollers.

4.2 Phase 2: Lauter Tun Runoff Clarity

The goal of the second phase of this project was to correlate the new optimized mill settings to lauter tun runoff clarity. After brewing two batches of Wachusett Blueberry Ale, the team was able to determine that there was a reduction of haze forming compounds in the beer.

From the start, the brewers indicated that the lauter tun runoff looked visually clearer using the newly optimized mill settings. This positive feedback was verified by the turbidity readings from the turbidity meter on the lauter tun. A scatter plot of the lauter tun runoff turbidity versus total runoff volume is shown in Figure 4.13.

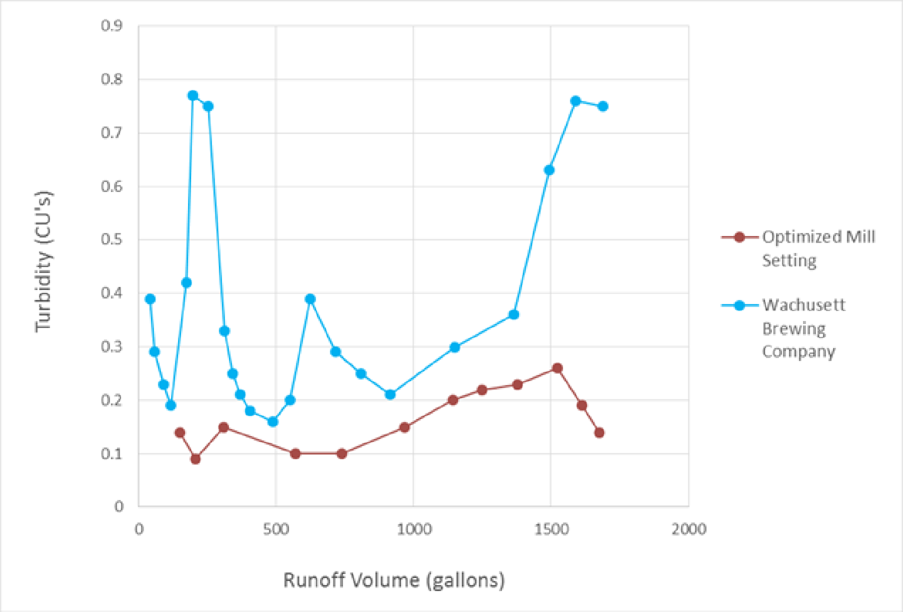

***Figure 4.13**: Turbidity Readings from Lauter Tun Process*

The turbidity readings for the newly optimized mill settings were consistently lower than Wachusett Brewing Company's current mill settings. The turbidity readings also stayed relatively constant around 0.2 CU's unlike the current mill settings used by Wachusett Brewing Company which appear more irregular. The quality control lab at Wachusett Brewing Company classifies a beer as "bright" when the turbidity reading from the lauter tun runoff is below 0.2 CU. Therefore the goal of producing a "bright" beer had been achieved.

A turbidity reading using a benchtop turbidity meter was also recorded for the final product for both batches of beer. The optimized mill settings produced a product with a turbidity of 298 FTU's. Wachusett Brewing Company's standard mill setting produced a product with a turbidity of 503 FTU's. As stated in the background chapter, this quantity shouldn't be used to indicate final beer clarity. However, it does show that the wort entering the kettle from the lauter tun was clearer when using the optimized mill settings.

The final method to prove if the newly optimized mill settings increased the clarity of the lauter tun runoff was to compute the integral of the flowrate*turbidity versus time elapsed during runoff. The graph used to compute the integral is shown below in Figure 4.14.

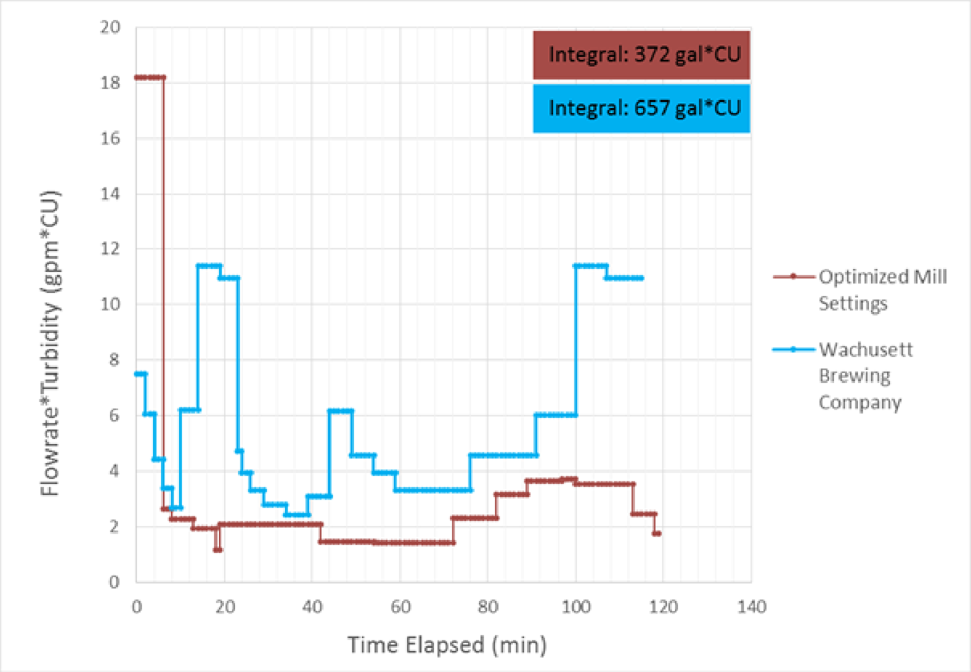

Figure 4.14: *The Integration of Flowrate*Turbidity as a Function of Time Elapsed During Lautering*

After completing the Riemann sum of both functions, the final quantity of haze forming compounds was determined to be 372 gal*CU for the optimized mill settings and 657 gal*CU for Wachusett Brewing Company's standard mill settings. This represents a 43% reduction in haze forming compounds in the beer.

The reduction in haze forming compounds came at the cost of lautering time. In total the lautering time was increased by 17 minutes and the overall lauter process took an additional 26 minutes from start to finish. The grain bed had to be cut twice during lautering to allow for a constant flow of runoff. Wachusett Brewing Company currently only cuts their grain beds once during lauter using their standard mill settings. This outcome challenges Wachusett Brewing Company's goal of mashing every two hours to keep up with business demand. Additional time also decreases profit margins, which is unfavorable.

Phase 2 of the project was completed with as little variability as possible. However, the two different batches of beer were brewed by two different brewers. Therefore, it is possible that there is some error in the calculation of the quantity of haze forming compounds. Another discrepancy between the two batches was the time intervals for recording turbidity. The turbidity of the first batch of beer brewed using Wachusett Brewing Company's standard mill settings was recorded in two minute intervals. The turbidity of the second batch brewed using the optimized mill settings, however, was recorded sporadically with no distinguishable trend. Consistent time intervals for both batches would have been ideal for comparing purposes.

5. Conclusions & Recommendations

The goal of this project was to increase beer clarity by modifying the barley milling process. The team concluded that a desirable husk volume can be achieved using the Buhler Group's six roller mill present at Wachusett Brewery. The roller gap settings that obtained the highest husk volume were 1.65 mm, 0.7 mm, and 0.6 mm for the first, second and third set of rollers. However, after discussions with Wachusett Brewing Company, the team decided to use 1.65 mm, 0.9 mm, and 0.8 mm to help accommodate Wachusett Brewing Company's unique brewing process. The results of running a full batch of Wachusett Blueberry Ale with new optimized mill settings were positive. The higher husk volume achieved with the optimized mill settings was proven to increase the clarity of the lauter tun runoff and subsequently, the clarity of the final beer. In total, the optimized mill settings reduced the quantity of haze forming compounds by 43%. The optimized mill settings produced a lauter tun extract with 372 gal*CU of haze forming compounds, compared to Wachusett Brewing Company's standard mill settings which contained 657 gal*CU of haze forming compounds.

Unfortunately, the increase in beer clarity came at a cost of increased lautering time. The lautering process took 150 minutes with the batch of grain milled using the optimized mill settings. Wachusett Blueberry Ale typically takes 124 minutes to lauter. Therefore, the optimized mill settings increased the lautering time by 26 minutes. Wachusett Brewing Company produces a large volume of beer each week, therefore, the increase in brewing time is undesirable for their business. Deciding between prioritizing process efficiency or beer clarity is a choice for Wachusett Brewing Company. Since the question of beer clarity started with customers' complaints, the team recommends collecting customer feedback on the importance of beer clarity while consuming Wachusett Brewing Company beer. If clarity is of utmost importance to customers, then the increase in lautering time can be justified.

Furthermore, Wachusett Brewing Company's beer clarity may not only be limited by the milling machine. Beer clarity can also be affected by other pieces of equipment in the beer production line such as the mash tun and lauter tun. Future projects should investigate how to optimize the operation of the mash and lauter tun. To ensure a clear, high quality beer, the milling machine, masher, and the lauter tun must be operating optimally.

Finally, the results from this report only apply to Wachusett Blueberry Ale. It is unclear if the optimized mill settings proposed in this report will work for all of Wachusett Brewing Company's different beers. Different beers require the addition of different malts and grains such as wheat and oats. The introduction of different grains can affect how well the milling machine and lauter tun operate. The gluten in wheat, for example, can cause the grain bed in the lauter tun to become sticky and slow down lautering. Future projects should be completed to find optimal mill settings for other beers.

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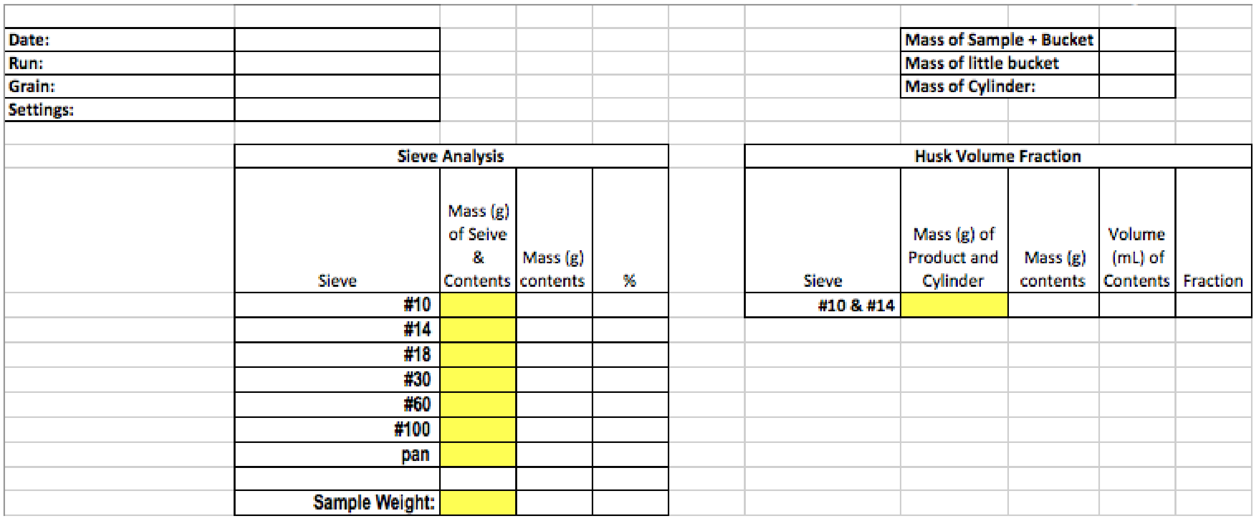
7. Appendices

Appendix A: Sieve Template



Date:	
Run:	
Grain:	
Settings:	

Mass of Sample + Bucket	
Mass of little bucket	
Mass of Cylinder:	

Sieve Analysis

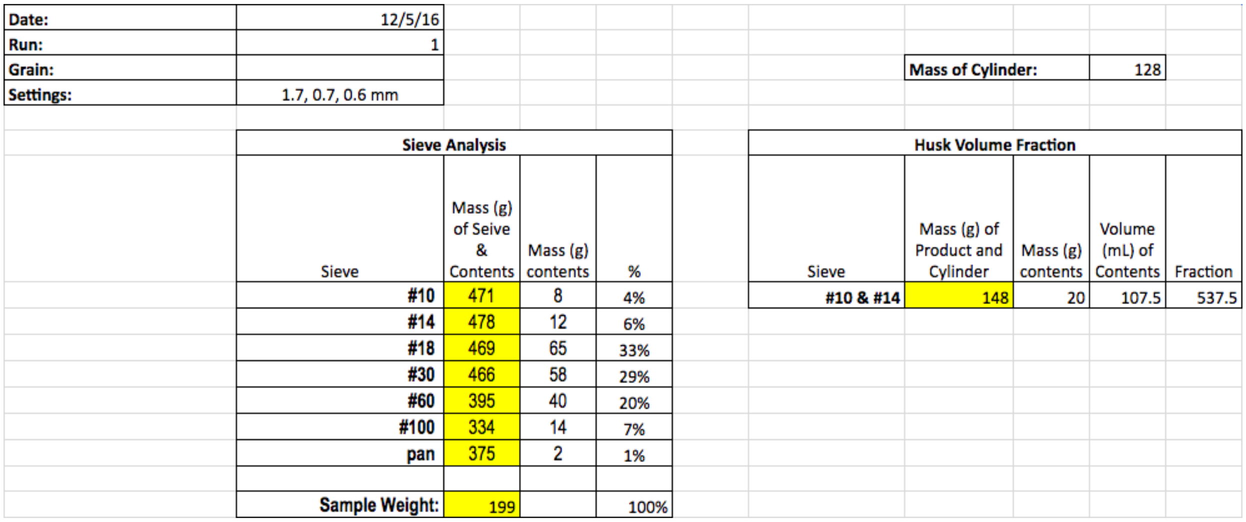
Sieve	Mass (g) of Seive & Contents	Mass (g) contents	%
#10			
#14			
#18			
#30			
#60			
#100			
pan			
Sample Weight:			

Husk Volume Fraction

Sieve	Mass (g) of Product and Cylinder	Mass (g) contents	Volume (mL) of Contents	Fraction
#10 & #14				

Appendix B: First Design of Experiments

Run 1:



Date:	12/5/16
Run:	1
Grain:	
Settings:	1.7, 0.7, 0.6 mm

Mass of Cylinder:	128

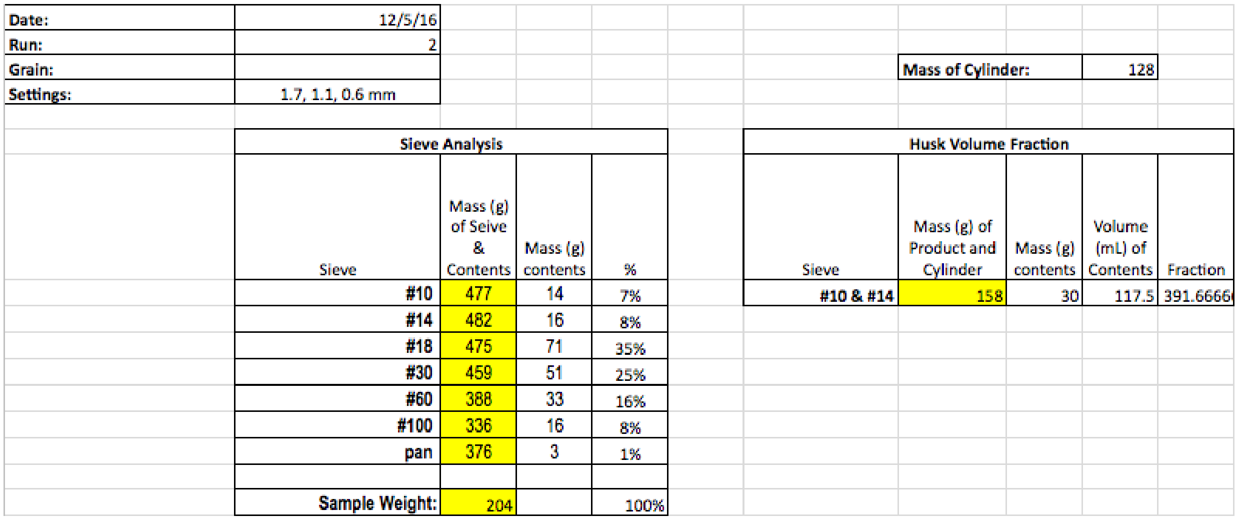
Sieve Analysis

Sieve	Mass (g) of Seive & Contents	Mass (g) contents	%
#10	471	8	4%
#14	478	12	6%
#18	469	65	33%
#30	466	58	29%
#60	395	40	20%
#100	334	14	7%
pan	375	2	1%
Sample Weight:	199		100%

Husk Volume Fraction

Sieve	Mass (g) of Product and Cylinder	Mass (g) contents	Volume (mL) of Contents	Fraction
#10 & #14	148	20	107.5	537.5

Run 2:



Date:	12/5/16
Run:	2
Grain:	
Settings:	1.7, 1.1, 0.6 mm

Mass of Cylinder:	128

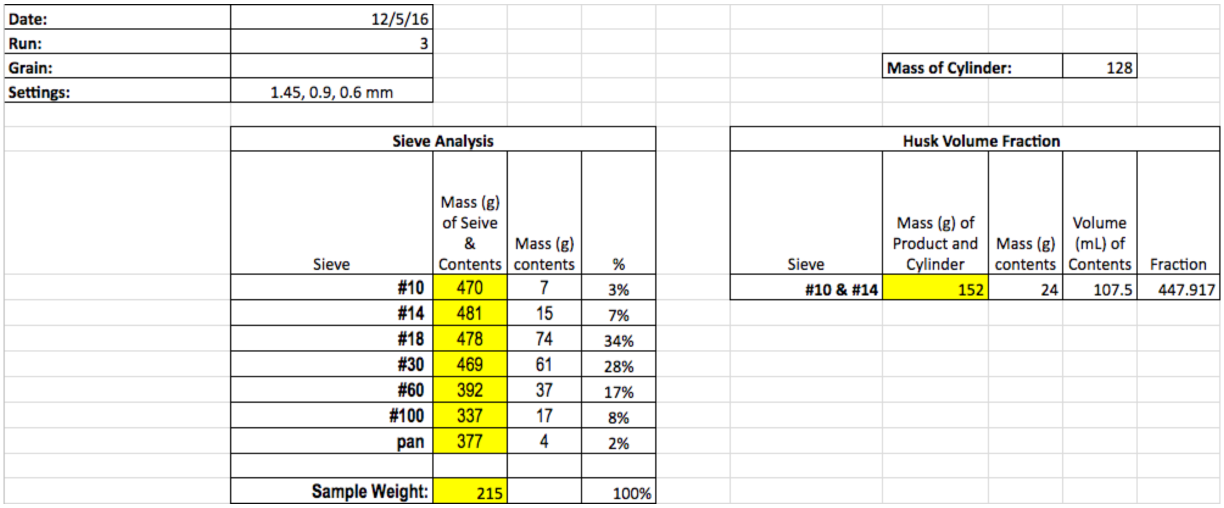
Sieve Analysis

Sieve	Mass (g) of Seive & Contents	Mass (g) contents	%
#10	477	14	7%
#14	482	16	8%
#18	475	71	35%
#30	459	51	25%
#60	388	33	16%
#100	336	16	8%
pan	376	3	1%
Sample Weight:	204		100%

Husk Volume Fraction

Sieve	Mass (g) of Product and Cylinder	Mass (g) contents	Volume (mL) of Contents	Fraction
#10 & #14	158	30	117.5	391.6666

Run 3:



Date:	12/5/16
Run:	3
Grain:	
Settings:	1.45, 0.9, 0.6 mm

Mass of Cylinder:	128

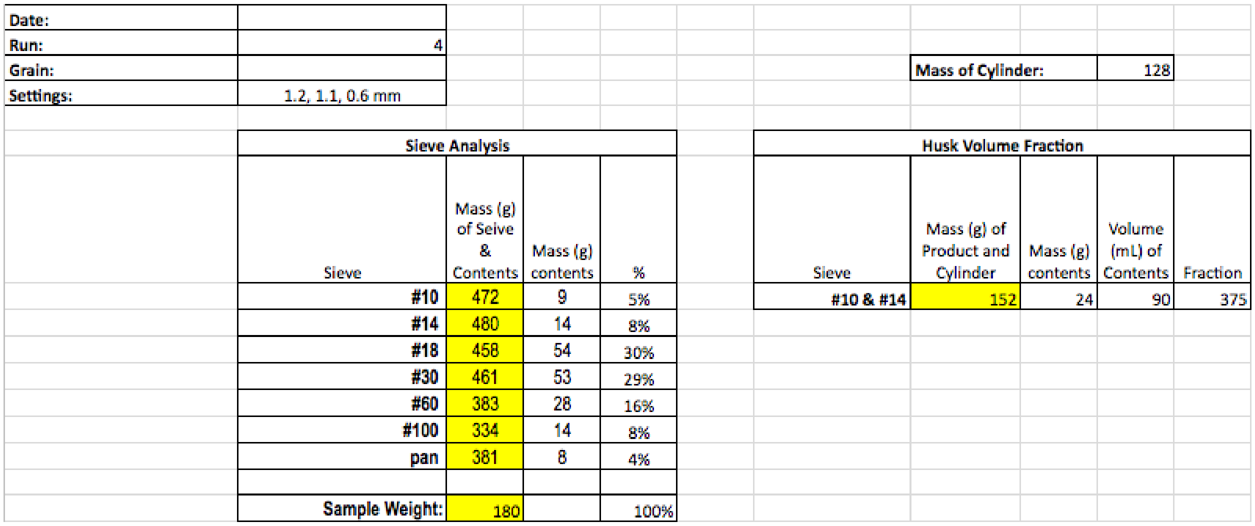
Sieve Analysis

Sieve	Mass (g) of Seive & Contents	Mass (g) contents	%
#10	470	7	3%
#14	481	15	7%
#18	478	74	34%
#30	469	61	28%
#60	392	37	17%
#100	337	17	8%
pan	377	4	2%
Sample Weight:	215		100%

Husk Volume Fraction

Sieve	Mass (g) of Product and Cylinder	Mass (g) contents	Volume (mL) of Contents	Fraction
#10 & #14	152	24	107.5	447.917

Run 4:



Date:	
Run:	4
Grain:	
Settings:	1.2, 1.1, 0.6 mm

Mass of Cylinder:	128

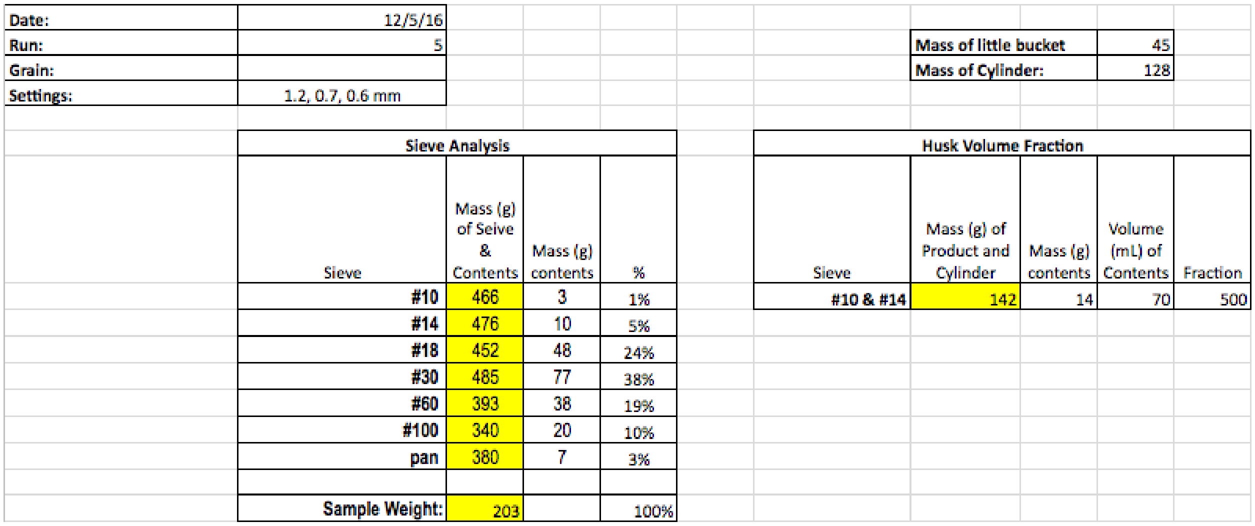
Sieve Analysis

Sieve	Mass (g) of Seive & Contents	Mass (g) contents	%
#10	472	9	5%
#14	480	14	8%
#18	458	54	30%
#30	461	53	29%
#60	383	28	16%
#100	334	14	8%
pan	381	8	4%
Sample Weight:	180		100%

Husk Volume Fraction

Sieve	Mass (g) of Product and Cylinder	Mass (g) contents	Volume (mL) of Contents	Fraction
#10 & #14	152	24	90	375

Run 5:



Date:	12/5/16
Run:	5
Grain:	
Settings:	1.2, 0.7, 0.6 mm

Mass of little bucket	45
Mass of Cylinder:	128

Sieve Analysis

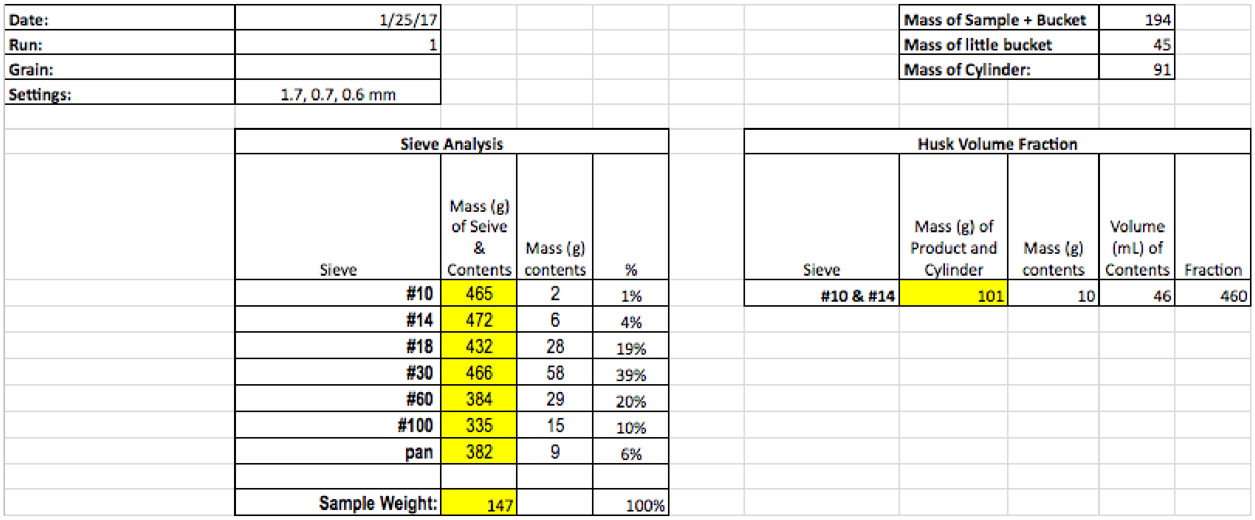
Sieve	Mass (g) of Seive & Contents	Mass (g) contents	%
#10	466	3	1%
#14	476	10	5%
#18	452	48	24%
#30	485	77	38%
#60	393	38	19%
#100	340	20	10%
pan	380	7	3%
Sample Weight:	203		100%

Husk Volume Fraction

Sieve	Mass (g) of Product and Cylinder	Mass (g) contents	Volume (mL) of Contents	Fraction
#10 & #14	142	14	70	500

Appendix C: Second Design of Experiments

Run 1:



Date:	1/25/17
Run:	1
Grain:	
Settings:	1.7, 0.7, 0.6 mm

Mass of Sample + Bucket	194
Mass of little bucket	45
Mass of Cylinder:	91

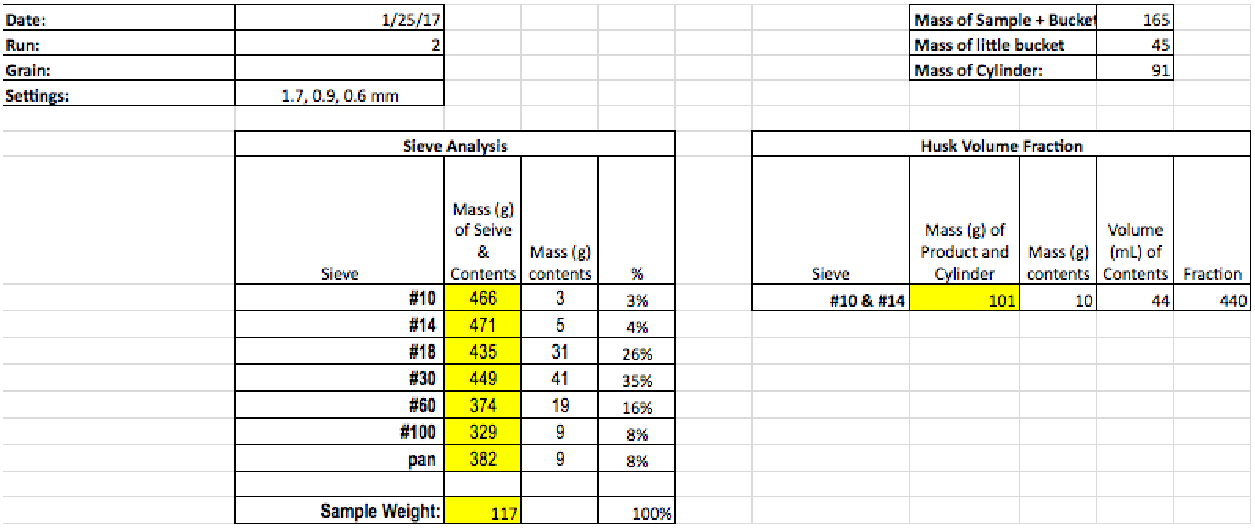
Sieve Analysis

Sieve	Mass (g) of Seive & Contents	Mass (g) contents	%
#10	465	2	1%
#14	472	6	4%
#18	432	28	19%
#30	466	58	39%
#60	384	29	20%
#100	335	15	10%
pan	382	9	6%
Sample Weight:	147		100%

Husk Volume Fraction

Sieve	Mass (g) of Product and Cylinder	Mass (g) contents	Volume (mL) of Contents	Fraction
#10 & #14	101	10	46	460

Run 2:



Date:	1/25/17
Run:	2
Grain:	
Settings:	1.7, 0.9, 0.6 mm

Mass of Sample + Bucke	165
Mass of little bucket	45
Mass of Cylinder:	91

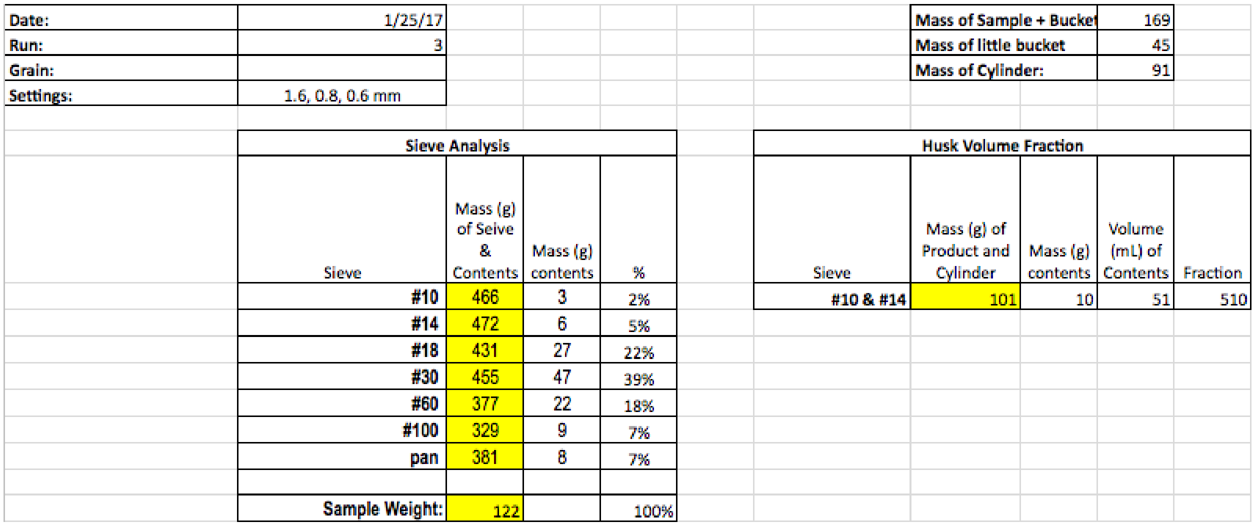
Sieve Analysis

Sieve	Mass (g) of Seive & Contents	Mass (g) contents	%
#10	466	3	3%
#14	471	5	4%
#18	435	31	26%
#30	449	41	35%
#60	374	19	16%
#100	329	9	8%
pan	382	9	8%
Sample Weight:	117		100%

Husk Volume Fraction

Sieve	Mass (g) of Product and Cylinder	Mass (g) contents	Volume (mL) of Contents	Fraction
#10 & #14	101	10	44	440

Run 3:



Date:	1/25/17
Run:	3
Grain:	
Settings:	1.6, 0.8, 0.6 mm

Mass of Sample + Bucket	169
Mass of little bucket	45
Mass of Cylinder:	91

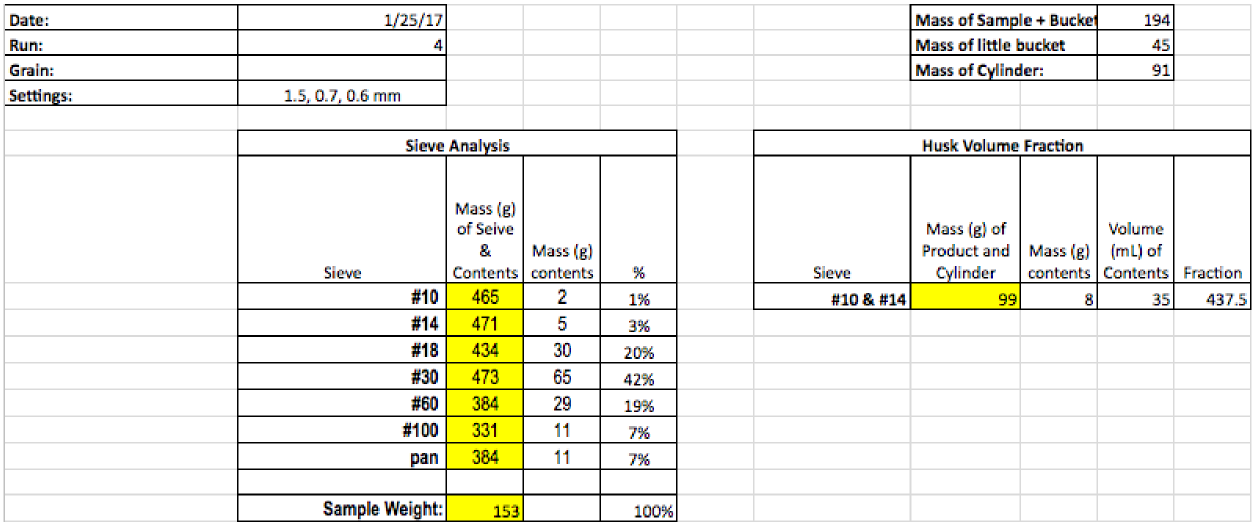
Sieve Analysis

Sieve	Mass (g) of Seive & Contents	Mass (g) contents	%
#10	466	3	2%
#14	472	6	5%
#18	431	27	22%
#30	455	47	39%
#60	377	22	18%
#100	329	9	7%
pan	381	8	7%
Sample Weight:	122		100%

Husk Volume Fraction

Sieve	Mass (g) of Product and Cylinder	Mass (g) contents	Volume (mL) of Contents	Fraction
#10 & #14	101	10	51	510

Run 4:



Date:	1/25/17
Run:	4
Grain:	
Settings:	1.5, 0.7, 0.6 mm

Mass of Sample + Bucket	194
Mass of little bucket	45
Mass of Cylinder:	91

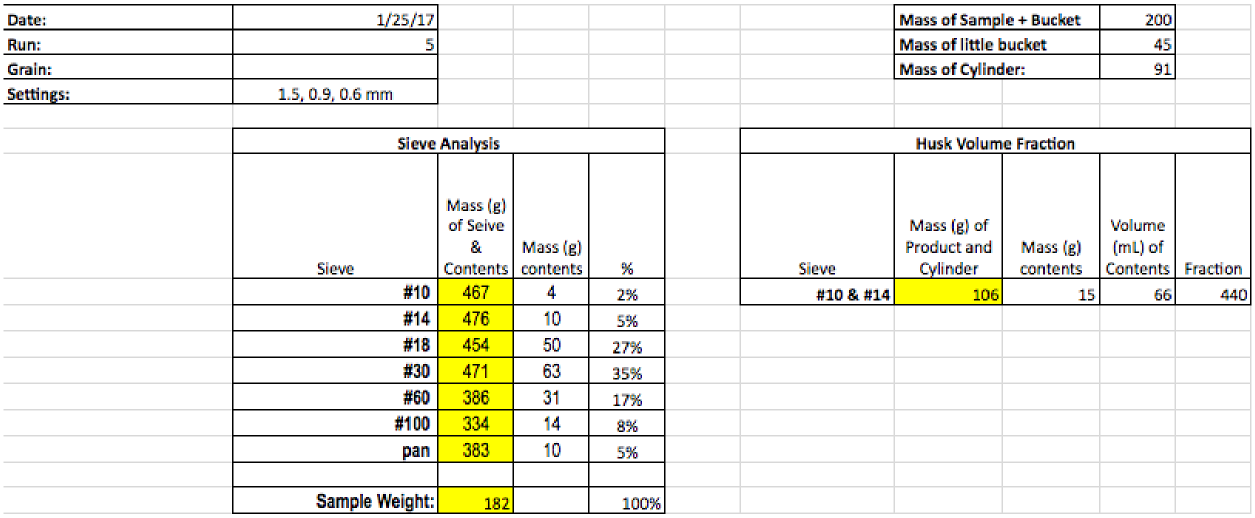
Sieve Analysis

Sieve	Mass (g) of Seive & Contents	Mass (g) contents	%
#10	465	2	1%
#14	471	5	3%
#18	434	30	20%
#30	473	65	42%
#60	384	29	19%
#100	331	11	7%
pan	384	11	7%
Sample Weight:	153		100%

Husk Volume Fraction

Sieve	Mass (g) of Product and Cylinder	Mass (g) contents	Volume (mL) of Contents	Fraction
#10 & #14	99	8	35	437.5

Run 5:



Date:	1/25/17
Run:	5
Grain:	
Settings:	1.5, 0.9, 0.6 mm

Mass of Sample + Bucket	200
Mass of little bucket	45
Mass of Cylinder:	91

Sieve Analysis

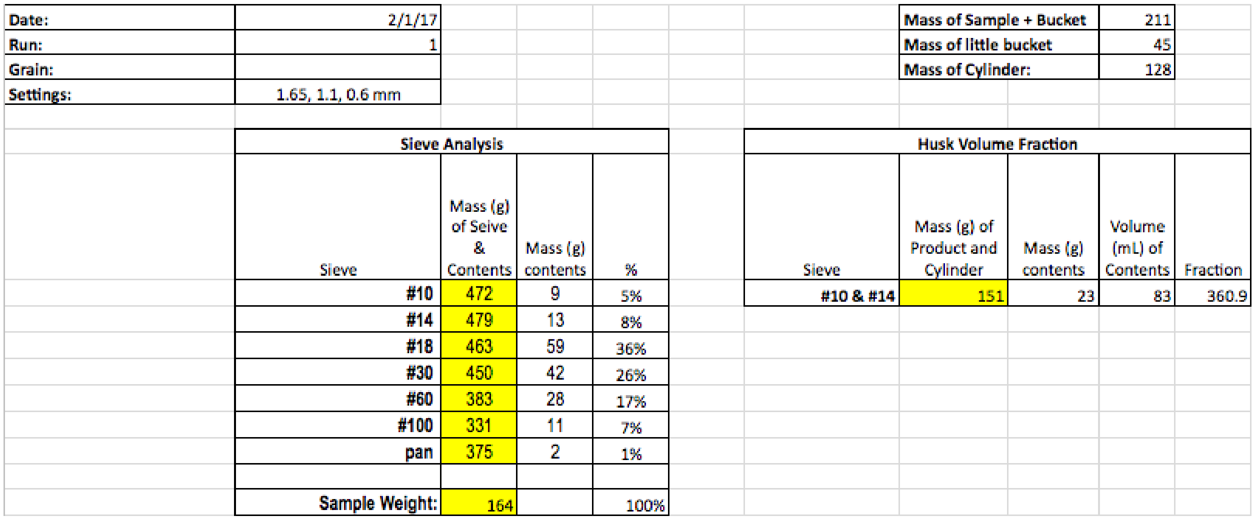
Sieve	Mass (g) of Seive & Contents	Mass (g) contents	%
#10	467	4	2%
#14	476	10	5%
#18	454	50	27%
#30	471	63	35%
#60	386	31	17%
#100	334	14	8%
pan	383	10	5%
Sample Weight:	182		100%

Husk Volume Fraction

Sieve	Mass (g) of Product and Cylinder	Mass (g) contents	Volume (mL) of Contents	Fraction
#10 & #14	106	15	66	440

7.4 Appendix D: Independent Second Roller Analysis

Run 1:



Date:	2/1/17
Run:	1
Grain:	
Settings:	1.65, 1.1, 0.6 mm

Mass of Sample + Bucket	211
Mass of little bucket	45
Mass of Cylinder:	128

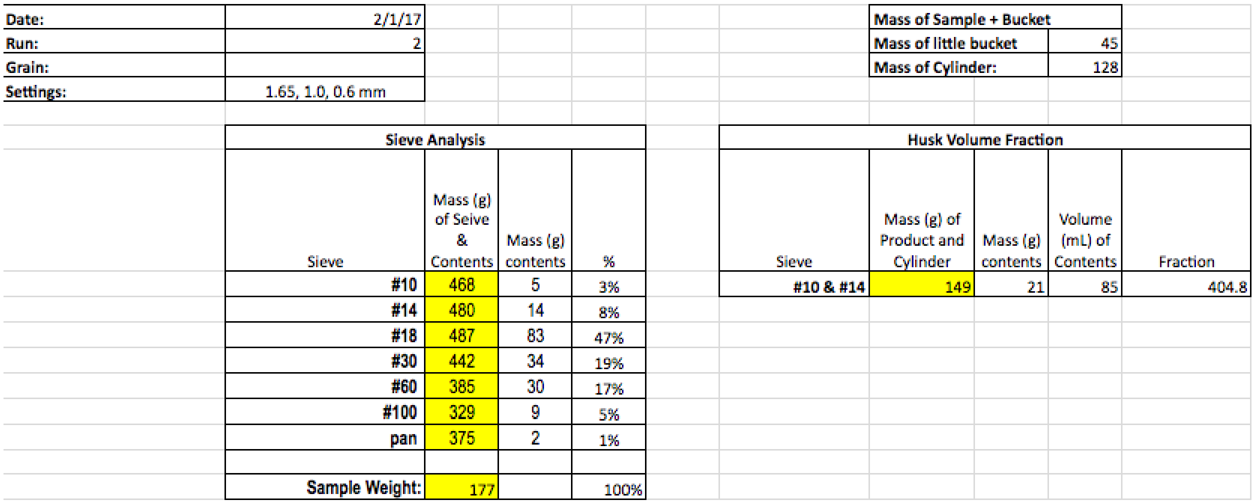
Sieve Analysis

Sieve	Mass (g) of Seive & Contents	Mass (g) contents	%
#10	472	9	5%
#14	479	13	8%
#18	463	59	36%
#30	450	42	26%
#60	383	28	17%
#100	331	11	7%
pan	375	2	1%
Sample Weight:	164		100%

Husk Volume Fraction

Sieve	Mass (g) of Product and Cylinder	Mass (g) contents	Volume (mL) of Contents	Fraction
#10 & #14	151	23	83	360.9

Run 2:



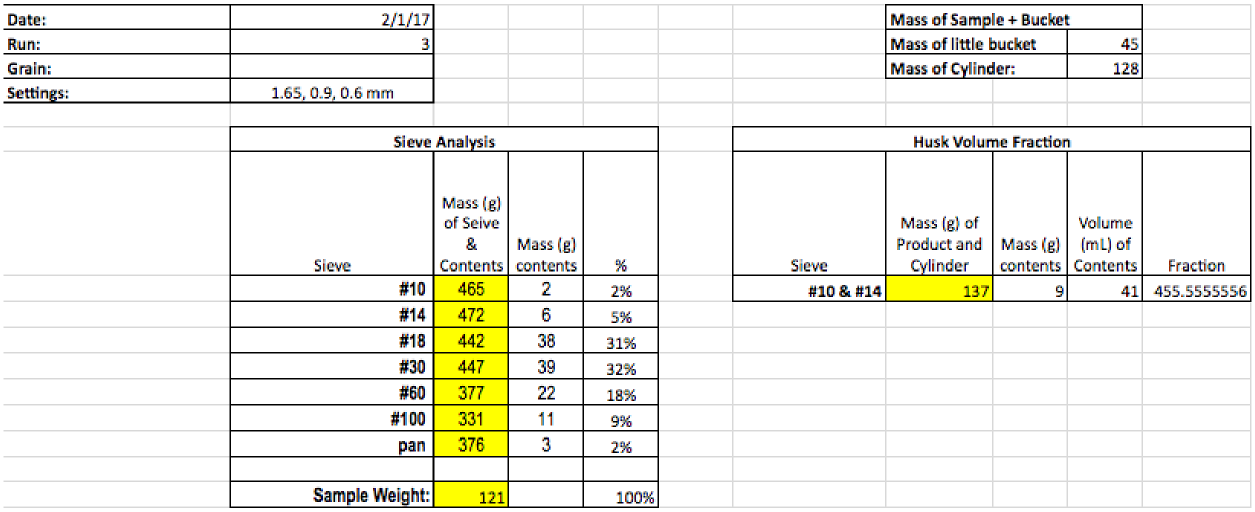
Date:	2/1/17
Run:	2
Grain:	
Settings:	1.65, 1.0, 0.6 mm

Mass of Sample + Bucket	
Mass of little bucket	45
Mass of Cylinder:	128

Sieve Analysis			
Sieve	Mass (g) of Seive & Contents	Mass (g) contents	%
#10	468	5	3%
#14	480	14	8%
#18	487	83	47%
#30	442	34	19%
#60	385	30	17%
#100	329	9	5%
pan	375	2	1%
Sample Weight:	177		100%

Husk Volume Fraction				
Sieve	Mass (g) of Product and Cylinder	Mass (g) contents	Volume (mL) of Contents	Fraction
#10 & #14	149	21	85	404.8

Run 3:



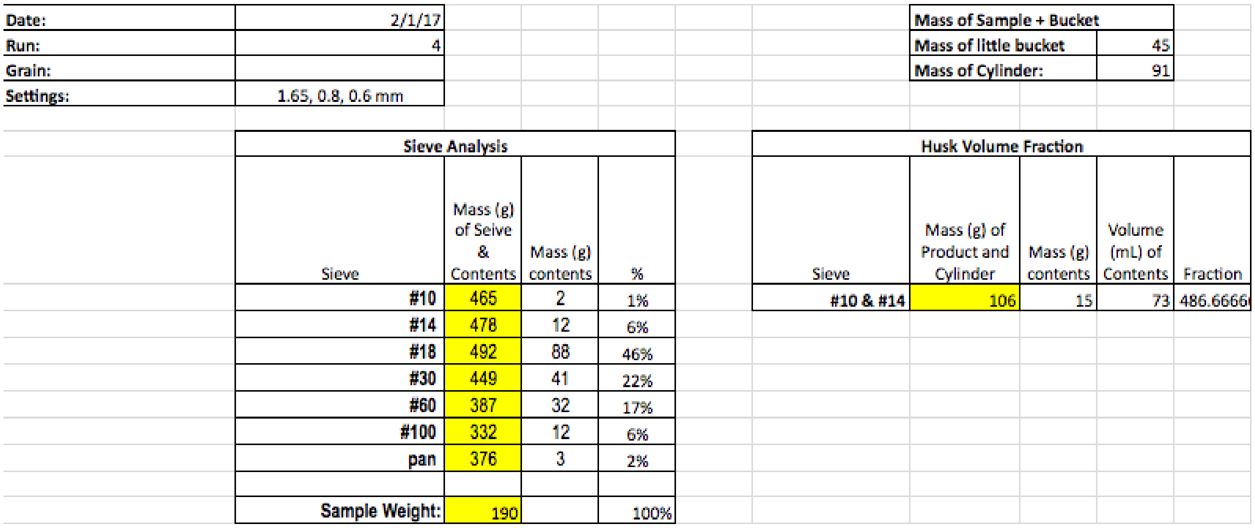
Date:	2/1/17
Run:	3
Grain:	
Settings:	1.65, 0.9, 0.6 mm

Mass of Sample + Bucket	
Mass of little bucket	45
Mass of Cylinder:	128

Sieve Analysis			
Sieve	Mass (g) of Seive & Contents	Mass (g) contents	%
#10	465	2	2%
#14	472	6	5%
#18	442	38	31%
#30	447	39	32%
#60	377	22	18%
#100	331	11	9%
pan	376	3	2%
Sample Weight:	121		100%

Husk Volume Fraction				
Sieve	Mass (g) of Product and Cylinder	Mass (g) contents	Volume (mL) of Contents	Fraction
#10 & #14	137	9	41	455.5555556

Run 4:



Date:	2/1/17
Run:	4
Grain:	
Settings:	1.65, 0.8, 0.6 mm

Mass of Sample + Bucket	
Mass of little bucket	45
Mass of Cylinder:	91

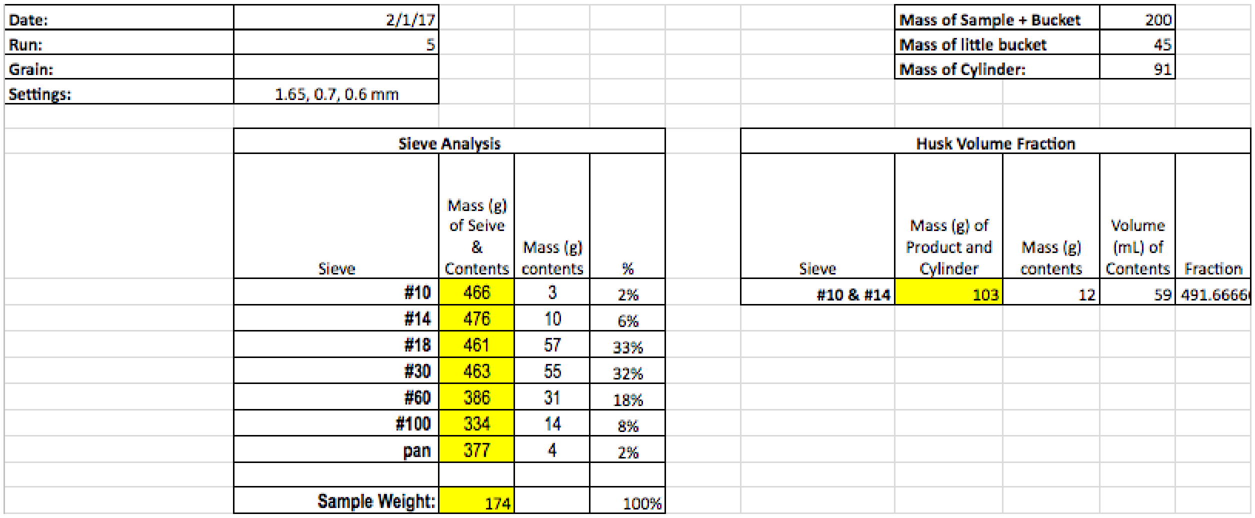
Sieve Analysis

Sieve	Mass (g) of Seive & Contents	Mass (g) contents	%
#10	465	2	1%
#14	478	12	6%
#18	492	88	46%
#30	449	41	22%
#60	387	32	17%
#100	332	12	6%
pan	376	3	2%
Sample Weight:	190		100%

Husk Volume Fraction

Sieve	Mass (g) of Product and Cylinder	Mass (g) contents	Volume (mL) of Contents	Fraction
#10 & #14	106	15	73	486.6666

Run 5:



Date:	2/1/17
Run:	5
Grain:	
Settings:	1.65, 0.7, 0.6 mm

Mass of Sample + Bucket	200
Mass of little bucket	45
Mass of Cylinder:	91

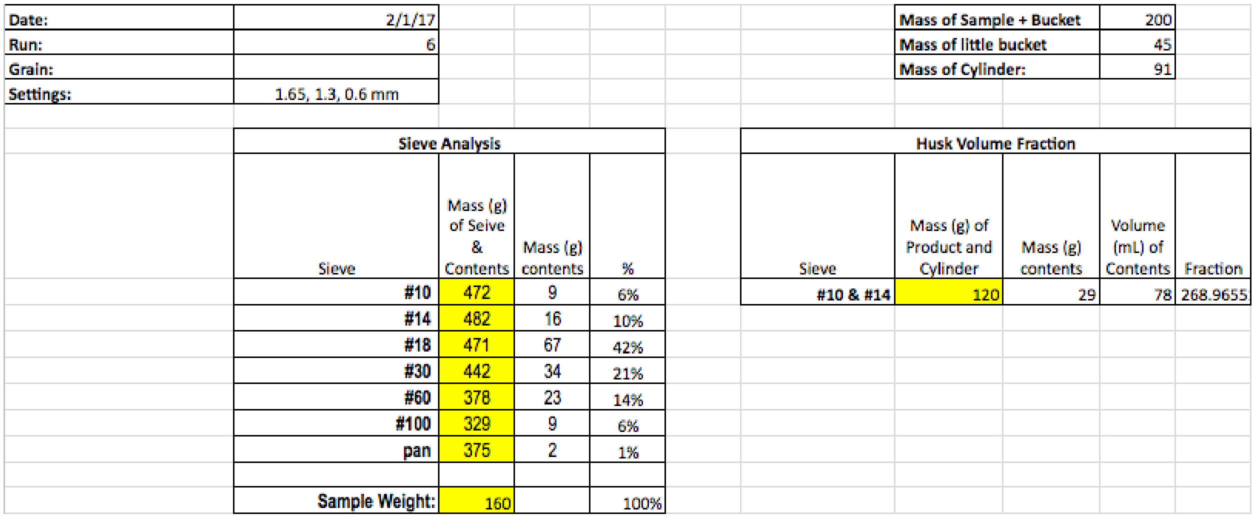
Sieve Analysis

Sieve	Mass (g) of Seive & Contents	Mass (g) contents	%
#10	466	3	2%
#14	476	10	6%
#18	461	57	33%
#30	463	55	32%
#60	386	31	18%
#100	334	14	8%
pan	377	4	2%
Sample Weight:	174		100%

Husk Volume Fraction

Sieve	Mass (g) of Product and Cylinder	Mass (g) contents	Volume (mL) of Contents	Fraction
#10 & #14	103	12	59	491.6666

Run 6:



Date:	2/1/17
Run:	6
Grain:	
Settings:	1.65, 1.3, 0.6 mm

Mass of Sample + Bucket	200
Mass of little bucket	45
Mass of Cylinder:	91

Sieve Analysis

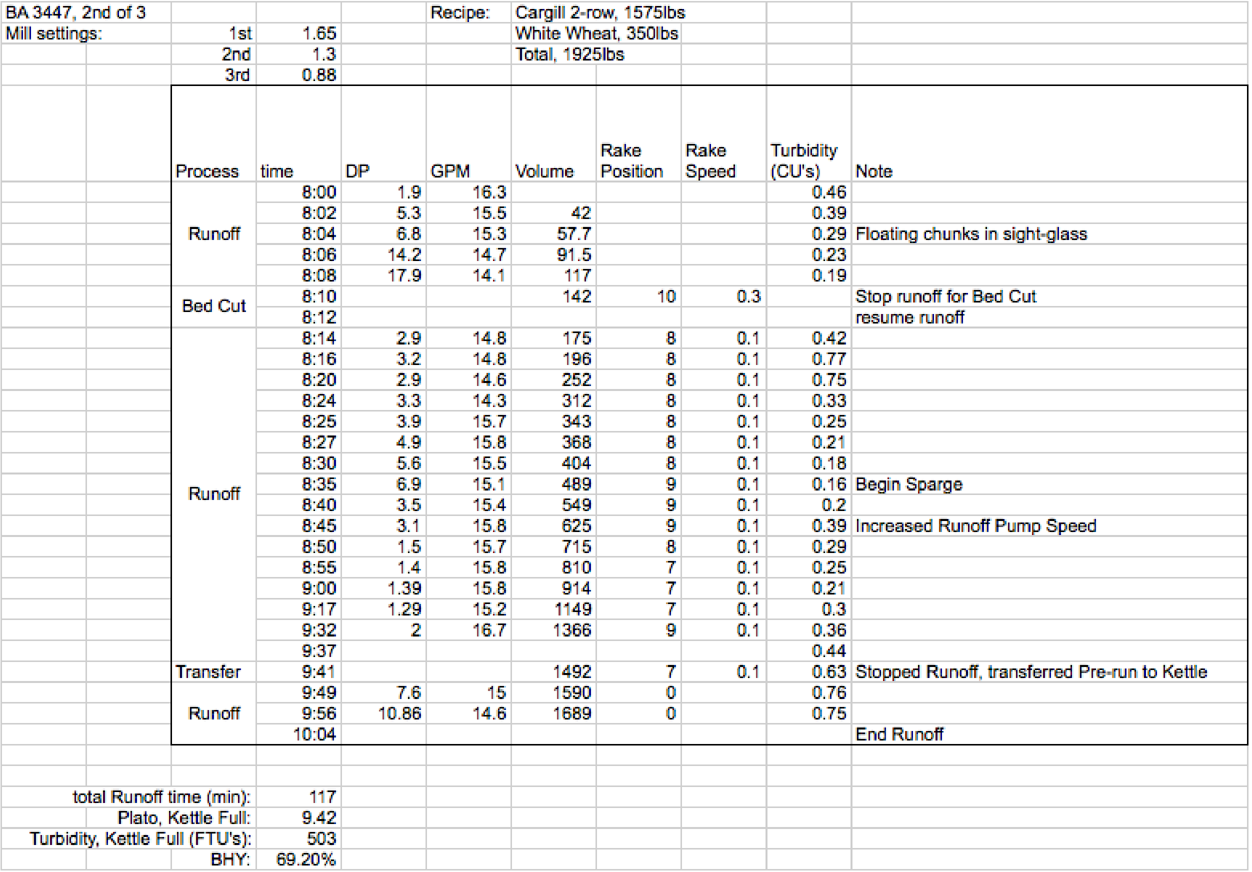
Sieve	Mass (g) of Seive & Contents	Mass (g) contents	%
#10	472	9	6%
#14	482	16	10%
#18	471	67	42%
#30	442	34	21%
#60	378	23	14%
#100	329	9	6%
pan	375	2	1%
Sample Weight:	160		100%

Husk Volume Fraction

Sieve	Mass (g) of Product and Cylinder	Mass (g) contents	Volume (mL) of Contents	Fraction
#10 & #14	120	29	78	268.9655

7.5 Appendix E: Lauter Tun Data

Mill Settings: 1.65mm, 1.3mm, and 0.88mm

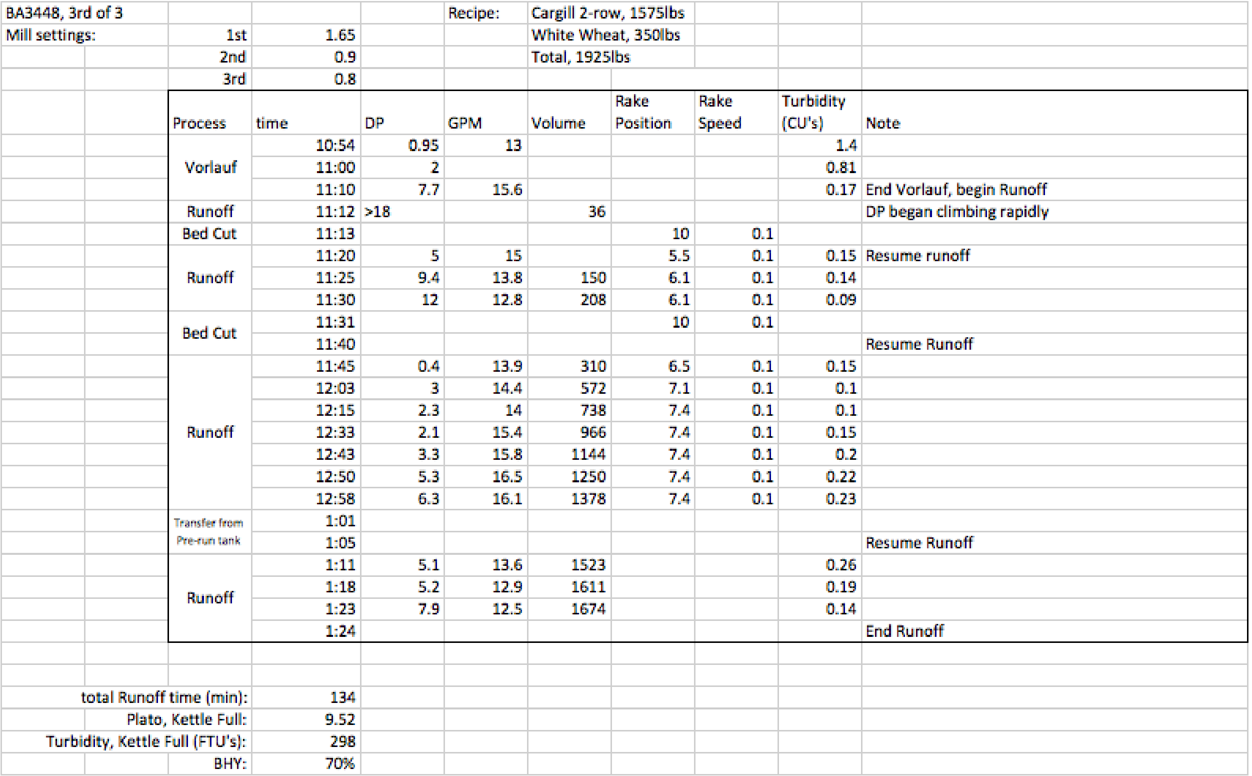


BA 3447, 2nd of 3			Recipe:	Cargill 2-row, 1575lbs
Mill settings:	1st	1.65		White Wheat, 350lbs
	2nd	1.3		Total, 1925lbs
	3rd	0.88		

Process	time	DP	GPM	Volume	Rake Position	Rake Speed	Turbidity (CU's)	Note
Runoff	8:00	1.9	16.3				0.46	
	8:02	5.3	15.5	42			0.39	
	8:04	6.8	15.3	57.7			0.29	Floating chunks in sight-glass
	8:06	14.2	14.7	91.5			0.23	
	8:08	17.9	14.1	117			0.19	
Bed Cut	8:10			142	10	0.3		Stop runoff for Bed Cut
	8:12							resume runoff
Runoff	8:14	2.9	14.8	175	8	0.1	0.42	
	8:16	3.2	14.8	196	8	0.1	0.77	
	8:20	2.9	14.6	252	8	0.1	0.75	
	8:24	3.3	14.3	312	8	0.1	0.33	
	8:25	3.9	15.7	343	8	0.1	0.25	
	8:27	4.9	15.8	368	8	0.1	0.21	
	8:30	5.6	15.5	404	8	0.1	0.18	
	8:35	6.9	15.1	489	9	0.1	0.16	Begin Sparge
	8:40	3.5	15.4	549	9	0.1	0.2	
	8:45	3.1	15.8	625	9	0.1	0.39	Increased Runoff Pump Speed
	8:50	1.5	15.7	715	8	0.1	0.29	
	8:55	1.4	15.8	810	7	0.1	0.25	
	9:00	1.39	15.8	914	7	0.1	0.21	
	9:17	1.29	15.2	1149	7	0.1	0.3	
	9:32	2	16.7	1366	9	0.1	0.36	
	9:37						0.44	
Transfer	9:41			1492	7	0.1	0.63	Stopped Runoff, transferred Pre-run to Kettle
Runoff	9:49	7.6	15	1590	0		0.76	
	9:56	10.86	14.6	1689	0		0.75	
	10:04							End Runoff

total Runoff time (min):	117
Plato, Kettle Full:	9.42
Turbidity, Kettle Full (FTU's):	503
BHY:	69.20%

Mill Settings: 1.65mm, 0.9mm, and 0.8mm



BA3448, 3rd of 3			Recipe:	Cargill 2-row, 1575lbs
Mill settings:	1st	1.65		White Wheat, 350lbs
	2nd	0.9		Total, 1925lbs
	3rd	0.8		

Process	time	DP	GPM	Volume	Rake Position	Rake Speed	Turbidity (CU's)	Note
Vorlauf	10:54	0.95	13				1.4	
	11:00	2					0.81	
	11:10	7.7	15.6				0.17	End Vorlauf, begin Runoff
Runoff	11:12	>18		36				DP began climbing rapidly
Bed Cut	11:13				10	0.1		
Runoff	11:20	5	15		5.5	0.1	0.15	Resume runoff
	11:25	9.4	13.8	150	6.1	0.1	0.14	
	11:30	12	12.8	208	6.1	0.1	0.09	
Bed Cut	11:31				10	0.1		
	11:40							Resume Runoff
Runoff	11:45	0.4	13.9	310	6.5	0.1	0.15	
	12:03	3	14.4	572	7.1	0.1	0.1	
	12:15	2.3	14	738	7.4	0.1	0.1	
	12:33	2.1	15.4	966	7.4	0.1	0.15	
	12:43	3.3	15.8	1144	7.4	0.1	0.2	
	12:50	5.3	16.5	1250	7.4	0.1	0.22	
	12:58	6.3	16.1	1378	7.4	0.1	0.23	
Transfer from Pre-run tank	1:01							
	1:05							Resume Runoff
Runoff	1:11	5.1	13.6	1523			0.26	
	1:18	5.2	12.9	1611			0.19	
	1:23	7.9	12.5	1674			0.14	
	1:24							End Runoff

total Runoff time (min):	134
Plato, Kettle Full:	9.52
Turbidity, Kettle Full (FTU's):	298
BHY:	70%