Friday 9-12 AM

Effect of Coffee Grind Size on Cold Brew pH and Concentration

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2.671 Measurement and Instrumentation

Friday AM, Prof. Bischofberger

ABSTRACT

Anecdotal claims suggest that coffee made with cold brew methods results in less acidic and more concentrated coffee solutions. This study explores the effects of varying grind sizes on the acidity and concentration when coffee is brewed using the immersion cold brew method in a room temperature (20-22℃) environment. This study finds a statistically significant negative correlation between coffee grain size ($\boldsymbol{D}$) and the characteristic time constants of concentration and acidity change ($\boldsymbol{\tau_{TDS}}, \boldsymbol{\tau_{pH}}$). However, by the end of the 16-hour experimental period, the grain size and the final values, $\boldsymbol{TDS_f}$ and $\boldsymbol{pH_f}$, were independent of each other.

Keywords: coffee, cold brew, grind size, immersion, TDS, acidity, room temperature

1. INTRODUCTION

Within the last decade, cold brew has exploded in popularity and innovations its brewing process have contributed to exploration of cold brew characteristics [1][2]. "Cold brewing" itself is an umbrella term that includes immersion, Japanese, and French Press methods. All these processes share the characteristic of exposing water to grounds in an environment at or cooler than room temperature over a relatively long period of time (a few hours to a full day). This experiment has explored the method needing the most accessible supplies: immersion (figure 1). In the experimental setup, samples of coffee were prepared in room temperature (20-22℃) solutions consisting of 20 grams of grounds immersed in 160 mL of water. For sixteen hours, pH and total dissolved solids (TDS) readings were taken from the coffee solution. To prevent contamination of TDS readings, grounds were isolated to a cold brew filter bag. Measurements for five samples each of different grind sizes will be collected, averaged, and plotted as a function of time. To draw conclusions about the effects of grind size, it will be important to verify statistically significant differences.

Figure 1: The immersion cold brew method.

2. BACKGROUND

It is critical to consider prior research regarding the immersion cold brew method to understand how the results of this experiment will build upon existing knowledge and what sort of information would be the most helpful to people who use the cold-brew method.

Why Cold Brew?

The effect of factors like grain size have been thoroughly explored for hot extraction methods, but there is a lot to be explored in the realm of cold extraction.[3] The pH and TDS measurements of cold brew are of particular interest because of anecdotal claims that cold brew tends to be acidic and more concentrated than other brewing methods. Previous investigations into cold brew techniques have considered the effects of qualitative factors (like bean origin or perceived coarseness of grind) and, as a result, there is ample opportunity to discover the effects of incremental changes of measurable factors like grind size. By understanding the effects of grind size on these characteristics, one may optimize for a more desirable result.

All in all, as the population of cold brew drinkers grows, hobbyists and businesses who brew in this style will seek out ways to tweak their method to highlight specific characteristics of the beverage. While pour over and espresso methods have been broken down to a precise science, there is a lack of quantitative research into cold brewing. By verifying and studying the effects of incremental changes to grind size on pH and TDS, the results from this paper contributes to a body work that may lead to the development of cold brewing techniques with repeatable results.

Cold Brewing Technique

There is a clear lack of consensus regarding technique, but also a shared desired result for individuals who cold brew. A pilot study conducted by Claasen L., et al. included an online survey of cold brew drinkers and their personal brewing practices at home. Most respondents brewed from 14 to 26 hours; the median extraction time was 16 hours. Preferred grind sizes ranged from medium to extra-coarse. The pilot study also found no agreement on the preferred ratio of grounds to water. Despite the dramatic differences in cold brewing practices the consensus regarding the motivation behind choosing cold brewing over other methods was for a smoother and less sour taste.[4]

Despite the diversity in technique differences, particularly regarding grind size, do have a significant effect on cold brew characteristics. A previous study by Cordoba N., *et al.* has shown that the cold brew process variables of grinding and contact time were statistically significant for TDS and pH. It was found that coarse grinding increased TDS. However, the granularity of how grind size was defined was unclear, as the study only characterized their grinds as either “coarse” or “medium.” [5]

3. EXPERIMENTAL DESIGN

The experiment was divided into two phases of data collection. The first was to create ground samples at different levels of coarseness and to find a mean grain size measurement of each sample. The second phase was to take pH and TDS measurements of coffee solutions over 16-hours.

Coffee Ground Sample Preparation

To produce the 25 samples used in the experiment, a *SHARDOR* electric flat-burr grinder was used. The SHARDOR uses a 14-step dial interface to adjust its grind-setting from very fine to very coarse. For this experiment, grounds were made in large batches at a certain grind-setting and then were divided into 20g samples using the *AccuWeight* Digital Scale (SCALE-300G). An additional subsample from the large batch was also put aside for imaging. To isolate the grounds from the brew during measurement sessions, the 20g samples were loaded into filter bags that would allow immersion brewing to occur without having grounds suspended throughout the brew.

The subsamples from each grind setting were then loaded onto a clear petri dish, put under a light microscope, and photographed. To get the clearest grain images, it was helpful to turn the brightness of the microscope to a high setting and then spread the grains out by shaking the dish or manually separating clumps with a tweezer. The images would later be post-processed to get the high contrast images shown in figure 2. About three to five images of different regions of the petri dish were taken and processed using ImageJ, a Java-based image processing program.

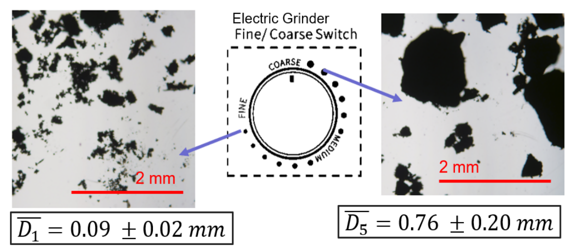


Figure 2: Grind-Settings were determined by the dial interface on the coffee grinder. This resulted in non-uniform coffee ground samples. The average grain particle feret for the lowest setting and coarsest setting are displayed above.

Measurement of Acidity and Concentration

At the start of the experiment, 120 mL samples of room temperature (20-22℃) tap-water were poured into 25 12oz paper cups. An initial pH and TDS reading was taken for each sample to be the initial brew measurements (t=0). The setup is illustrated in figure 3.

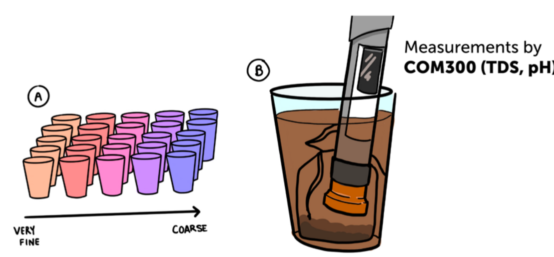


Figure 3: A) Experimental set up of 25 simultaneous brews of five different ground types produced at different grind-settings. B) Grounds are isolated from the surrounding brew with the use of a filter bad.

Timing began after a filter bag containing 20g coffee ground sample was added to a cup. There were five 20g samples of each grind level. For the first four hours of the 16-hour period, pH and TDS measurements were taken with the COM-300 every 15 to 30-minutes. Afterward, measurements were taken every 60 to 90 minutes. In total, eighteen sets of timed measurements occurred. Since the timing of measurements varied, the time at which each measurement was taken was recorded as well.

4. RESULTS AND DISCUSSION

During the execution of the experiment, pH and TDS measurements were collected under the assumption that all grind settings were going to make statistically different populations of grain sizes. Other sources of error were from the equipment used like the grinder and COM-300. Consequences for the low sample size and accuracy of equipment are further explored in this section.

Verifying Grain Size Distribution

Prior to brewing, sub-samples from each grind-setting were photographed and analyzed using ImageJ. Results from this analysis of the grains made with the SHARDOR grinder revealed nonuniformity in the ground samples. Samples were made with incremental adjustments on the grinder's dial interface. T-tests comparing each sample's feret (largest grain diameter) determined that there is not a statistical difference between the samples of grains made at middle-coarseness settings 4,7, and 10 (figure 4). The coarsest and finest grind setting created a grain sample that was significantly different from all other settings. Full details about the image analysis procedure are described in the appendix of this paper. Despite the lack of statistical significance between the middle grind-settings, averages and their uncertainties for each grind-setting size were calculated (figure 5) and used draw correlations between coffee ground size and pH or TDS.

T-TEST TABLE (Grain Distribution)

	G1	G4	G7	G10	G13
G1		0.000	0.000	0.002	0.000
G4			0.088	0.920	0.000
G7				0.137	0.032
G10					0.000
G13					

Figure 4: A table of p-values used to determine whether the distribution of grain sizes is significantly different between settings. Pairs of significantly different populations are highlighted in orange.

Measured Grind Sizes per Grind-Setting

Setting	Average Feret (mm)
1	0.09 ± 0.02
4	0.34 ± 0.07
7	0.47 ± 0.10
10	0.42 ± 0.10
13	0.76 ± 0.20

Figure 5: Table of Grind-Setting versus the average measured grain feret with uncertainty.

Cold Brew Concentration

Each group of timed measurements contained 25 data points for measured TDS. These data points were used to create the fitted curve for each grain size shown in figure 6.

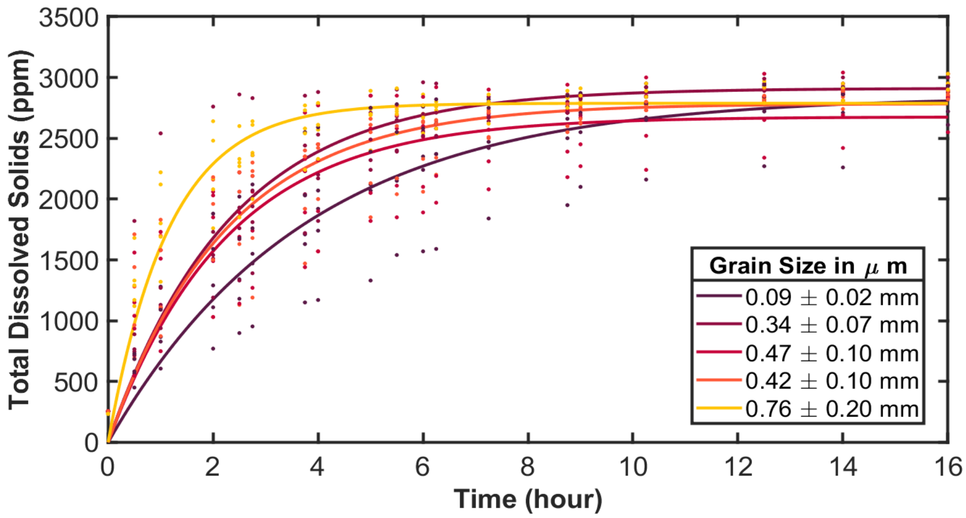


Figure 6: All measurements taken during the experiment are plotted above as points within the space of total dissolved solid versus the time the measurement was taken. An exponential model, $A(1 - e^{-t/\tau})$, is imposed on this data. Each curve corresponds to average fit-line of five individual curves fitted to the change in TDS of one cup.

For all brews, measured TDS values increased significantly until they approached some final concentration. An exponential cumulative distribution was fit to the raw data, $A(1 - e^{-t/\tau})$. In this equation, A represents the final concentration and τ is the time constant of the concentration curve.

Plotting τ against grain size, as shown in figure 7 reveals a correlation between them. This negative correlation between the rate of change (from τ) in concentration can be modeled as an exponential curve that is fitted to the time constants of all 25 samples. This curve shows that coarser grinds brewed faster. This finding contradicts the popular theory that more surface area (from finer grinds) leads to faster extraction rates.

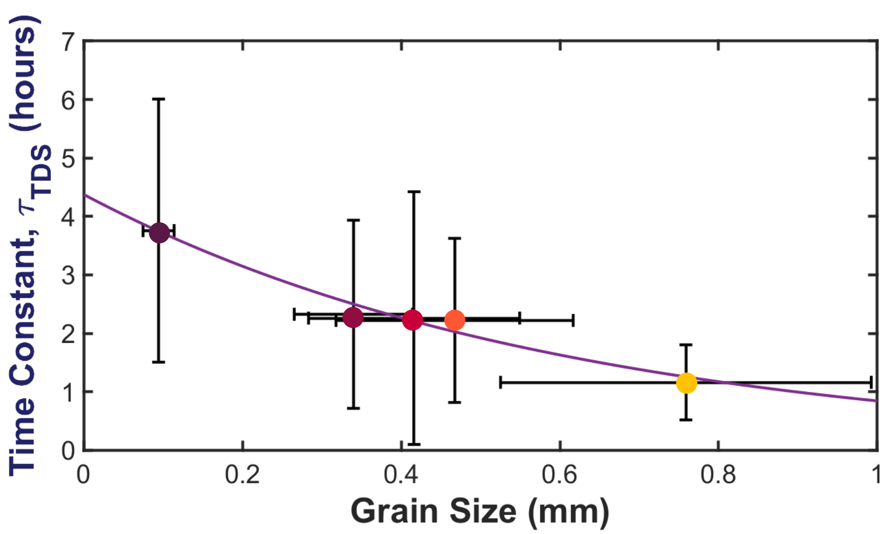


Figure 7: The average time constant, τ, with uncertainty is compared to the average grain size of each corresponding grind-setting. A fitted curve, $\boldsymbol{\tau_{TDS}(D) = 4.37e^{\left(\frac{-D}{0.61}\right)}}$ were derived from the time constant and grain size for each sample.

The resulting plot of final TDS versus Grain Size, figure 8, reveals that there is no statistical significance between the two parameters. This suggests that the coarseness of coffee grounds used in cold brew is independent of its final concentration. This data contradicts previous studies, like Cordoba et al., which suggest that coarser grinding led to higher concentration brews. A direct comparison to other coffee brew concentrations cannot be done due to the limitations of the COM-300, which measures TDS of salts.

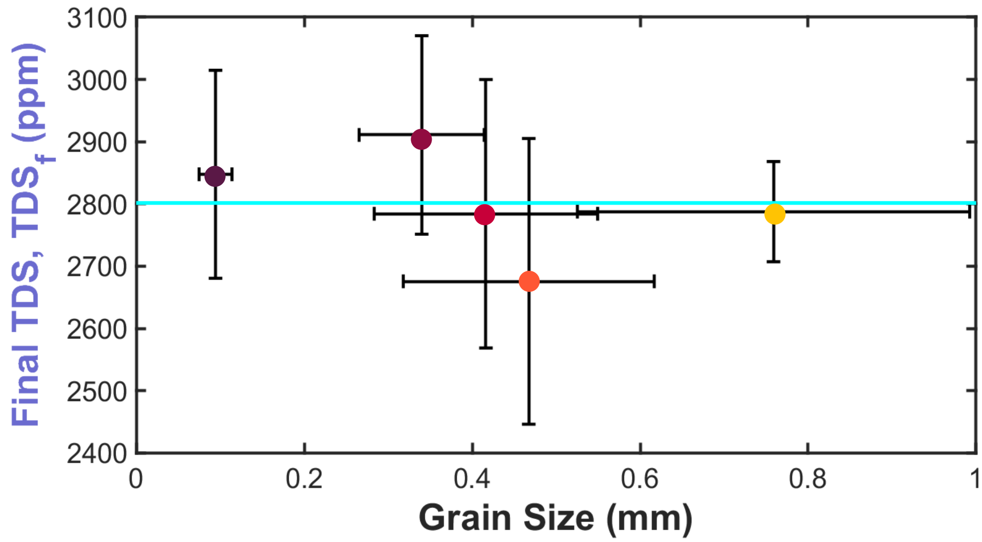


Figure 8: The final TDS, A, with uncertainty is compared to the average grain size of each corresponding grind-setting. The horizontal line in cyan represents the average final TDS, $\overline{TDS_f} = \mathbf{2800}$

Cold Brew Acidity

The addition of coffee grounds to water caused a drop in pH to occur. As plotted in figure 9, the drop in pH occurs within the first hour and stays consistent for the rest of the 16-hour measurement session.

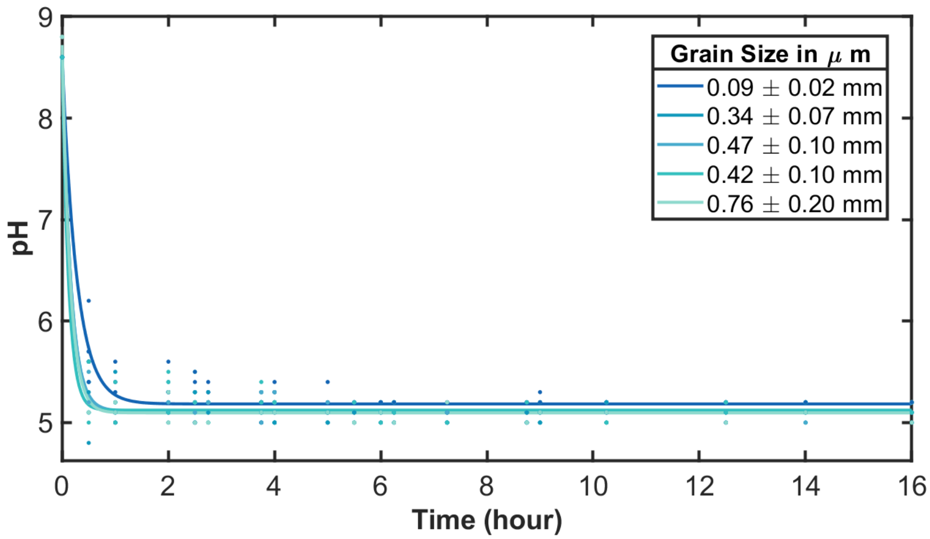


Figure 9: All measurements taken during the experiment are plotted above as points within the space of measure pH versus the time the measurement was taken. An exponential model, $\mathrm{Ae}^{-t/\tau} + \mathrm{C}$, is imposed on this data. Each curve corresponds to average fit-line of five individual curves fitted to the change in pH of one cup.

This sudden change in acidity across all samples can be modeled as an exponential decay, $Ae^{-t/\tau} + C$. A is the magnitude of the drop in pH, τ is the time constant, and C is the final pH. While the curves appear very similar, comparing τ against grain size exposes an underlying negative correlation that is shown as an exponential curve fitted to the 25 time-constants of each sample. This is shown in figure 10.

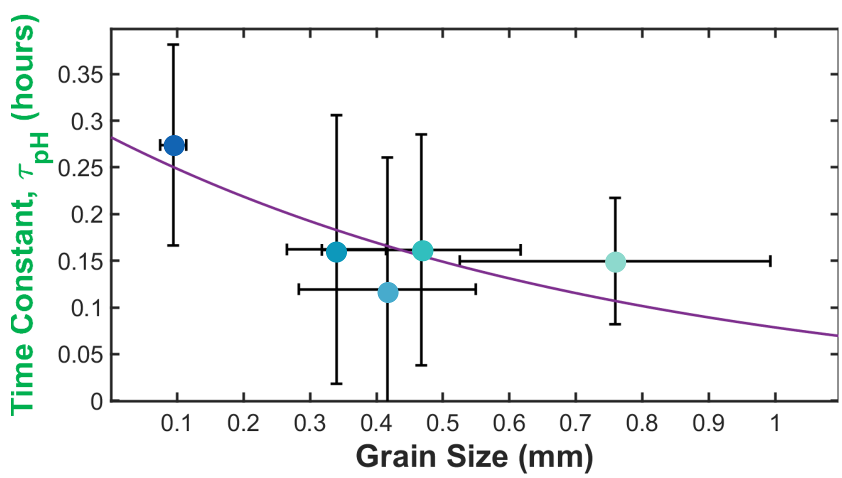
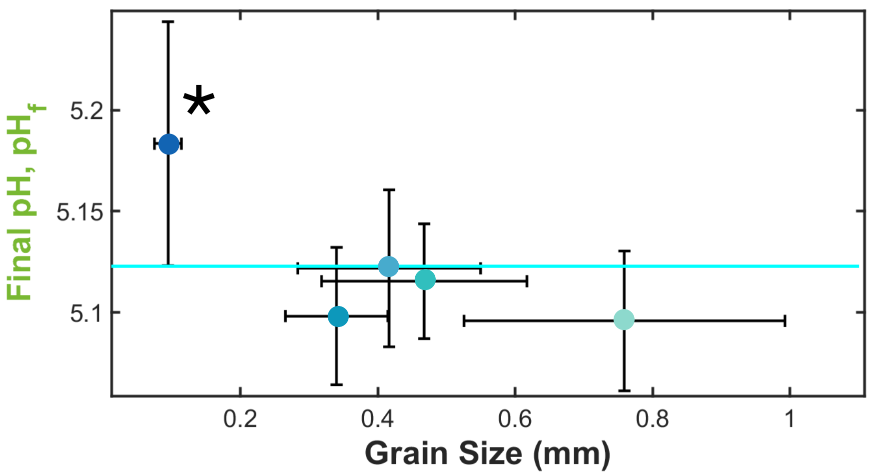


Figure 10: The average time constant, τ, with uncertainty is compared to the average grain size of each corresponding grind-setting. A fitted line, $\boldsymbol{\tau_{pH}(D) = 0.28e^{\left(\frac{-D}{0.78}\right)}}$ is displayed in purple and were derived from the time constant and grain size for each sample.

This relationship indicates that coarser grinds result in a faster change in pH. This finding is consistent with the observed relationship between coarse grinds and changes in TDS. Since coffee is an acidic beverage, one would expect that changes in concentrations would result in changes in pH as well.

While there was no significant correlation between final pH and Grain Size, there was an interesting significant different between the final pH of the brew made with the finest grain size, shown in Figure 11. It is possible that if measurements were taken at more granular changes in grain size, we may see a drop off in final pH value after a certain size is reached. This may also be an artifact of the lack of accuracy of the COM-300 which only read pH to the tenth of a pH.



T-TEST TABLE (final pH)

	0.09 mm	0.34 mm	0.47 mm	0.42 mm	0.76 mm
0.09 mm		0.004	0.010	0.023	0.004
0.34 mm			0.143	0.111	0.862
0.47 mm				0.610	0.147
0.42 mm					0.111
0.76 mm					

Figure 11: (left) The final pH, C, with uncertainty is compared to the average grain size of each corresponding grind-setting. The horizontal line in cyan represents the average final pH, $\overline{\mathbf{pH_f}} = \mathbf{5.12}$. (right) t-test table for comparing each pair of final pH populations of each grain size.

The average final pH of all the sample brews was 5.12. This is consistent with what is expected from typical coffee beverages. The SCA (Specialty Coffee Association) asserts that the pH of coffee tends to fall between 4.5 and 6. Interestingly, the average pH of these brews indicates that the cold produced during the experiment is not on the more basic end of the range of possible coffee acidities. Therefore, this study is unable to substantiate the claim that cold brewing tends to result in less acidic coffee.

5. CONCLUSIONS

Findings from this study may be used to inform ways to adjust the timing of cold brewing by changing coffee grain coarseness. By the end of the 16-hour experimental period, there was no significant relationship between grain size and the TDS values of the final brew. This was also true for final pH, except for the finest grain size, which has a significantly high pH. However, this study finds that there is a statistically significant correlation between coffee grain size and the rate of change of concentration and acidity. Though, the time scales of change in pH and TDS are different, with the characteristic time of pH being a magnitude smaller than TDS.

The variances in each parameter for this study suggests that there may be an opportunity to increase control over cold brew characteristics when provided with more precise tools. Further, while many questions remain regarding the relationship between grain size, concentration, and acidity, future research into this brewing method may address other parameters considered while cold brewing. After all, this study was conducted at a temperature and time frame that only some users of the cold brew method incorporate into their process.

6. ACKNOWLEDGEMENTS

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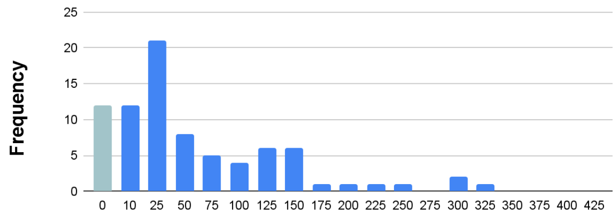
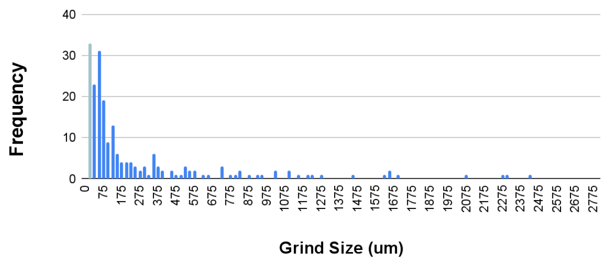
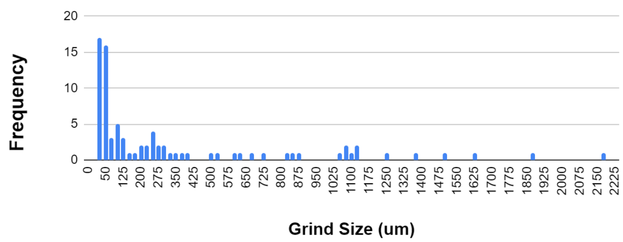
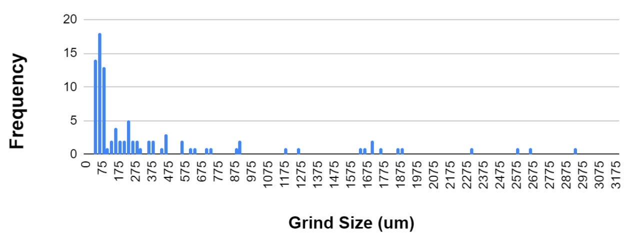
APPENDIX

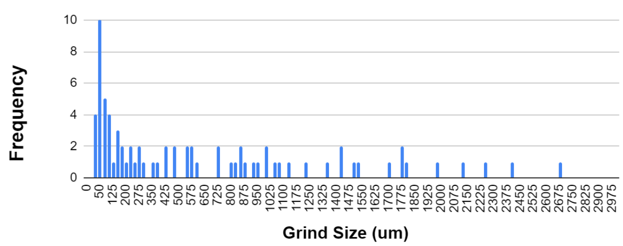
A. IMAGE ANALYSIS METHOD











Feret measurements were taken by ImageJ, but the images still contained noise and microfine coffee grounds that created a large amount of uncertainty in the measured average, making the average insignificant. Thus, grains with a feret of less than ten micrometers were excluded from the data set. After these grains were excluded, the histograms of the recorded feret followed similar distribution curves and had a smaller uncertainty.