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Evaluation of Ethanol Measuring Techniques

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EVALUATION OF ETHANOL MEASURING TECHNIQUES

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Abstract

The goal of this project was to determine a methodology to accurately measure the percent ethanol of the beverages produced by Wachusett Brewery. Based on gas chromatograph tests, it was determined that using propanol as an internal standard and a Chaney adaptor provided accurate results. In addition, using a vial with a septum cap prevented ethanol evaporation from the sample and 597 Qualitative Filter Paper decarbonized the beer without absorbing ethanol. From the developed methodology using a gas chromatograph, Wachusett IPA was determined to be 5.2% ABV. Due to the multicomponent nature of beer, a density measurement, provided by a hydrometer and digital density meter, was not an accurate method to determine alcohol percent in Wachusett Brewery's beverages.

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Introduction

The measurement of alcohol content is an important quality control aspect in the final steps of the brewing process. The practice currently in use by Wachusett Brewery involves measurements taken from a high-quality hydrometer, and correcting for the temperature of the sample. More rigorous and high-cost methods exist, including the use of a digital density meter, and gas chromatography. The goal of this project was to determine a methodology to accurately measure the percent ethanol of the beverages produced by Wachusett Brewery. The various instruments and laboratory equipment used for the determination of ethanol content in beer will be discussed in this section.

Use of Hydrometers

A hydrometer is a measurement tool for determining the specific gravity of a liquid. Typically, a hydrometer is made of glass and has a weighted bulb on the bottom filed with lead so that the tool will float in a liquid. The hydrometer has measurement increments on the upper half for taking readings when the hydrometer reaches its equilibrium point in the liquid. When the hydrometer is floating properly, the bottom of the meniscus will read the correct specific gravity value of the liquid trying to be measured. The proper method to read a hydrometer is illustrated in Figure 1. This specific gravity can also be known as relative density, because the density of the measured liquid is determined by its density compared to the density of water (Grapestompers).

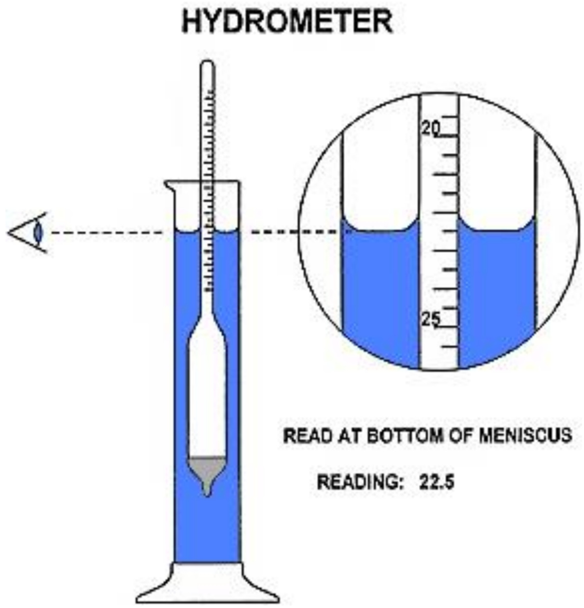

Figure 1: Reading a Hydrometer
(Source: http://www.windward.org/notes/notes70/andrew7010.htm)

There are several different measurement ranges for hydrometers, so they can be used for various liquids of different densities. Also, most hydrometers are calibrated by reading the density of water at a certain temperature, usually 60 degrees Fahrenheit. A liquid being tested should be at the same temperature that the hydrometer was calibrated with, if not, then appropriate calculations must be done to compensate for the temperature change for accurate results (Grapestompers).

Gas Chromatography

A gas chromatograph (GC) can be used to separate the components of a sample and indicate what compounds exist, as well as the relative quantity of it, based on peaks at certain resonance times. A small amount of sample is first introduced into the GC via the injection port. Automatic liquid samplers can also be used to inject the sample, but one was not available for use in the Unit Operations Laboratory. The GC system that was used can be seen in Figure 2, below. The sample enters the oven in the GC, which vaporizes the sample so that it can move through the remainder of the column. The column contains long tubing, and allows various components to separate based on volatility. These individual components are then carried through the tubing by a carrier gas, helium, with highly volatile species reaching the mass spectrometer at a faster rate. The first part of the mass spectrometer is the flame ionization detector, which is fueled from a hydrogen and air stream and mixes with the sample. The combustion of this mixture produces ions, which then enter the mass analyzer. This compartment contains an electromagnetic field, which deflects the ions based on mass and charge. Finally, the separated ions enter a mass detector that measures the quantity of each ion at a given mass (Oregon State University*)*. A gas chromatograph is very accurate in determining the concentration of hydrocarbons and was therefore one of the methods that was studied for determining the amount of ethanol in a sample of beer.

Figure 2: The Gas Chromatograph System in the Unit Operations Laboratory of Goddard Hall

Digital Density Meter

Digital density meters are another analytical tool that can be used to determine the amount of ethanol in a sample. The digital density meter first draws up a small amount of sample, which is analyzed via an oscillating U-tube. Through this technique, the sample enters a tube that oscillates due to an external electromagnetic force with the frequency corresponding to the density of the liquid. Measurements of the frequency and duration of the oscillation are obtained by the instrument, in order to provide a digital reading of the density of the sample. A liquid with a greater density will oscillate with a higher frequency than one with a lower density (A. Furtado, GPS Instrumentation Ltd). As digital density meters are very accurate, they were also one of the tools used in developing a methodology to determine ethanol content in beer samples.

Methodology

Throughout the course of this project, the methodology for determining ethanol concentration in beer samples was constantly evolving. In addition, three different types of instrumentation were used in order to compare the calculated volumetric percentage of ethanol among techniques. The final methodology for these three instruments is discussed in this section.

Filtration and Decarbonization

The first step for all of the various ethanol measuring techniques was the filtration of the beer. This step is essential to remove the carbon dioxide from the beer in order to minimize air bubbles, as well as remove any foreign particles that may be present. Whatman 597 Qualitative Filter Paper, S&S was selected for the filtration and decarbonization of the beer samples. This filter paper is specifically designed for testing in the food industry, including the removal carbon dioxide and turbidity from beverages (General Laboratory Supply). The filter paper was placed into a Buchner funnel, which was then placed in a Buchner flask. A vacuum filtration apparatus was assembled, but it was determined that the filter paper was porous enough to allow for a fast filter time without the use of a vacuum. Once the beer was filtered, it was placed into a glass bottle for storage and testing.

Hydrometer

A hydrometer with specific gravity values between 0.900 and 1.200 was used. In order to test the beer using the hydrometer, it was first filtered as discussed above. Fifty milliliters of the filtered beer was then poured into a 100 mL graduated cylinder, and more of the sample was added so that the hydrometer would float. A specific gravity measurement was recorded from the instrument and corrected for temperature using a table of ethanol-water mixture densities at varying temperatures. The step-by-step procedure used to determine the concentration of ethanol in the beer samples is described below.

Procedure:

1. Decarbonate and filter the beer as discussed in the previous section.
2. Record the temperature of the beer sample.
3. Pour 50 mL of the filtered beer into a 100 mL graduated cylinder.
4. Place the hydrometer in the graduated cylinder and add more of the filtered beer if needed to make the hydrometer float.
5. Record the specific gravity measurement from the hydrometer and correct for temperature, using a table of ethanol densities, to determine the percentage of ethanol in the sample by volume.

Gas Chromatograph

The Agilent 7820A Gas Chromatograph (GC) system in Goddard Hall was used for the testing of beer samples. An internal standard was first generated, using propanol as a reference solution. It was very important that these solutions were prepared accurately, as they were used as a basis for determining the ethanol content of the beer samples. Equal volumes of a 5% propanol solution and 1% ethanol solution were mixed and poured into a ½ dram vial. The vial was capped using a septum cap, before being tested in the GC. A Sample of 5 μL was injected, using a Chaney adaptor to ensure that equal volumes were used for every trial. The Chaney adaptor set-up and the ½ dram vial with the septum cap can be seen in Figure 3, below. The sample was analyzed for 1.8 minutes, with the ethanol peak resonating after 1 minute and the propanol peak after 1.6 minutes. A ratio of the peak height of ethanol to the peak height of propanol was recorded. This was repeated 20 times to reduce error in the measurement, and outliers were removed before taking the average. Ethanol solutions of 4, 5, and 6% were prepared and mixed with an equal volume of the 5% propanol solution before being tested, using the internal standard ratio. In this process, the ratio of the ethanol peak height and propanol peak height was calculated, and then divided by the ratio determined from the 1% ethanol solution. This resulting number was the percentage of ethanol in the sample, by volume. In order to test the samples of beer, the beer was first filtered, as discussed previously. Equal parts of the filtered beer sample and the 5% propanol solution were mixed before being injected into the GC. Similarly, the ratio of the peak height of ethanol to the peak height of propanol was divided by the internal standard ratio, to determine the ethanol content to the beer sample. The procedure implemented to determine the ethanol content via gas chromatography is discussed below.

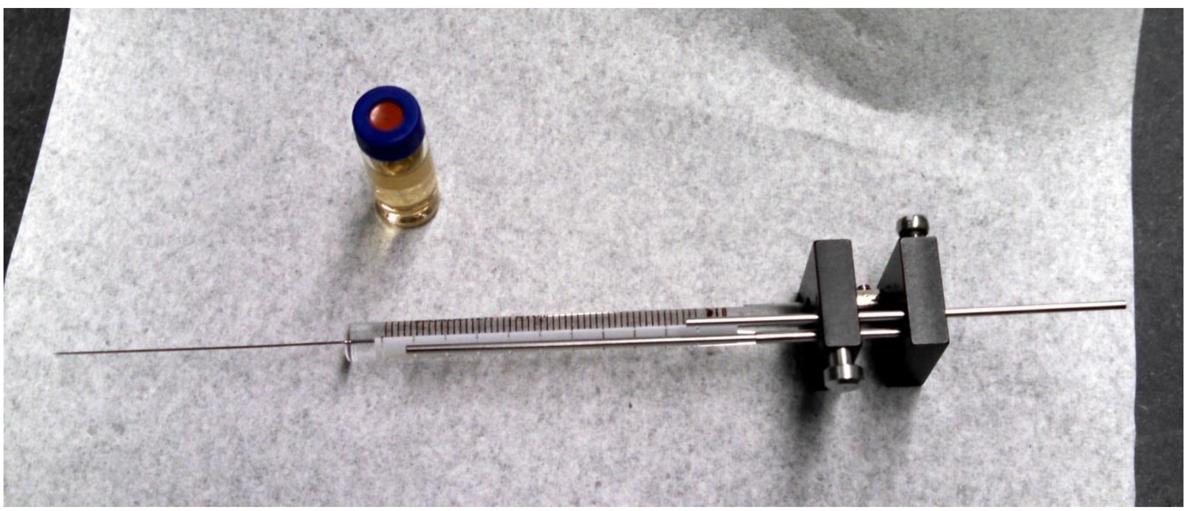

Figure 3: Chaney Adaptor and Vial with Septum Cap

<u>Procedure:</u>

Internal Standard Determination

1. Using a micropipette, measure 1 mL of ethanol and add it to a 100 mL graduated cylinder. Dilute the ethanol to a 1% solution by filling the graduated cylinder with water to the 100 mL mark.

2. Using a micropipette, measure 5 mL of propanol and add it to a 100 mL graduated cylinder. Dilute the ethanol to a 5% solution by filling the graduated cylinder with water to the 100 mL mark.
3. Using a micropipette, measure 1 mL of the 1% ethanol solution and 1 mL of the 5% propanol solution, and pour into a ½ dram vial. Cap the vial using a septum cap to prevent evaporation.
4. Prepare the Chaney adaptor to measure 5 μL.
5. Turn on the Gas Chromatograph, and set to the following conditions (we will check what these values are and put them into the final report):
    a. Oven Temperature:
    b. Inlet Temperature:
    c. Detector Temperature:
    d. Flow Rates:
6. Once the GC is ready, inject the sample into the inlet and let the system run for 1.8 minutes.
7. Record the peak height of ethanol (1 minute) and propanol (1.6 minutes), and determine the ratio of the peak height of ethanol to the peak height of propanol.
8. Repeat this process (steps 6 and 7) for 20 trials.
9. After removing any outliers, calculate the average of the determined ratios. This internal standard value will be used as a comparison for determining the ethanol content in the beer samples.

Testing of Beer Samples

1. Filter the beer as discussed in a previous section.

2. Using a micropipette, measure 1 mL of the filtered beer and 1 mL of the prepared 5% propanol solution, and pour into a ½ dram vial before capping it with a septum cap.
3. Prepare the Chaney adaptor to measure 5 μL.
4. Turn on the Gas Chromatograph, and set to the specified conditions discussed above.
5. Inject 5 μL of the propanol-beer mixture into the GC, and the let the system analyze the sample for 1.8 minutes.
6. Record the peak height of ethanol (1 minute) and propanol (1.6 minutes), and determine the ratio of the peak height of ethanol to the peak height of propanol. Divide this ratio by the internal standard ratio previously determined. This resulting number will be the volumetric percentage of ethanol in the beer sample.
7. Repeat this process (steps 5 and 6) for 20 trials.
8. After removing any outliers, calculate the average of the determined ethanol percentages.

Digital Density Meter

A hand-held digital density meter was used to determine the density of the beer, in order to compare the obtained value to results calculated from the hydrometer and gas chromatograph. The beer was first filtered as discussed above, and a small amount was poured into a beaker for testing. The digital density meter was turned on, and a small amount of beer sample was drawn up the tube for analysis. The displayed density (g/cm^3) and temperature (ºC) were then recorded.

Addition of Ethanol to the Beer Samples

A known volume of ethanol (1 mL) was added to a 99 mL sample of filtered beer in order to raise the alcohol percentage by 1. The beer was then tested using the three methods discussed above to determine the sensitivity of the measurements in determining ethanol content.

Results and Discussion

As the goal of the project was to determine a methodology to accurately measure the percent ethanol of the beverages produced by Wachusett Brewery, this section will present the refinement and development of the gas chromatograph methodology. In addition, the results from these gas chromatograph tests will be compared to measurements from a hydrometer and a digital density meter.

Initial Gas Chromatograph Methodology

When gas chromatograph tests were initially performed, the area of each spike was recorded so that this data could be correlated to a known ethanol percent. For a known ethanol concentration, the recorded areas were not consistent and did not provide meaningful results that could be used to determine a trend in area vs. ethanol percent. This can be seen in Table 1, which shows the data for a known solution of 4% ethanol and the corresponding areas. In addition, the volume used for each run was not reproducible due to the human error in measuring the syringe volume. In order to account for this, the syringe was weighed when empty and then when filled with a sample volume of 5 μL, but the difference in mass was too insignificant to ensure that the same volume was used for each run.

Table 1: 4% Ethanol Solution Recorded Areas

Trial	Peak 1 Area	Peak 2 Area	Peak 3 Area	Total Area
1	1.890E+04	6.014E+03		2.491E+04
2	1.578E+04			1.578E+04
3	1.719E+04			1.720E+04
4	8.314E+00	1.315E+04	4.361E+03	1.752E+04
5	2.642E+00	1.041E+04		1.041E+04
6	1.954E+04			1.954E+04
7	1.775E+04			1.775E+04
8	2.719E+04	1.064E+03		2.825E+04
9	1.386E+04	7.601E+02		1.462E+04
10	1.891E+04			1.892E+04

Use of Chaney Adaptor and Implementation of an Internal Standard

To reduce errors in measurement of the sample volume from the initial methodology, a Chaney adaptor was used. This was attached to the needle to improve reproducibility of the sample volumes, by drawing up the same amount of liquid for each trial. An internal standard of propanol was also used so that the ethanol peaks could be compared to a known percentage of propanol in an unknown sample. In addition, the peak heights of each of the ethanol and propanol spikes were analyzed instead of the area, as this data was more consistent among trials. To create an internal standard, a reference solution of 1% ethanol – 5% propanol was prepared, and the data was analyzed as discussed in the methodology. Known solutions of 4%, 5%, and 6% ethanol were then tested, with equal parts of the 5% propanol solution. The data is presented in Table 2, below, and all of the raw data can be found in the Appendix.

Table 2: Prepared Solutions vs. GC Measurements

Prepared Solution	GC Measured %Ethanol	Percent Error
4% Ethanol	3.97	0.75%
5% Ethanol	4.89	2.20%
6% Ethanol	5.34	10.9%

From the data presented in Table 2, it can be seen that the gas chromatograph was able to accurately measure the content of ethanol for the pre-made 4% and 5% ethanol solutions. However, the 6% ethanol solution was determined to be inaccurate, as there was a difference in measurement of 0.66%, resulting in a 10.9% error. Based on analyzing the collected data, which can be found in the Appendix, a trend of decreasing ethanol percent with additional runs was observed for the 6% ethanol solution. This is also presented in Figure 4 below.

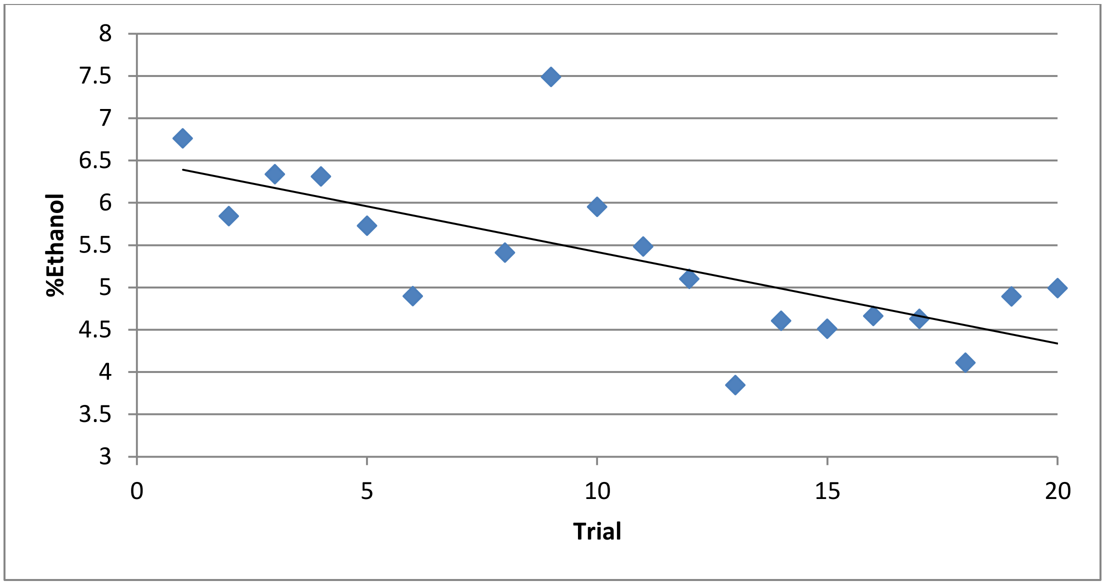

Figure 4: 6% Ethanol Solution, Decreasing %Ethanol Measurements over Additional Trials

Use of Septum Caps

Based on the observed trend of decreasing ethanol percent measured as additional tests were performed, it was determined that small amounts of ethanol were evaporating from the sample over time. In order to reduce the evaporation of ethanol in the sample, vials with septum caps were used. This resulted in an improved consistency in the collected data, as the amount of ethanol evaporating from the sample drastically reduced for subsequent tests. The data for the gas chromatograph analysis of Wachusett IPA (5.6%), mixed with an equal volume of the 5% propanol solution, is shown in Figure 5, below. From the graph, it can be seen that the ethanol percent measurement was far more consistent and did not decrease as drastically as previous tests.

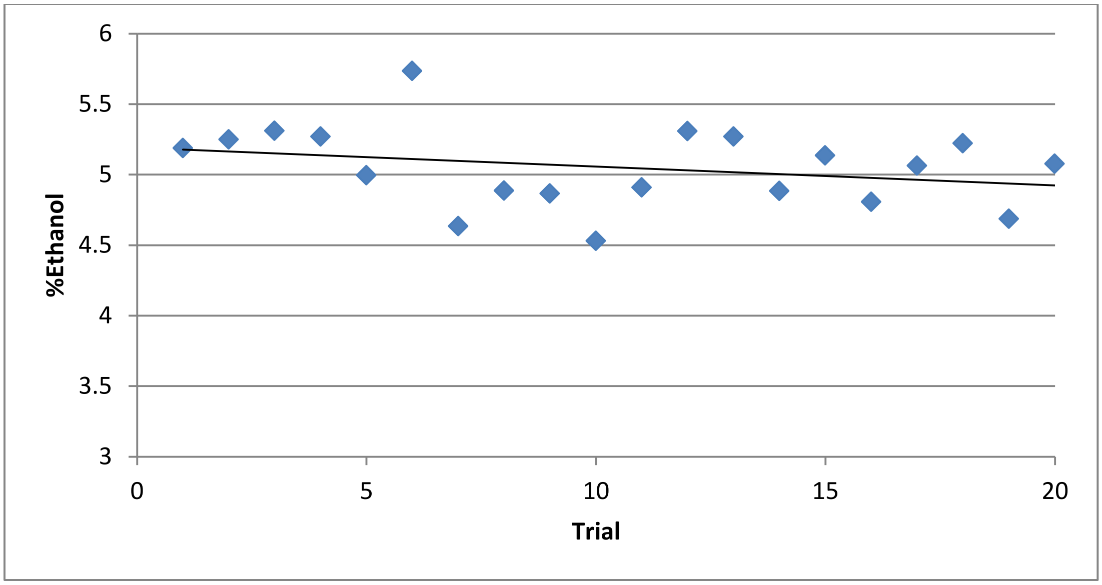

Figure 5: Wachusett IPA (5.6%), Improved Consistency of %Ethanol Measurements

Filter Paper

Although the results obtained from the gas chromatograph were improved, a value of 5.05% ethanol was observed for the Wachusett IPA. The reported ethanol percent value by Wachusett Brewery was 5.6%. Through additional testing of various beer samples, lower ethanol percent measurements were obtained than what was reported by Wachusett Brewery. It was determined that filter paper used to decarbonate the beer was not suitable, and may have been absorbing small amounts of ethanol. To resolve this issue, 597 Qualitative Filter Paper was obtained, which is commonly used in the food testing industry to remove carbonization and turbidity from beverages (General Laboratory Supply). Once this new filter paper was used to decarbonate the beer, improved results were obtained.

Hydrometer Measurements

In order to determine the accuracy of the gas chromatograph in determining percent ethanol, the obtained results were compared to hydrometer measurements. The specific gravity measurements were corrected using a table of ethanol densities at varying temperatures (Perry, 3-

84). This hydrometer data and the gas chromatograph data are presented and compared in Table 3, below.

Table 3: Prepared Ethanol Solutions, GC vs. Hydrometer Reported %Ethanol

Prepared Solution	GC Measured %Ethanol	Corrected Hydrometer %Ethanol	Percent Difference
4% Ethanol	3.97	4.02	1.25%
5% Ethanol	4.89	4.95	1.22%
6% Ethanol	5.34	5.89	9.80%

From Table 3, it can be seen that there was good agreement between the prepared 4% and 5% ethanol solutions among the gas chromatograph and hydrometer measurements. However, the prepared 6% ethanol solution did not have good agreement among measurement techniques, as indicated by the 9.80% difference. This further validates the hypothesis that the ethanol was evaporating from the sample during gas chromatograph testing, as discussed in the previous section, as the hydrometer indicates that the ethanol percent is closer to the prepared value of 6%.

Comparison of Results among Techniques

In order to measure the ethanol percent of the Wachusett IPA, the gas chromatograph was first used with propanol as an internal standard, septum caps to avoid evaporation, and 597 Qualitative Filter Paper. From the developed technique, the percent ethanol of the Wachusett IPA was determined to be 5.2%, compared to the value of 5.6% provided on the label. This discrepancy shows that the corrected hydrometer technique used by Wachusett Brewery is not as accurate as the gas chromatograph, which had provided measurements with a percent error of less than 3% for the prepared ethanol solutions.

The inaccuracy of the hydrometer in determining ethanol percent in beer was further demonstrated by measurements taken in Goddard Hall. For the Wachusett IPA, hydrometer readings indicated a specific gravity of 1.003. Based on a mixture of water, with a density of 1 g/cm^3, and ethanol, with a density of 0.789 g/cm^3, the value of the specific gravity should be lower than 1. This indicates that the beer has several other components, and a density reading does not provide accurate results for determining ethanol percent. The inaccuracy of using a density measurement was also shown via the use of a digital density meter, which provided an average density of 1.004 g/cm^3.

To further demonstrate the accuracy of the gas chromatograph, 1 mL of pure ethanol was added to 99 mL of filtered beer, to increase the ethanol percent of the beer by 1%. Using the gas chromatograph, an ethanol percent value of 6.14% was obtained for this mixture, which was expected based on the expected increase of 1% ethanol by volume. In addition, the hydrometer and digital density meter readings were found to be 1.002 and 1.003 g/cm^3, respectively. These values only changed by 0.001 for a 1% difference in ethanol percent, showing that these techniques are not sensitive to changes in ethanol percent for a multi-component sample, such as beer.

Conclusions and Recommendations

Through completing this project, the overall goal was to determine a methodology to accurately measure the percent ethanol of the beverages produced by Wachusett Brewery. This was carried out by refining a process to obtain accurate values from a gas chromatograph. Through initial testing, it was determined that an internal standard of propanol be used as a basis of comparison for the ethanol peaks. In addition, a Chaney adaptor should be used so that the same sample volume can be used for each trial. Based on further tests, it was concluded that ethanol was evaporating from the sample. Therefore, it is necessary to use a vial with a septum cap, in order to greatly reduce evaporation from occurring. Finally, it was determined that filter paper designed for the decarbonization of beverages, such as 597 Qualitative Filter Paper, should be used, as it was found that other filter papers absorbed a small amount of ethanol. Based on the defined methodology for the use of a gas chromatograph, a value of 5.2% alcohol by volume was obtained for Wachusett IPA, with a reported value of 5.6%. The hydrometer and digital density meter techniques, however, did not provide accurate results for the beer samples. Therefore, the discrepancy between the gas chromatograph and label values for ethanol percent can be attributed to Wachusett Brewery using hydrometers.

Based on its accuracy, it is recommended that Wachusett Brewery invest in a gas chromatograph, and use the methodology established in this report. Alternatively, samples of the brewed beer can be sent to an outside testing company or university that can perform the analysis. In future projects, the accuracy of a YSI Industrial Analyzer should be tested, as these may be able to provide accurate ethanol measurements using a less expensive piece of equipment.

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Appendix

All of the raw data presented in this section includes the numerical values obtained after outliers were removed.

Table 4 presents the gas chromatograph data for the 1% ethanol – 5% propanol solution used to determine the internal standard ratio.

Table 4: Determination of Internal Standard Ratio (12-5-2014)

Peak Height Ethanol	Peak Height Propanol	Ratio
2154.351	8947.325	0.240782
4142.829	1.36E+04	0.304083
1647.229	9314.02	0.176855
3622.968	1.12E+04	0.32322
2893.744	1.06E+04	0.273433
1831.197	8.59E+03	0.213118
2468.616	1.01E+04	0.24341
3004.112	1.15E+04	0.262336
4005.525	1.25E+04	0.319864
2688.66	1.05E+04	0.255625
3073.007	1.08E+04	0.283626
2660.126	1.11E+04	0.240264
3127.388	1.13E+04	0.275589
2760.781	1.08E+04	0.254464
2828.376	1.05E+04	0.270205
2859.511	1.09E+04	0.262175
	average	0.262440

Tables 5, 6, and 7 present the data from the gas chromatograph analysis for the prepared 4, 5, and 6% ethanol solutions, respectively. This is the data before a vial with a septum cap was used for the samples.

Table 5: GC Analysis of 4% Ethanol Solution

Peak Height Ethanol	Peak Height Propanol	%Ethanol
13809.1	11218.3	4.6903749
11898.3	10321.4	4.3925381
14785.3	12807.9	4.3986706
10868.8	10372.4	3.992745
14900.9	13241.9	4.2877695
10421	10195.8	3.8945503
9155.0498	10339	3.3740492
11409.3	10589.5	4.1053744
10874	10246.3	4.043817
12698.2	12008.9	4.0291011
11439.6	11726.3	3.7172269
10879.9	10282.4	4.0318061
11682.7	11620.1	3.8309156
12781	11430.6	4.2605438
11423.4	10302.4	4.2249951
8125.2759	10857.5	2.8515271
9855.374	9917.1133	3.7866666
9515.4268	10143.3	3.5745241
	average	3.9715108

Table 6: GC Analysis of 5% Ethanol Solution

Peak Height Ethanol	Peak Height Propanol	%Ethanol
10908.3	8745.963	4.752462
16293.3	11557.9	5.371547
14807.5	11646.3	4.844657
15043	11544.6	4.965063
14638.7	10815	5.157571
16094.1	11705.2	5.239105
13339.9	10222.9	4.97219
11068.3	8650.063	4.875631
11421.5	9139.563	4.761754
10291	8925.232	4.393466
13179.2	9738.26	5.15676
16373.6	11264.7	5.538521
12348.9	10204.8	4.610978
11034	9030.77	4.655619
11278.2	9020.399	4.764126
13128.6	9771.642	5.119412
10790.9	8981.673	4.577935
10138.4	8371.186	4.614787
11994	9319.353	4.903967
9918.699	8366.932	4.517079
	average	4.889632

Table 7: GC Analysis of 6% Ethanol Solution

Peak Height Ethanol	Peak Height Propanol	%Ethanol
17845.4	10058.2	6.760444
13219.2	8624.507	5.840367
17032.6	10245.1	6.334816
17118.4	10338.1	6.309452
12267.5	8161.394	5.727446
10644.9	8284.963	4.895761
13265.9	9346.37	5.408327
22649.4	11529.8	7.485213
15774.2	10102	5.949894
14263.4	9915.729	5.481099
12525.4	9357.663	5.100273
8562.244	8486.838	3.844244
11193.5	9268.248	4.601903
12984.4	10974.2	4.508356
9901.713	8092.659	4.662172
10599.2	8729.107	4.626712
9793.225	9083.039	4.108315
12715.2	9907.153	4.890391
12824	9793.486	4.989482
	average	5.343404

Table 8 presents the data for the gas chromatograph analysis of the Wachusett IPA. This data was collected before it was determined that 597 Qualitative Filter Paper should be used.

Table 8: GC Analysis of Wachusett IPA

Peak Height Ethanol	Peak Height Propanol	%Ethanol
10769.6	7909.924	5.187958
14930.9	10838.9	5.248921
13702.9	9833.745	5.309612
9507.986	6874.451	5.270111
13526.4	10316.7	4.995865
13138.4	8729.089	5.735124
8479.851	6971.409	4.634863
9497.171	7406.537	4.885942
12895.4	10101.5	4.864276
7764.144	6530.41	4.530252
10855.2	8426.375	4.908698
12071.3	8666.811	5.307182
11851.4	8570.414	5.269108
11899.9	9284.589	4.88371
12027	8923.955	5.135339
9274.512	7353.574	4.805757
12052	9071.378	5.062384
15068.6	10995.1	5.222073
11928.9	9698.312	4.686768
13299.1	9980.222	5.077516
	average	5.051073

In order to maintain accurate results, a new solution of 5% propanol was prepared. The corresponding internal standard ratio was then determined, as shown in Table 9.

Table 9: Determination of Internal Standard Ratio (2-1-2015)

Peak Height Ethanol	Peak Height Propanol	Ratio
2505.4	10087.8	0.248359
2911.983	10295	0.282854
1566.548	6770.286	0.231386
2110.142	8289.192	0.254565
2575.93	11331.9	0.227317
2369.922	8803.713	0.269196
2441.522	10310.8	0.236793
2438.597	8852.355	0.275474
2035.392	8458.05	0.240646
2594.747	10337.3	0.251008
2780.173	10164.8	0.27351
2170.398	8443.238	0.257057
2486.156	9842.878	0.252584
2157.48	8771.483	0.245965
1842.553	7620.118	0.241801
2079.028	8609.995	0.241467
2105.086	8336.518	0.252514
2202.575	8046.56	0.273729
1934.734	7775.409	0.248827
2102.409	8266.303	0.254335
	average	0.252898

Table 10 presents the data for the gas chromatograph analysis of the Wachusett IPA, using the new internal standard ratio presented in Table 9. The beer that was analyzed was filtered with 597 Qualitative Filter Paper.

Table 10: GC Analysis of Wachusett IPA

Peak Height Ethanol	Peak Height Propanol	%Ethanol
14816.6	10493.2	5.583365
10515.2	9078.779	4.57979
11445.1	9915.541	4.564136
14166.9	10900	5.139298
12640.2	9607.626	5.202275
12335.5	9925.392	4.914332
12386.6	10490.2	4.668999
13897	10348.5	5.310056
13103.7	10052.4	5.154418
11428.8	8927.306	5.062158
13596.3	10300	5.219621
13247.1	9744.434	5.37551
12675.8	8852.648	5.66184
15522.8	10845.2	5.659629
14034	10207.1	5.43669
11924.5	9225.044	5.111251
12438.7	9339.375	5.266385
11315.1	8688.96	5.149275
14189.6	10127.3	5.540283
12354.2	9015.391	5.41858
	average	5.200895

Table 11 presents the data for the gas chromatograph analysis of the Wachusett IPA with an additional 1% ethanol, accomplished by adding 1 mL of pure ethanol to the 99 mL beer sample.

Table 11: GC Analysis of Wachusett IPA (+1% Ethanol by Volume)

Peak Height Ethanol	Peak Height Propanol	%Ethanol
14904	9655.555	6.10353
15875.9	9525.4	6.590382
14621.3	9783.438	5.909489
14966.1	9576.459	6.179583
15069.9	9951.179	5.988131
15252.6	9896.3	6.094337
14907.1	9148.4	6.443227
14957.4	10076.1	5.869743
14925.1	9539.193	6.186728
15641.2	10092.5	6.128113
15453.9	10141.6	6.025416
15470.7	10362	5.903667
14894.4	10065.6	5.851117
15827.1	9062.477	6.905734
15194.4	10085.56	5.957156
	average	6.142423