How is the percentage of acetic acid present in different types of vinegar impacted by the region of origin?

I. Introduction

The topic of this investigation is the titration of different types of vinegar to determine which sample of vinegar has the highest percentage of acetic acid based on the origin and type of production of each vinegar.

I chose this topic because I was curious to see how the origins of certain ingredients impacts the way that they are made. I selected several types of vinegar purposefully from different regions of the world and wanted to see how the percent of acetic acid varied in these vinegars. For example, in Asia rice vinegars are commonly used whereas wine vinegars produced from grapes are common in southern Europe.[1] I was curious to discover how our tastes are shaped by the chemical makeup of simple ingredients.

Due to the fact that vinegar and sodium hydroxide will be used throughout this investigation, safety precautions must be taken. Vinegar is a common, household ingredient and is a mixture of acetic acid, water, amino acids, mineral salts, and other organic acids.[2] This mixture is not dangerous. However, vinegar does act as an irritant when in contact with eyes and open wounds and can lead to corneal damage.[3] Safety goggles will be worn throughout the duration of experimentation to prevent the vinegar from coming in contact with they eyes and all wounds should be covered. Sodium hydroxide is a dangerous chemical and should be treated with care at all times because of its basic pH levels. Sodium hydroxide causes pain, redness, blisters, and burns when in contact with skin and can cause blurred vision when in contact with eyes.[4] Safety goggles and gloves should be used while handling sodium hydroxide.

II. Investigation

A. Background

Vinegar has been commonly used to prepare foods for decades. Vinegar produces a sharp, almost stinging taste. Hard apple cider, beer, and vodka are all used in the production of different types of vinegar.[5] Vinegar contains a mixture of substances, however, its main components are acetic acid diluted with water.

Acetic acid is a colorless liquid with a strong odor of vinegar. Acetic acid molecular formula is $C_2H_4O_2$ and the molecule has a weight of 60.1 grams/mol.[6] It is commonly used as a

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[1] "A Guide to Vinegars," The Epicentre, , accessed March 28, 2019, http://theepicentre.com/ingredient/a-guide-to-vinegars/.

[2] "Vinegar," Poison and Prevention Info, accessed March 28, 2019, https://www.poison.org/articles/vinegar-164.

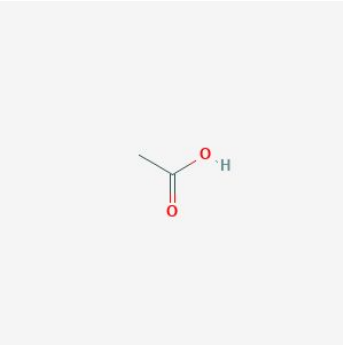
[3] Ibid.

[4] "Sodium Hydroxide," Canadian Centre for Occupational Health and Safety, March 26, 2019, , accessed March 28, 2019, https://www.ccohs.ca/oshanswers/chemicals/chem_profiles/sodium_hydroxide.html.

[5] Alex Delany, "What Is White Vinegar Made Of?" Bon Appétit, October 13, 2017, accessed March 28, 2019, https://www.bonappetit.com/story/what-is-white-vinegar-made-of.

[6] "Acetic Acid," National Center for Biotechnology Information. PubChem Compound Database, accessed April 08,

food additive and is also used during the production of petroleum. The structure can be seen below:



Vinegar can be found in most households and, as stated previously, acetic acid provides the solution with most of its characteristics. In a study to determine the acidity of vinegar performed by Penn State University, a similar technique of titration was used to determine the percent of acetic acid in each vinegar solution. An acid-base reaction (shown below) is performed in a neutralization reaction.[7]

$$HC_2H_3O_2 + NaOH \rightarrow NaC_2H_3O_2 + H_2O$$

When the volume of NaOH that has been added to the neutralization reaction is known the amount of acetic acid can be calculated.[8]

Furthermore, according to Dr. Walter Scharf of Baruch College, "the point at which both reactants have been completely consumed by the known reaction can be detected (end point" and the amount of one reactant can be calculated from the known concentration of reactant".[9] Using this information I was able to conduct a reliable experiment to determine different amounts of acetic acid present in different solutions of vinegar.

B. Materials:

- 40.0 grams of NaOH diluted with distilled water to .200 liters
- Phenolphthalein indicator solution
- 50.0 mL burette
- Burette clamp
- Flasks
- Pipette

2019, https://pubchem.ncbi.nlm.nih.gov/compound/acetic_acid.

[7] "Analyzing the Acid in Vinegar." Accessed March 20, 2019. http://chemistry.bd.psu.edu/halmi.

[8] Ibid.

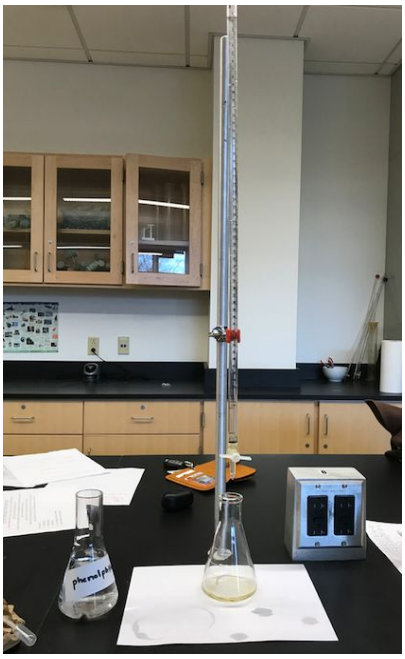
[9] Walter Scharf and Charles Malerich, "Determination of Acetic Acid Content of Vinegar," , accessed March 25, 2019,
http://v-www.baruch.cuny.edu/wsas/academics/natural_science/chm_1000/vinegar.pdf.

- Graduated cylinder
- Assorted samples of vinegar (for this experiment white vinegar, sherry vinegar, apple cider vinegar, and rice vinegar were used)

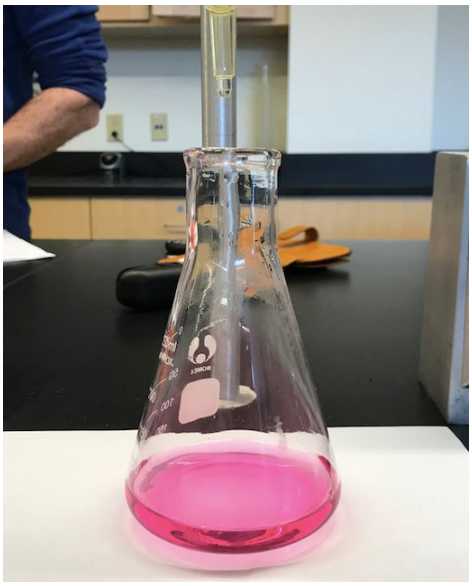
Vinegar sample used in this experiment (from left to right: Marukan Rice Vinegar, Heinz Apple Cider Vinegar, Maitre Jacques Sherry Vinegar, Centrella White Vinegar)

C. Procedure:

1. Fill a burette with 1.00 mole/Liter NaOH
2. Add exactly 25.0 mL of your first sample of vinegar and 3 drops of phenolphthalein to a flask and place it under the burette
3. Drip in the 1.00 M NaOH until the solution reaches a pale pink endpoint (it will help to swirl the flask as you drip in the NaOH)
4. Record final volume of NaOH in the burette
5. Repeat steps 1-4 for two more trials
6. Repeat steps 1-5 for each sample of vinegar



Setup of burette



Vinegar, phenolphthalein, and NaOH solution with pink coloration

D. Results

Centrella White Vinegar:

	Trial 1	Trial 2	Trial 3	Average
NaOH added (mL)	22.3± .15	21.9± .15	22± .15	22.1± .15

Maitre Jacques Sherry Vinegar:

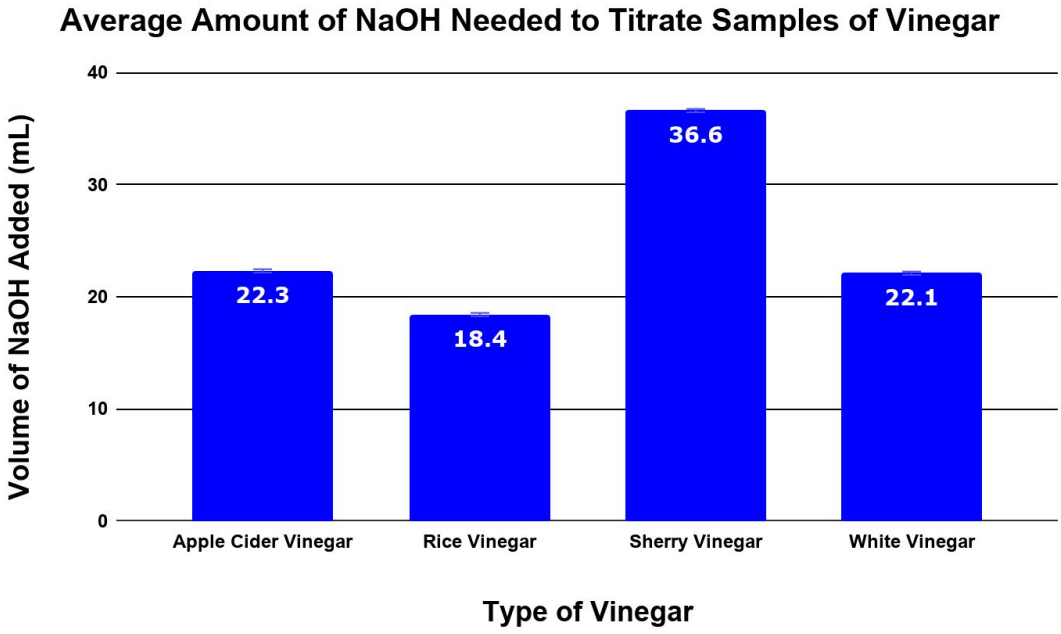
	Trial 1	Trial 2	Trial 3	Average
NaOH added (mL)	38.4± .15	34.7± .15	36.6± .15	36.6± .15

Marukan Rice Vinegar:

	Trial 1	Trial 2	Trial 3	Average
NaOH added (mL)	18.3± .15	18.2± .15	18.7± .15	18.4± .15

Heinz Apple Cider Vinegar:

	Trial 1	Trial 2	Trial 3	Average
NaOH added (mL)	22.5± .15	22.4± .15	21.9± .15	22.3± .15



E. Calculations

In order to determine the molarity of each sample of vinegar the following equation was utilised:

Molarity of Unknown = (molarity of known)(liters of known)/liters of unknown

The molarity of unknown was the variable that was being determine in this equation. The molarity of the known substance was 1M of the NaOH given at the beginning of the experiment. The liters of the known substance was the data collected throughout the experiment of the NaOH that was used to titrate the vinegar. Finally, the liters of the unknown substance was always 25 mL because 25 mL of vinegar was always used. The equation can be improvised as seen below:

Molarity of Vinegar = (NaOH molarity)(NaOH volume)/Vinegar volume

The molarity of each sample of vinegar was determined to be:

- White Vinegar: .88M
- Sherry Vinegar: 1.46M
- Rice Vinegar: .736M
- Apple Cider Vinegar: .89M

Percent Acetic Acid in Each Sample of Vinegar:
In order to calculate the percent of acetic acid in each sample of vinegar that following equation was used:

Moles of acetic acid/1 Liter x 60 grams acetic acid/1 mole acetic acid x 1 Liter solution/1000 grams solution x 100%

This equation simplified to determine the grams of acetic acid over the total grams used in the solution, or the percent of acetic acid in solution. Using the data collected and this equation, the following percents of acetic acid in each sample of vinegar were found:

White Vinegar: 5.28% $C_2H_4O_2$
Sherry Vinegar: 8.76% $C_2H_4O_2$
Rice Vinegar: 4.42% $C_2H_4O_2$
Apple Cider Vinegar: 5.34% $C_2H_4O_2$

F. Error Analysis

There was a reported ± .15 error margin for each measurement that was taken. This error margin was derived from the volume of one drop of solution from the burette. On average a drop of solution has a volume of .05 mL.[10] Based off of this information, i was accurate to two drops of the equivalence point while using the burette. I was able to come to the conclusion that a ± .1 error margin would be sufficient.

The final .05 added or subtracted to the error margin was taken from rounding numbers during mathematical conversions and data processing. Due to the fact that with the human eye, you are only able to be precise to the tenths place when measuring volumes on the burette that was used, this human error was manifested in calculations and rounding leading to the final ± .05 being added to the data.

Further error analysis can be conducted to compare the experimental percentage of acetic acid in each vinegar sample to the expected percentage of acetic acid in each type of vinegar. White vinegar has an expected acetic acid percentage of 5%.[11] Heinz apple cider vinegar had an actual acetic acid percentage of 5% as well.[12] The actual percentage for rice vinegar was 4.3%.[13] Finally, sherry vinegar has an expected percentage of 7% acetic acid. When compared to the

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[10] "Drop (unit)," Wikipedia, March 13, 2019, accessed April 09, 2019, https://en.wikipedia.org/wiki/Drop_(unit).
[11]"Essential Everyday Distilled White Vinegar (64 Oz) from Strack & Van Til," Instacart, , accessed April 09, 2019, https://www.instacart.com/strack-van-til/products/3290720-essential-everyday-distilled-white-vinegar-64-oz.
[12] "Heinz® Apple Cider Vinegar," Heinz Vinegar, , accessed April 09, 2019, http://www.heinzvinegar.com/products-apple-cider-vinegar.aspx.
[13] "Genuine Brewed Rice Vinegar," Marukan, December 28, 2018, , accessed April 09, 2019, https://www.marukan-usa.com/products/genuine-brewed-rice-vinegar/.

experimental values of each (white vinegar: 5.28%, sherry vinegar: 8.76%, rice vinegar: 4.42%, apple cider vinegar: 5.34%) the percent error could be found using the equation:

$$(\text{Experimental} - \text{Actual})/\text{Actual} \times 100\%$$

Using this calculation its was determined that white vinegar had a percent error of 5.6%, apple cider vinegar had a percent error of 6.8%, sherry vinegar was 25.1%, and rice vinegar was 2.7%. With the exception of sherry vinegar, all of the results proved to be reliable. Sherry vinegar had a dark colored initial solution, which made it difficult to determine a color change when NaOH was added.

III. Conclusion

From the data and research collected I was able to find the varying levels of acetic acid in each type of vinegar. According to my calculations sherry vinegar contained the highest amount of acetic acid by percentage with 8.76% followed by apple cider vinegar with 5.34%.

These results were unexpected as I believed that white vinegar would have the highest percentage of acetic acid. I believed white vinegar would have the highest percentage of acetic acid initially because of qualitative observations. White vinegar is clear and this lead me to believe that it had the least number of ingredients to dilute the percentage of acetic acid. This hypothesis was further supported after my research. According to this research, white vinegar has between 5-10% acetic acid, which is comparatively higher than the other samples of vinegar. However, I found that the white vinegar only had 5.28% acetic acid. While this is within the expected range, it is lower than I had predicted. The vinegar may have been diluted by leftover water in the beaker that would make the acetic acid percentage lower than usual.

I found rice vinegar to have 4.42% acetic acid concentration. This was supported by research which found rice vinegars usually have between 2-4% acetic acid concentrations. My experimental measurement may have been slightly higher because of the leaking connection point in the burette that would have increased the amount of NaOH added to the vinegar solution.

I came to the conclusion that several factors influenced the percent of acetic acid found in different types of vinegar. First of all, environmental factors in the growing stage can influence the acetic acid percentages. Soil conditions, temperature, and precipitation levels all impact the degree to which crops ripen and ferment. This will have significant impacts on the degree to which acetic acid is present in each type of vinegar. Secondly, the type of crop used as the foundation for vinegars impacts the percentage of acetic acid in each. For example, rice vinegar had 4.34% less acetic acid by concentration on average when compared to sherry vinegar. As the name suggests, rice vinegar utilises liquids from rice to produce vinegar. Sherry vinegar on the other hand, is a wine vinegar that relies on grapes. This lead me to the conclusion that grapes

contain a higher concentration of microflora and yeast to turn sugars into alcohol to be used in the production of acetic acid.

Additionally, I came to the conclusion that grapes have a higher concentration of sugars than rice. The increased concentration of sugar in the grape crop increases the alcohol output by yeast and microflora. In turn, with greater alcohol the acetic bacteria can make more acetic acid. Lastly, the process that is used to ferment vinegar contributes to the percentage of acetic acid present. The Orleans method used to ferment the sherry vinegar places the liquid in barrels and exposes them to oxygen to be fermented. Depending on the time allowed for the sherry vinegar to mature and ferment, the vinegar will have greater percentage of acetic acid. Apple cider vinegar also uses the Orleans process and recorded the second highest percentage of acetic acid at 5.34%.

The titration method proved very successful in finding the molarity of acetic acid on vinegar as I was able to find the percent of acetic acid with very little error. There will always be the human error of adding too much NaOH after the point of equivalence, however, this played a small role in my final calculations. I believe that this experiment could be expanded upon to by reversing the NaOH and acetic acid. For example, you can find the percentage of NaOH in different types of bleach to find the most effective cleaning product by dripping in a liquid with acetic acid into a bleach solution with phenolphthalein.

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