CHEMISTRY EXTENDED ESSAY

"Investigating the differences in the amounts of acetic acid in 100 ml of lemon, pomegranate and grape vinegars and determining which one is most suitable for pickling"

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ABSTRACT

Vinegar is an important substance that has many uses in our daily life due to its acidic properties. It is used in pickling process which involves maintaining the nutritive quality of certain foods. Its acidic property provides a bacteria-free medium for pickling which is essential when keeping the food healthy. As the acidity increases, so does the ability to prevent bacteria formation. Vinegar's acidic property is a result of acetic acid, an organic acid of two carbons, which is present 4% - 5% in a bottle of vinegar. There are many types of vinegars in markets, which include different fruits, flavors and different percentages of acetic acid, the question is: Which type of vinegar is more acidic and, therefore, more suitable for pickling? In this study, the differences in the amounts of acetic acid in 100 milliliters of lemon, pomegranate and grape vinegars are investigated.

Simple acid-base titration was used as vinegar contains acetic acid. The titrations were done with 1.00 ± 0.01 $molL^{-1}$ sodium hydroxide solution as the titrant and samples of 30 milliliters of each different kind of vinegar as the analyte. By using a pH meter, the pH value of the analyte solution was recorded for each addition of 0.50 ± 0.05 milliliters of the titrant, 1.00 ± 0.01 $molL^{-1}$ sodium hydroxide solution. The S-shaped graphs of titrations were drawn and the equivalence points of each titration were determined. This data is used to find the amount of acetic acid in a 100 milliliters sample.

With a 3.880% acetic acid in it, the grape vinegar is found to be the most acidic and therefore the most suitable one for pickling among the other types of vinegars tested. It is also found that the lemon vinegar has 3.682% and the pomegranate vinegar has 3.282% acetic acid in them.

(300 Words)

Key Words: Vinegar, Pickling, Amount of Acetic Acid, Acids and Bases

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INTRODUCTION

Vinegar has many uses in our daily life. It is one of the most common acidic substances that can be found in our kitchen. It is used for salad dressing, it is put inside the meals in order to give flavor, it is used as a cleaning reagent due to its ability to kill most bacteria and germs as it is acidic and it is also used in the pickling process. Pickling is a very interesting process when you think of it. You put food in a container with excess amount of vinegar alongside with some spices in order to preserve them and add them a sour salty flavor. In Turkey, pickling is a very common domestic process applied in order to obtain pickles. Pickles are called “turşu” in Turkish and they have a very important part in our kitchen. They can be and are advised to be eaten with almost each Turkish meal as they are said to bring out the true flavor of the meal. In my surrounding environment, there are many people, from my family and my friends’ families, who do pickling, but they did not use the same kind of vinegar. An acidic substance, vinegar, is used to produce pickles to give a sour flavor and the primary aim was to preserve food by killing the microbes using the acidic nature of vinegar, so more acidic the vinegar, better the pickling will be. I made research and learned that vinegar contains acetic acid. Having seen the abundance of pickling and the usage of different kinds of vinegars in the process, a question came to my head: How do different types of vinegars differ in amount of acetic acid? Is the percentage of acetic acid in different types of vinegars same? If not, which one is more acidic, therefore is more suitable for pickling?

RESEARCH QUESTION

Which type of vinegar is more acidic and, therefore, more suitable for pickling?

BACKGROUND INFORMATION

An Introduction to Acids & Bases:

Acids and Bases are an important part of our daily life. First, the substances which have a sour taste were called acids. Examples include citric acid in lemon, ascorbic acid in orange juice and acetic acid in vinegar. Conversely, the substances which have a bitter taste and a slippery feeling were called bases, i.e. alkalis. The hygiene materials such as, soaps, detergents, floor cleaners and drain openers consist of bases. Later, a Danish and an English chemist (Johannes Brønsted and Thomas Lowry), classified acids and bases according to the Brønsted-Lowry model. This model states that acids are proton (H^+) donors, whereas, bases are proton acceptors. This model also states that substances that dissolve in water created conjugate acid-base pairs. In order to form a conjugate acid, one substance should gain H^+ ions, while a conjugate base is formed by losing of this ion. So we can say that, when an acid dissolves in water it creates a conjugate base, losing H^+ ions, and a basic substance creates a conjugate acid, gaining H^+ ions. During the ionization of acids in water, between water molecules and the conjugate base molecules formed by the acidic substance, a competition to gather protons takes place. If the affinity for H^+ ions of conjugate base formed by the substance is weaker than that of water, the acid ionizes 100%, and creates hydronium ions (H_3O^+) but if the conjugate base molecules have more affinity, the acid cannot fully ionize and create equilibrium between the reactants and the products. Such substances are called weak acids. For bases the same phenomena is also applied while dissociating in water, but instead of a conjugate base, a conjugate acid is formed and the competition is not for gaining protons but for losing them.

$$\underset{\text{(Acid)}}{HA_{(aq)}} + H_2O_{(l)} \rightleftharpoons H_3O^+_{(aq)} + \underset{\text{(Conjugate Base)}}{A^-_{(aq)}}$$

Figure 1: Ionization of Acids

Acidity of a substance can be defined by the concentration of H^+ ions in its solution. As concentration values of H^+ ions tend to be rather small, pH is used. It can be defined as a mathematical operation in which negative common logarithm of H^+ ion concentration is calculated.

$$pH = -\log[H^+]$$

Equation 1: Calculation of pH

The pH of a solution determines its place in the pH scale, a scale in which the solutions are sorted with respect to their pH levels from 1 to 14, 1 indicates high acidity where 14 indicates low acidity, i.e. high basic property.

Figure 2: The pH Scale

Information on Vinegar and Pickling:

The term vinegar comes from French word “vin aigre”, which means sour wine. It is obtained by the acetic fermentation of dilute alcoholic liquids. As bacteria convert alcohol to acetic acid by means of oxidative fermentation, vinegar is formed. [1]

$$C_2H_5OH + O_2 \rightarrow CH_3COOH + H_2O$$

Figure 3: Formation of Acetic Acid by Means of Oxidative Fermentation

Although acetic acid is an important ingredient of vinegar, a solution of acetic acid cannot be counted as vinegar. Vinegar contains many vitamins and other compounds not found in acetic acid such as riboflavin, Vitamin B-1 and mineral salts from the starting material that impart vinegar with its distinct flavor. Any fruit or any material that contains sugar can be used to produce vinegar. [1]In USA, the commercial vinegars consist of 4 grams of acetic acid per 100 ml[2]. Normally, vinegar is made up of approximately 5% acetic acid. [3] It is also used in pickling process.

Pickling can be defined as sustaining food, usually cucumber, pepper, cabbage and tomato, by storing it in an acidic medium. As an acidic medium, vinegar is used.[4] The resulting salty and the sour taste of pickles come from the acid medium. It is an effective way of preserving food because of the low pH level of the acidic medium. Lower the pH, better the pickling. So, one can say that the acidity of vinegar, the acidic medium, is directly related to

Figure 4: Pickles formed as a result of pickling

[1] The Vinegar Institute – Frequently Asked Questions, <http://www.versatilevinegar.org/faqs.html>
[2] CPG Sec. 525.825 Vinegar, Definitions – Adulteration with Vinegar Eels <http://www.fda.gov/ICECI/ComplianceManuals/CompliancePolicyGuidanceManual/ucm074471.htm>
[3] Acetic acid -- Britannica Online Encyclopedia <http://www.britannica.com/EBchecked/topic/3235/acetic-acid>
[4] Pickling & Pickles – Food Facts – Food Reference < http://www.foodreference.com/html/artpickles.html>

the proper preserving of the food. It is clear that more acidic vinegar should be used in the process of pickling. In home-pickling (Making pickles at home), commercial vinegars are used.

Some Facts about Acetic Acid: The Main Constituent of Vinegar:

With a chemical formula of CH_3COOH and a molecular weight of 60.05 grams, [5] acetic acid, also referred as ethanoic acid, is the most important of the carboxylic acids.[3] It is a weak acid, meaning it does not completely ionize in water. Like all acids, its pure solution is also dangerously corrosive. In the form of vinegar, acetic acid solutions (typically 5% to 18% acetic acid, with the percentage usually calculated by mass) are used directly as a condiment, and also in the pickling of vegetables and other foodstuffs. Table vinegar tends to be more diluted (5% to 8% acetic acid), while commercial food pickling generally employs more concentrated solutions. The amount of acetic acid used as vinegar on a worldwide scale is not large, but historically this is by far the oldest and most well-known application.[6]

$$CH_3COOH + H_2O \leftrightarrow CH_3COO^- + H_3O^+$$

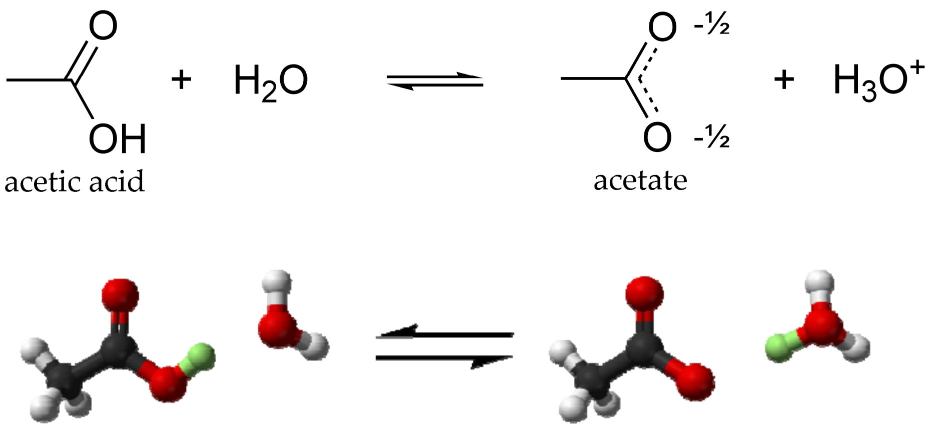


Figure 5: Ionization of Acetic Acid in Water

[5] Acetic Acid < http://www.pesticideinfo.org/Detail_Chemical.jsp?Rec_Id=PC32883>
[6] Acetic Acid < http://en.wikipedia.org/wiki/Acetic_acid#Vinegar>

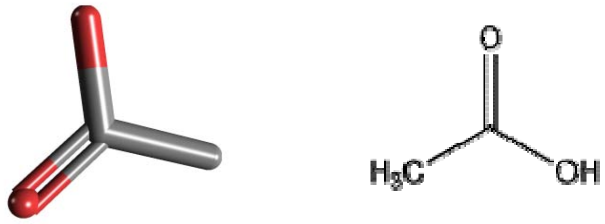


Figure 6: Molecular Structure of Acetic Acid[7]

Acid-Base Titration:

Titration is a volumetric analysis technique that is used to determine the amount of a certain substance. This process involves slowly adding a solution which has known concentration (the titrant) from a burette, enabling the measurement of the volume delivered, to a solution containing the substance being analyzed (the analyte). The reaction between the titrant and analyte must be known in order to determine the equivalence point, the point where enough titrant has been added to react exactly with the analyte. Equivalence point is sometimes referred as the stoichiometric point. The titrations involving acid-base reactions are called acid-base titrations and a neutralization reaction between an acid and a base takes place. There are various ways to determine the equivalence point of an acid-base titration.

One way is the usage of an indicator, a substance that is added at the beginning of the titration and changes color at (or very near) the equivalence point. The point where the indicator changes color is called the end point. One should not mistake the equivalence point and the end point as the color change of an indicator is dependent to pH whereas the equivalence point is determined by stoichiometry. It is a must to choose a suitable indicator with an end point near the equivalence point of the reaction.

Another way is to use a pH meter. While adding the titrant to the analyte, one can observe the pH change and note down the values for every unit of volume added. The rapid

[7] Acetic Acid – PubChem Public Chemical Database
<http://pubchem.ncbi.nlm.nih.gov/summary/summary.cgi?cid=176&viewopt=PubChem&hcount=2#MeSH>

increasing of the pH indicates that the equivalence point is reached, in other words, the characteristic properties of the solution will dramatically switch when continued to add the titrant. For example if a base is used as a titrant and an acid as an analyte, after the equivalence point the solution will become basic rather than acidic.

I chose to use this method because as the method is very simple the probability of a high error outcome is low. In laboratory assessments, we often used titration, so I was very familiar with the process. I will calculate the equivalence points of the titrations by sketching pH of the analyte solution versus volume of the added base solution graphs and finding the mid points of the expected “S-Shaped Curves” for each trial. I will not use an indicator as it will be very hard to observe the color change since the vinegars are colored too.

DATA PROCESSING[8]

- Graphs are sketched by using Microsoft Office Excel 2007 and Logger Pro 3.4.5.

LEMON VINEGAR

	Volume of $NaOH_{(aq)}$ used / ml (± 0.05)	Mole Number of $CH_3COOH_{(aq)}$ in 30 ml of Vinegar	Amount of $CH_3COOH_{(aq)}$ in 30 ml of Vinegar / g	Amount of $CH_3COOH_{(aq)}$ in 100 ml of Vinegar / g
Trial 1	17.34	0.01734 ± 1.29%	1.041 ± 1.29%	3.470 ± 1.29%
Trial 2	19.26	0.01926 ± 1.26%	1.157 ± 1.26%	3.857 ± 1.26%
Trial 3	18.58	0.01858 ± 1.27%	1.116 ± 1.27%	3.720 ± 1.27%

Table 1: Calculated V_{NaOH}, $n_{CH3COOH}$, Amount of Acetic Acid in 30 ml and 100 ml of Vinegar Values for Lemon Vinegar

POMEGRANATE VINEGAR

	Volume of NaOH(aq) used / ml (± 0.05)	Mole Number of $CH_3COOH_{(aq)}$ in 30 ml of Vinegar	Amount of $CH_3COOH_{(aq)}$ in 30 ml of Vinegar / g	Amount of $CH_3COOH_{(aq)}$ in 100 ml of Vinegar / g
Trial 1	16.20	0.01620 ± 1.31%	0.973 ± 1.31%	3.243 ± 1.31%
Trial 2	17.10	0.01710 ± 1.29%	1.027 ± 1.29%	3.423 ± 1.29%
Trial 3	15.88	0.01588 ± 1.31%	0.954 ± 1.29%	3.180 ± 1.31%

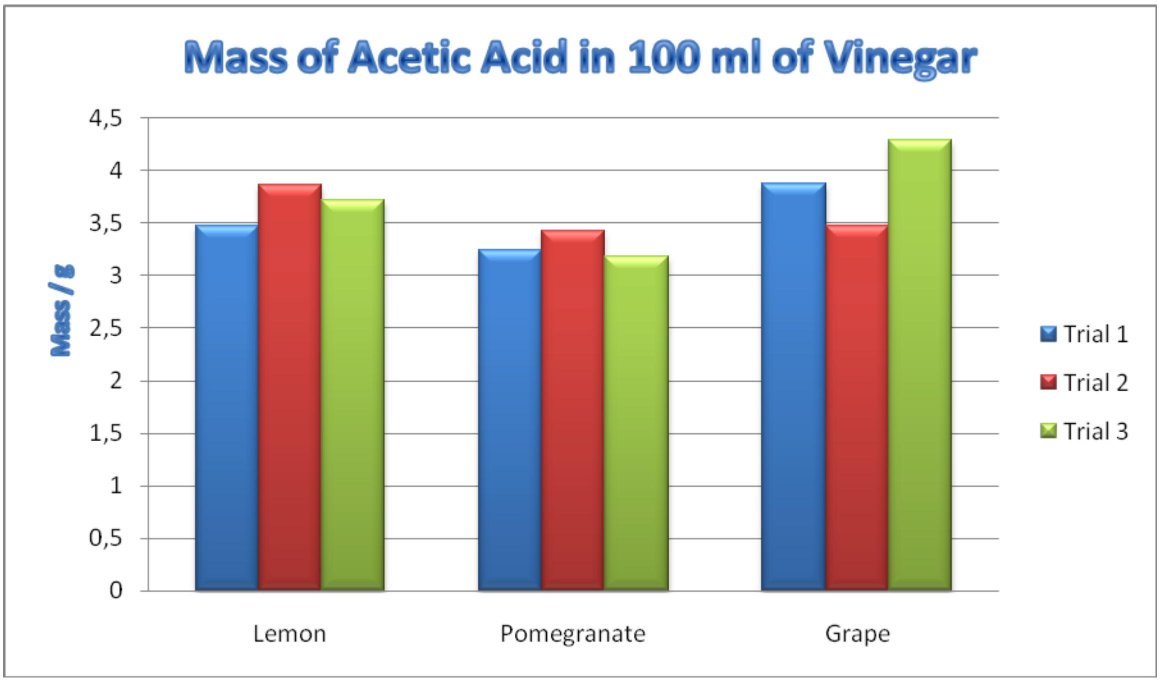
Table 2: Calculated V_{NaOH}, $n_{CH3COOH}$, Amount of Acetic Acid in 30 ml and 100 ml of Vinegar Values for Pomegranate Vinegar

[8] Experiment, method, data collection, calculations and the individual graphs for each trial is given in the appendix.

GRAPE VINEGAR

	Volume of $NaOH_{(aq)}$ used / ml (± 0.05)	Mole Number of $CH_3COOH_{(aq)}$ in 30 ml of Vinegar	Amount of $CH_3COOH_{(aq)}$ in 30 ml of Vinegar / g	Amount of $CH_3COOH_{(aq)}$ in 100 ml of Vinegar / g
Trial 1	19.37	0.01937 ± 1.26%	1.163 ± 1.26%	3.877 ± 1.26%
Trial 2	17.36	0.01736 ± 1.29%	1.042 ± 1.29%	3.473 ± 1.29%
Trial 3	21.44	0.02144 ± 1.23%	1.287 ± 1.23%	4.290 ± 1.23%

Table 3: Calculated V_{NaOH}, $n_{CH3COOH}$, Amount of Acetic Acid in 30 ml and 100 ml of Vinegar Values for Grape Vinegar

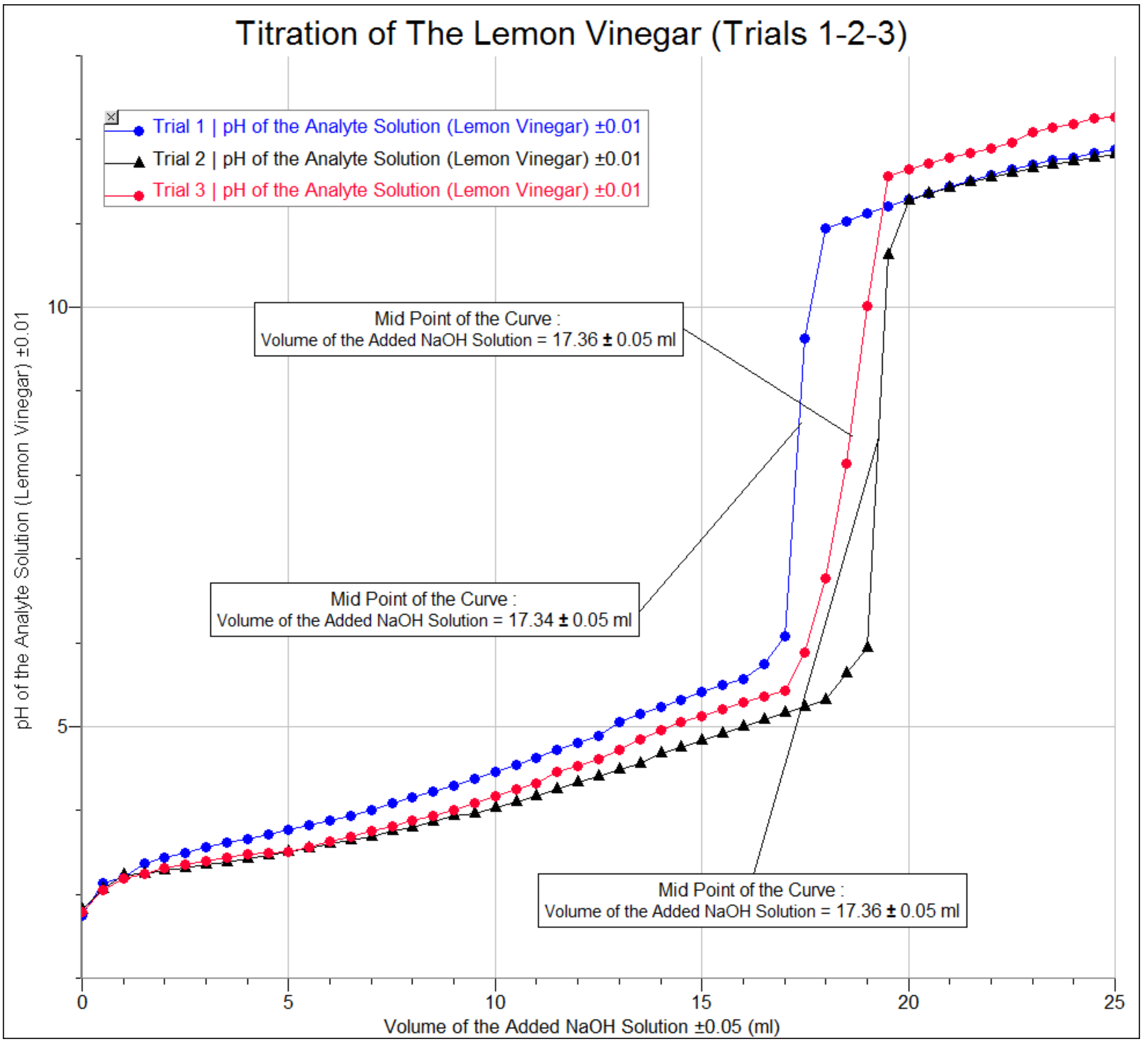


Graph 1: Bar Graph Showing the Calculated Masses of Acetic Acid in 100 ml of Each Kind of Different Vinegar Samples (Trials 1-2-3).

RESULTS

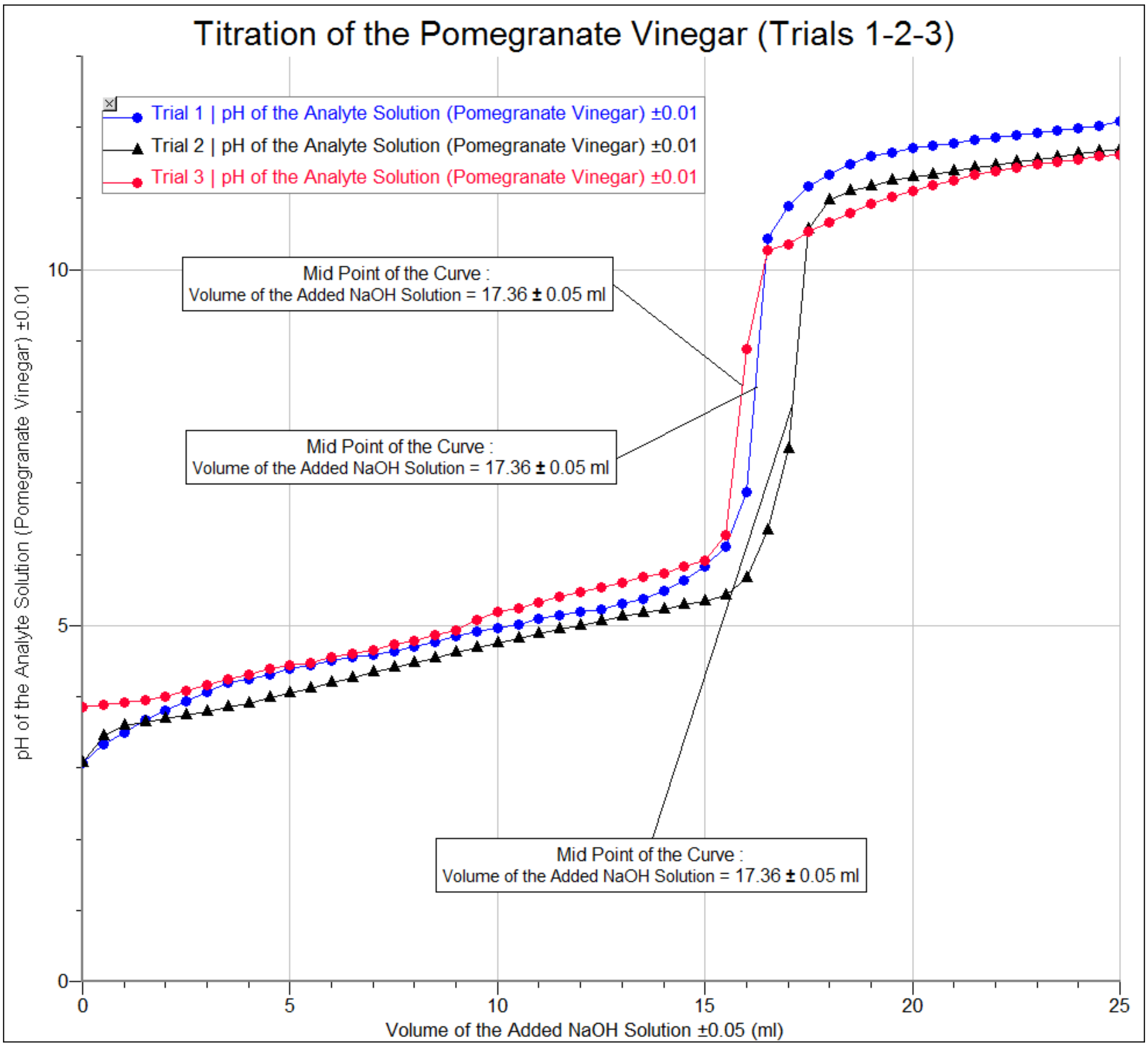
As the amounts of acetic acid in 100 ml of vinegar are calculated for each sample of vinegar for all trials, the average amounts of acetic acid in them can be found by calculating the arithmetical mean of the results for each trial done for every sample of vinegar. There were three trials performed for every sample of vinegar, trials done were consistent so three trials for every sample of vinegar was seen enough. The average values from all three trials for every sample can be used to analyze the acidity, and therefore the suitability for pickling of types of vinegars used in the experiment can be determined.

In the experiment with the lemon vinegar of 30 ml, 17.34 ± 0.05 ml, 19.26 ± 0.05 ml and 18.58 ± 0.05 ml of sodium hydroxide was used until the equivalence point was reached in trials 1, 2 and 3 respectively. These values are calculated from the mid-points of the “S” curves of the graphs that are sketched by using the collected data. The graphs for lemon vinegar are combined in Graph 2. The amount of acetic acid in 100 ml of lemon vinegar is found to be 3.470 ± 1.29% grams (Trial 1), 3.857 ± 1.26% grams (Trial 2) and 3.720 ± 1.27% grams (Trial 3). The average value is then found to be 3.682 ± 0.196 grams. In other words, the lemon vinegar is found to contain averagely 3.682 ± 0.196 grams of acetic acid per 100 ml.



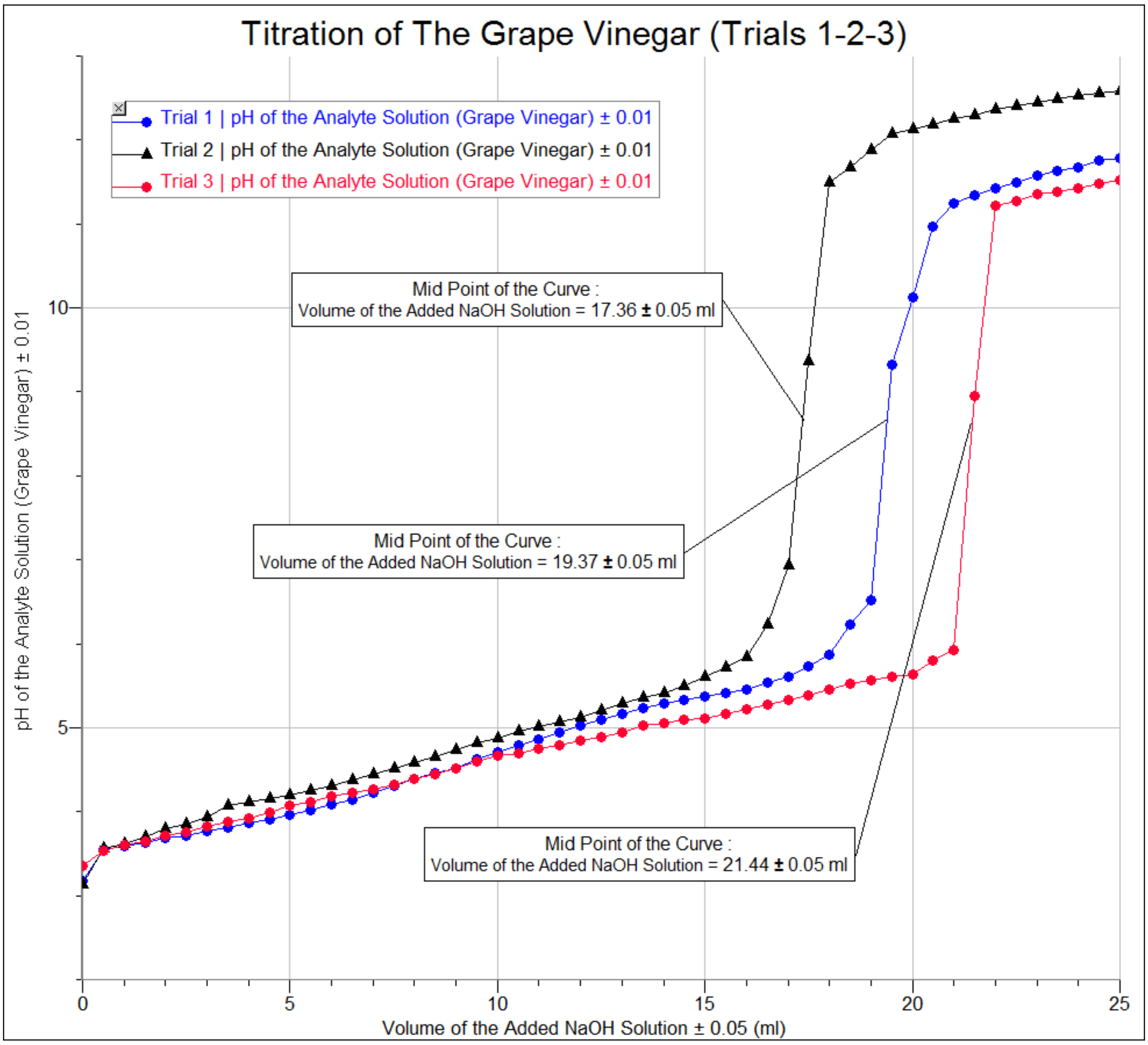
Graph 2: pH of the Analyte Solution Versus Volume of the Added NaOH Solution for the Titration of The Lemon Vinegar (Trials 1-2-3)

For the pomegranate vinegar of 30 ml to reach to the equivalence point, 16.20 ± 0.05 ml, 17.10 ± 0.05 ml and 15.88 ± 0.05 ml of sodium hydroxide was used in trials 1, 2 and 3 respectively. These values are calculated from the mid-points of the "S" curves of the graphs that are sketched by using the collected data. The graphs for pomegranate vinegar are combined in Graph 3. The calculated amounts of acetic acid in 100 ml of pomegranate vinegar are 3.243 ± 1.31% grams (Trial 1), 3.423 ± 1.29% grams (Trial 2) and 3.180 ± 1.31% grams (Trial 3). The average value is then found to be 3.282 ± 0.126 grams. In other words, the pomegranate vinegar is found to contain averagely 3.282 ± 0.126 grams of acetic acid per 100 ml.



Graph 3: pH of the Analyte Solution Versus Volume of the Added NaOH Solution for the Titration of The Pomegranate Vinegar (Trials 1-2-3)

Similarly for a sample of 30 ml of grape vinegar, 19.37 ± 0.05 ml, 17.36 ± 0.05 ml and 21.44 ± 0.05 ml of sodium hydroxide was used until the equivalence point was reached in trials 1, 2 and 3 respectively. These values are calculated from the mid-points of the "S" curves of the graphs that are sketched by using the collected data. The graphs for grape vinegar are combined in Graph 4. 3.877 ± 1.26% grams (Trial 1), 3.473 ± 1.29% grams (Trial 2) and 4.290 ± 1.23% grams (Trial 3) of acetic acid are found to exist in 100 ml of grape vinegar. The average value is then found to be 3.880 ± 0.408 grams. In other words, the grape vinegar is found to contain averagely 3.880 ± 0.408 grams of acetic acid per 100 ml.



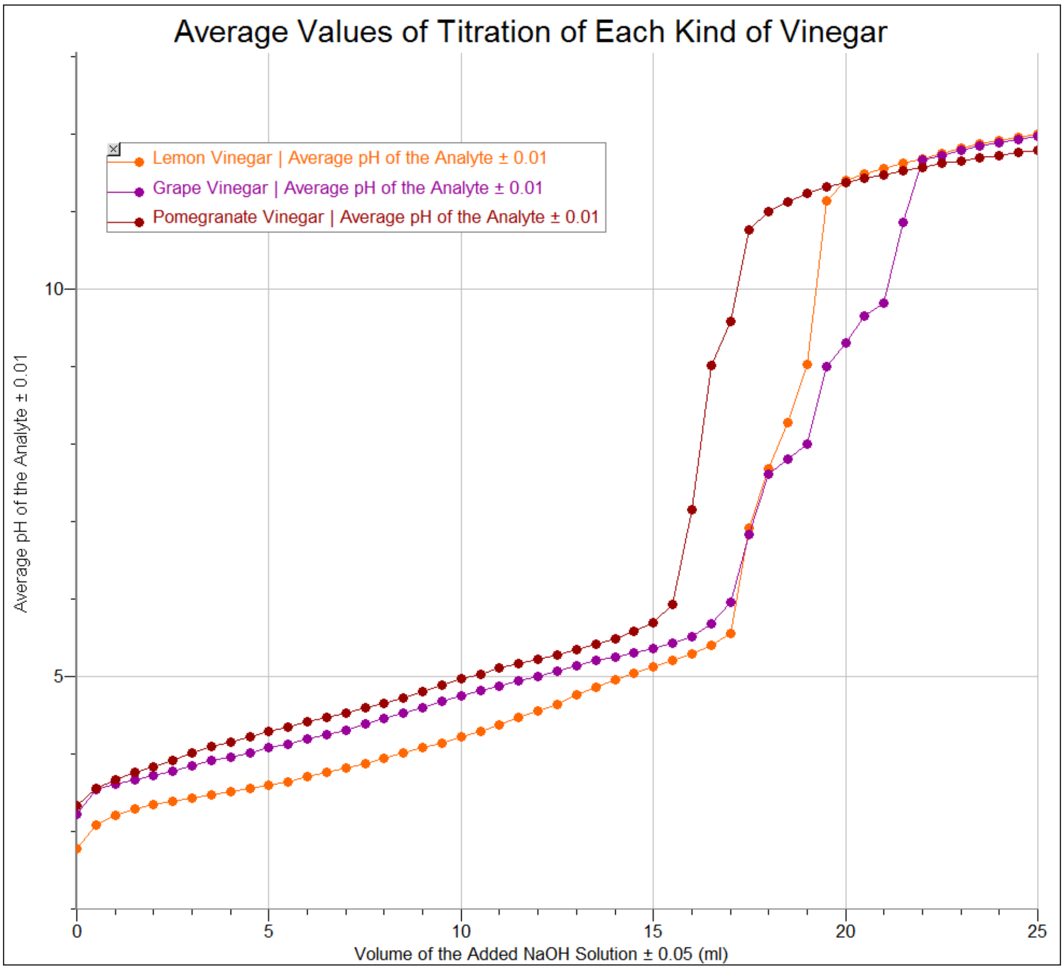
Graph 4: pH of the Analyte Solution Versus Volume of the Added NaOH Solution for the Titration of The Grape Vinegar (Trials 1-2-3)

Briefly, the lemon vinegar averagely has 3.682 ± 0.196 grams of acetic acid in a 100 ml sample, while a 100 ml of the pomegranate sample contains an average of 3.282 ± 0.126 grams of acetic acid and, last but not least, there is 3.880 ± 0.408 grams of acetic acid in a sample of 100 ml of grape vinegar in average. These values are summarized in Table 4. Also, average titration values can be seen in Graph 5. By considering these values, we can say that the grape vinegar is the most acidic, whereas the pomegranate vinegar is the least. These values can be compared by looking at the Graph 6. Further explanation of the significance of these values will be done in the conclusion part.

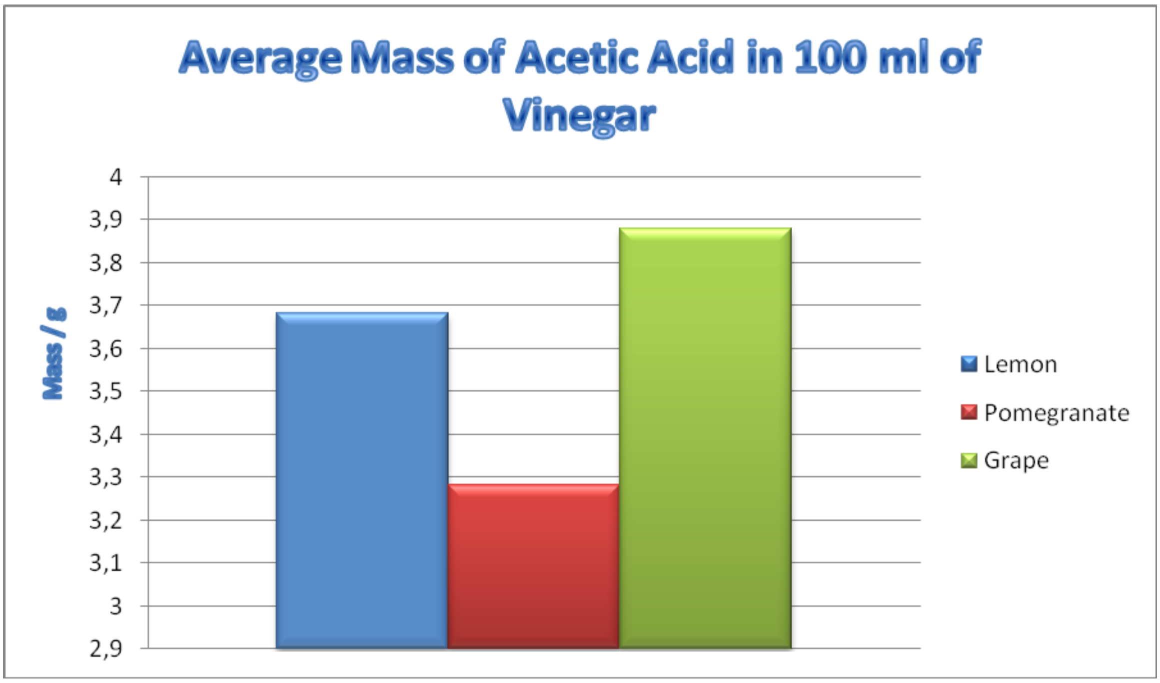
	Average Amount of $CH_3COOH_{(aq)}$ in 100 ml of Vinegar / g
Lemon Vinegar	3.682 ± 0.196
Pomegranate Vinegar	3.282 ± 0.126
Grape Vinegar	3.880 ± 0.408

Table 4: Average[9] Amount of Acetic Acid for All Kinds of Vinegar

[9] Average values and uncertainties are calculated with TI-84 Plus Silver Edition.



Graph 5: Average pH of the Analyte Solution Versus Volume of the Added NaOH Solution for Each Kind of Vinegar



Graph 6: Bar Graph Showing the Calculated Average Masses of Acetic Acid in 100 ml of Each Kind of Different Vinegar Samples. (Notice that the lowest mass value in the table is 2.9; the range is adjusted in order to visualize the comparison more efficiently.)

ERROR PROPAGATION

All of the vinegar samples used in the experiment has the same percent composition of acetic acid on their labels, which is 4 %. The average experimental values of each different kinds of vinegar will be compared to the theoretical value of 4 %.

$$\textbf{Random Error} = \frac{|Observed\ Value \quad Theoretical\ Value|}{Theoratical\ Value} \times 100$$

Equation 2: Random Error Calculation

- **For Lemon Vinegar:**

$$\frac{|3.682 - 4.000|}{4.000} \times 100 \;=\; 7.95\%$$

- **For Pomegranate Vinegar:**

$$\frac{|3.282 - 4.000|}{4.000} \times 100 \;=\; 17.95\%$$

- **For Grape Vinegar:**

$$\frac{|3.880 - 4.000|}{4.000} \times 100 \;-\; 3\%$$

CONCLUSION

The titration values of every different kind of vinegar sample shows us that the amount of acetic acid present in 100 ml of vinegar is roughly between 3.2 – 4.3 grams and when we look at the average values for each sample of vinegar, it is seen that the amount of acetic acid in 100 ml of vinegar is between 3.2 – 3.9 grams. By looking at the values in table 4, graph 5 and graph 6, the difference between each kind of different vinegar sample used in the experiment in terms of acidity can be seen clearly. This difference points out that not every kind of vinegar has the same amount of acetic acid inside, quite the contrary; each vinegar has a different acidity, which depends on the amount of acetic acid in them. With an average abundance of 3.880 %, grape vinegar is found to be the most acidic while the pomegranate vinegar, which has 3.282% acetic acid averagely, is the least acidic one. The lemon vinegar, with a 3.682% average acidity, lies between these two values and it is somewhat closer to the grape vinegar in terms of acidity. If you look at the graph 6, you can see the comparison of the average masses of acetic acid in 100 ml of vinegar for each sample. The graph 5 shows that the average volume of added NaOH solution for each kind of vinegar sample is coherent with this trend as the mid points of the curves (i.e. the equivalence points) correspond to an increasing volume of added NaOH solution from pomegranate to grape vinegar.

As the grape vinegar is found to be the most acidic among all other kinds used in the experiment, it can be advised that grape vinegar should be used for pickling. The more the acidity the more effective the vinegar will be in preserving the food as the pH will be the lowest. The acidity is the main factor that prevents the formation of harmful bacteria and germs inside the food container so the most acidic vinegar will be the most successful. Commercial vinegars are said to be used while pickling at home, so between grape, lemon and pomegranate vinegar, it would be wise to use grape vinegar in pickling, if your aim is to preserve your food. However there is another important factor in pickling that affects the choice of vinegar besides the ability to preserve: Taste. The taste has a vital role in pickling since many people produce pickles because they like the flavor. Given that vinegar is the most abundant reagent that is present in the pickling container, it contributes to the taste of the food vastly; that is to say, the taste of vinegar can be sensed in the flavor of the pickles. In the past, people only considered pickling as a way of preserving food, but today pickles are eaten alongside with meals. Especially in Turkey, pickles are the integral parts of the Turkish Kitchen. It is said that pickles bring out the true taste of the meals. Consequently, in our day, taste is the main concern of the people when it comes to pickles. The grape vinegar can be the most acidic among other kinds used in the experiment, but in my surrounding environment, the lemon vinegar is widely used as the sour, lemony taste is preferred instead of a slight sweet grape taste. The conditions are very different today when we compare them with the ones in the past. People were in need of healthy food and they needed to preserve their food in good conditions, while today healthy food can be found easily and it is not a big problem so the selectivity shifts from health to taste. It is very important to determine the purpose of pickling before selecting which kind of vinegar to use. The experiment was done considering the health of the food rather than the taste, so according to the experiment grape vinegar should be used in the pickling process.

The random errors, which can be seen in the error propagation section, show us the experiments performed were somewhat erroneous. The experiment with the grape vinegar was the most accurate one with a random error of 3% while in doing the experiment with pomegranate vinegar the random error was found to be 17.95% The theoretical value taken was the value which was written in the label and it was same for each kind of vinegar. This experiment proves that not every kind of vinegar has the same amount of acetic acid in them. So such a theoretical value is not very trustworthy but still it gives an idea about the accuracy of the results. The results found in the experiment are very consistent since the interval in which the results take place is very small (0.7 grams). However it is not possible to rule out the sources of error present in the experiment.

The volume intervals on the beaker are very large so the volume measurements are done with a graduated cylinder. As the volume values on the burette are very small, one can easily pour more or less NaOH solution than the needed value. Despite all efforts the temperature may have also changed which would result in different measurements of pH than the actual value. As the temperature affects the pH, the equivalence points of the titrations may have changed which leads to an incorrect calculation of mass of acetic acid in vinegar. When the temperature increases, pH increases due to the exothermic reaction of the equilibrium condition. The importance of pH brings us to another source of error: sensitivity of the pH meter. As the pH meter is thoroughly used in the experiment, it is possible that it may have lost its sensitivity, losing its calibration. Last but not least, the presence of other material in the vinegar may have affected the found acidity value. In the experiment, acetic acid is counted to be solely responsible for the acidity of vinegar, but some ingredients such as trace amounts of antioxidants may have contributed to its acidity.

With some additions, the experiment can be made more reliable. Although the random error is not very much in the experiment, there is still room for improvement. Firstly, to check the equivalence point of the titration, a suitable indicator can be used. But when you consider the colors of vinegars (grape vinegar is yellowish orange, pomegranate vinegar is purplish red and lemon vinegar is light yellow), it is very hard to find a suitable indicator that both has a noticeable color and a suitable end point. Also, the reaction with the indicator may affect the calculated values due to the fact that indicators are weak acids; therefore I did not consider using an indicator. Moreover, the number of trials can be increased to reach to more solid results. As the trials performed were seen to be consistent with each other, three trials were seen enough for this experiment. Furthermore, other samples of vinegar (other than grape, lemon and pomegranate) can be tested in order to reach to a wider understanding of the acidity of the vinegar. Lastly, an isolated container can be used while titrating in order to diminish the temperature change that affects the pH reading.

Finding that the grape vinegar is the most acidic among the examined types leads to the rise of many new questions. Firstly, one may wonder whether the grape vinegar is the most acidic among all types of vinegars. The find out, this investigation can be repeated utilizing different kinds of vinegar, thus expanding the range of the research. Secondly, it is said that the trace amounts of antioxidants are present in commercial vinegars which may affect the acidity of the vinegar, so one can find the amounts of antioxidants by applying an ORAC (Oxygen Radical Absorbance Capacity) test which is a standard in measuring the antioxidant amount. Moreover, by conducting pickling containers using the types of vinegars used in this research, one can periodically measure the amount of bacteria produced in containers in order to test and increase validity of the results of this study. Last but not least, the relation between the acidity of the vinegar and its cleaning ability can be examined.

APPENDIX

Experiment:

Purpose: To Find and Compare the Amounts of Acetic Acid in Lemon, Pomegranate and Grape Vinegars by Performing an Acid-Base Titration

Variables:

- **Independent Variables:** Kinds of vinegar (Lemon, Pomegranate and Grape), Acidity of Vinegar
- **Dependent Variables:** pH readings, Amounts of Acetic Acid in Samples, Volume of Base Used
- **Controlled Variables:**
  - *Pressure:* There are no sudden changes in pressure in the lab since the altitude is constant and the windows are closed, providing that there is no net air flow inside the lab.
  - *Temperature:* It is kept constant by preparing and ice bath and cooling the system when necessary. The system is expected to warm up as the observed reaction is an acid-base neutralization reaction and acid-base neutralization reactions are exothermic.
  - *Amount of Vinegar*
  - *Type and Concentration of Base*

Materials:

- 250 ml 1.00 ± 0.01 $molL^{-1}$ NaOH
- Burette (50.00 ± 0.05 ml)
- A 100 ml Beaker
- 500 ml Distilled Water
- pH Meter (± 0.01)
- Graduated Cylinder
- Stand with a Burette Holder
- A Utility Clamp
- Grape Vinegar
- Lemon Vinegar
- Pomegranate Vinegar
- Buffer Solutions (4-7)
- Thermometer (-10°C – 110°C)
- Barometer (hPa)

(Note that, the uncertainties besides the concentration of the NaOH solution, volume of the burette and the uncertainty of the pH meter is not given as the measurement only depend on given uncertainties. For example, the graduated cylinder and the beaker is only used to fill the burette or as a container to the solutions. Distilled water is essential for cleaning pH probes and other materials and will not be used in the experiment calculations so its uncertainty is irrelevant.)

Method:

1. I rinsed the burette with distilled water and discarded the water, then rinsed the burette with a little amount of 1.00 ± 0.01 $molL^{-1}$ sodium hydroxide solution and again discarded the 1.00 ± 0.01 $molL^{-1}$ sodium hydroxide solution. I did this in order to guarantee that there was no change in the concentration of sodium hydroxide solution.

2. After all sodium hydroxide solution was discarded, I closed the stopcock and filled all of the burette with sodium hydroxide solution (1.00 ± 0.01 $molL^{-1}$). In order to eliminate any bubbles at the tip; I filled the burette a little more than 0.00 ml and released some amount of sodium hydroxide solution. The bubbles would have caused a miscalculation of the volume of the used sodium hydroxide solution.

3. For the calibration of the pH meter, I used buffer 4 and buffer 7 solutions. I placed the probe of the pH meter inside the buffer 4 solution and measured its pH. With a help of a screwdriver, I adjusted the pH meter to 4.00. I did the same for buffer 7 solution. After I calibrated the pH meter, I cleaned the probe of the pH meter with distilled water and dried it. By cleaning and drying the probe, I made sure that it would measure proper pH values.

4. I cleaned the beaker with distilled water and dried it. Drying was necessary as pure water can dilute the solution preserved in the beaker.

5. I prepared an ice bath in order to minimize the temperature change. As acid-base neutralization reactions are exothermic, I expected the system to warm up. I used a thermometer to measure the temperatures of the solutions. I tried to keep the temperature around 25 °C during the experiment by using the ice bath when necessary. As the temperature changes the measured pH values also changes, it was very important to keep it constant at 25 °C.

6. By using graduated cylinder, I placed 30 ml vinegar into the beaker, and then I placed the probe of the pH meter inside the beaker by using the utility clamp. I made sure that I had set the level of the utility clamp accordingly so that the tip of the pH meter probe is inside the solution.

7. I checked if it was easy to stir the beaker when I was titrating the vinegar with sodium hydroxide solution. It is essential to stir as the titrant must fully react with the analyte in order perform a healthy titration; stirring increases the rate of reaction between the acid and the base.

8. I recorded the initial volume of the sodium hydroxide solution and the initial pH of the vinegar, and then started the titration and recorded the pH for every 0.5 ml of sodium hydroxide solution used by stopping the burette at relevant volume values until I had dripped around 25 ml. When I reached 25 ml, I stopped the burette and the pH meter. I performed the titration until I reached 25 ml of base because I wanted to obtain properly "S-Shaped Graphs" in order to calculate the equivalence point proficiently.

9. I repeated the process for each different kind of vinegar (Lemon, Pomegranate and Grape) for 3 times. In the end, I had a total of 9 data sets, 3 sets of data for each kind of vinegar. I presumed that the grape vinegar was the most acidic one and the pomegranate vinegar was the least acidic so I started to perform the titration from the least acidic to the most acidic in order to ensure proper data measurement.

Qualitative Observations:

Sodium hydroxide solution is colorless and has a soapy smell and gives a slippery feeling when touched. On the other hand, the vinegars are very colorful. Grape vinegar is yellowish orange, pomegranate vinegar is purplish red and lemon vinegar is light yellow. As the vinegars are colored, it is difficult to use an indicator since it is very had to notice the color change. All vinegars had sour odors, especially lemon vinegar had a very sour odor, and it might be because lemon fruit also has the sourest odor when compared to pomegranate and grape. Last but not least, as acid base titration is an exothermic reaction, the container warmed up a bit, as expected.

Data Collection:

- Lemon Vinegar

Volume of the Added NaOH Solution / ml (±0.05)	pH Readings / (±0.01)			Volume of the Added NaOH Solution / ml (±0.05)	pH Readings / (±0.01)		
	Trial 1	Trial 2	Trial 3		Trial 1	Trial 2	Trial 3
0.00	2.74	2.81	2.79	13.00	5.06	4.49	4.72
0.50	3.13	3.07	3.05	13.50	5.15	4.56	4.85
1.00	3.20	3.23	3.19	14.00	5.23	4.68	4.96
1.50	3.37	3.25	3.25	14.50	5.31	4.75	5.05
2.00	3.44	3.28	3.31	15.00	5.41	4.83	5.13
2.50	3.49	3.31	3.35	15.50	5.49	4.91	5.21
3.00	3.56	3.35	3.40	16.00	5.57	5.00	5.29
3.50	3.61	3.38	3.44	16.50	5.75	5.08	5.36
4.00	3.66	3.42	3.48	17.00	6.07	5.16	5.43
4.50	3.71	3.46	3.49	17.50	9.63	5.24	5.89
5.00	3.77	3.51	3.50	18.00	10.94	5.32	6.77
5.50	3.82	3.55	3.56	18.50	11.03	5.64	8.14
6.00	3.88	3.60	3.63	19.00	11.12	5.94	10.02
6.50	3.94	3.64	3.69	19.50	11.21	10.63	11.56
7.00	4.01	3.69	3.75	20.00	11.29	11.27	11.64
7.50	4.08	3.75	3.81	20.50	11.36	11.35	11.72
8.00	4.15	3.80	3.88	21.00	11.44	11.42	11.78
8.50	4.23	3.87	3.94	21.50	11.51	11.49	11.84
9.00	4.30	3.93	4.01	22.00	11.58	11.55	11.90
9.50	4.38	3.96	4.08	22.50	11.64	11.61	11.97
10.00	4.46	4.03	4.17	23.00	11.70	11.66	12.09
10.50	4.54	4.10	4.25	23.50	11.75	11.70	12.14
11.00	4.63	4.17	4.32	24.00	11.79	11.74	12.19
11.50	4.72	4.25	4.46	24.50	11.84	11.79	12.25
12.00	4.80	4.34	4.53	25.00	11.88	11.83	12.27
12.50	4.89	4.41	4.61				

Table A1: Data Collected for Lemon Vinegar in Trials 1-2-3.

- Pomegranate Vinegar

Volume of the Added NaOH Solution / ml (±0.05)	pH Readings / (±0.01)			Volume of the Added NaOH Solution / ml (±0.05)	pH Readings / (±0.01)		
	Trial 1	Trial 2	Trial 3		Trial 1	Trial 2	Trial 3
0.00	3.07	3.07	3.86	13.00	5.30	5.12	5.60
0.50	3.33	3.44	3.89	13.50	5.37	5.18	5.68
1.00	3.50	3.59	3.92	14.00	5.48	5.23	5.74
1.50	3.68	3.65	3.96	14.50	5.63	5.29	5.83
2.00	3.81	3.69	4.00	15.00	5.83	5.34	5.92
2.50	3.93	3.74	4.08	15.50	6.10	5.43	6.27
3.00	4.07	3.79	4.17	16.00	6.88	5.67	8.89
3.50	4.19	3.85	4.24	16.50	10.44	6.33	10.27
4.00	4.24	3.91	4.31	17.00	10.89	7.48	10.35
4.50	4.31	3.98	4.39	17.50	11.17	10.56	10.54
5.00	4.39	4.05	4.44	18.00	11.33	10.98	10.67
5.50	4.44	4.12	4.48	18.50	11.48	11.10	10.79
6.00	4.51	4.19	4.55	19.00	11.59	11.17	10.92
6.50	4.55	4.27	4.61	19.50	11.65	11.25	11.03
7.00	4.59	4.34	4.66	20.00	11.71	11.30	11.10
7.50	4.64	4.41	4.73	20.50	11.75	11.34	11.19
8.00	4.71	4.47	4.79	21.00	11.78	11.39	11.25
8.50	4.77	4.54	4.86	21.50	11.82	11.43	11.33
9.00	4.85	4.62	4.93	22.00	11.85	11.47	11.39
9.50	4.92	4.68	5.08	22.50	11.89	11.51	11.44
10.00	4.96	4.76	5.19	23.00	11.92	11.55	11.48
10.50	5.02	4.82	5.25	23.50	11.95	11.58	11.52
11.00	5.09	4.89	5.33	24.00	11.98	11.62	11.55
11.50	5.15	4.95	5.40	24.50	12.02	11.66	11.59
12.00	5.19	4.99	5.47	25.00	12.08	11.69	11.61
12.50	5.23	5.06	5.54				

Table A2: Data Collected for Pomegranate Vinegar in Trials 1-2-3.

- Grape Vinegar

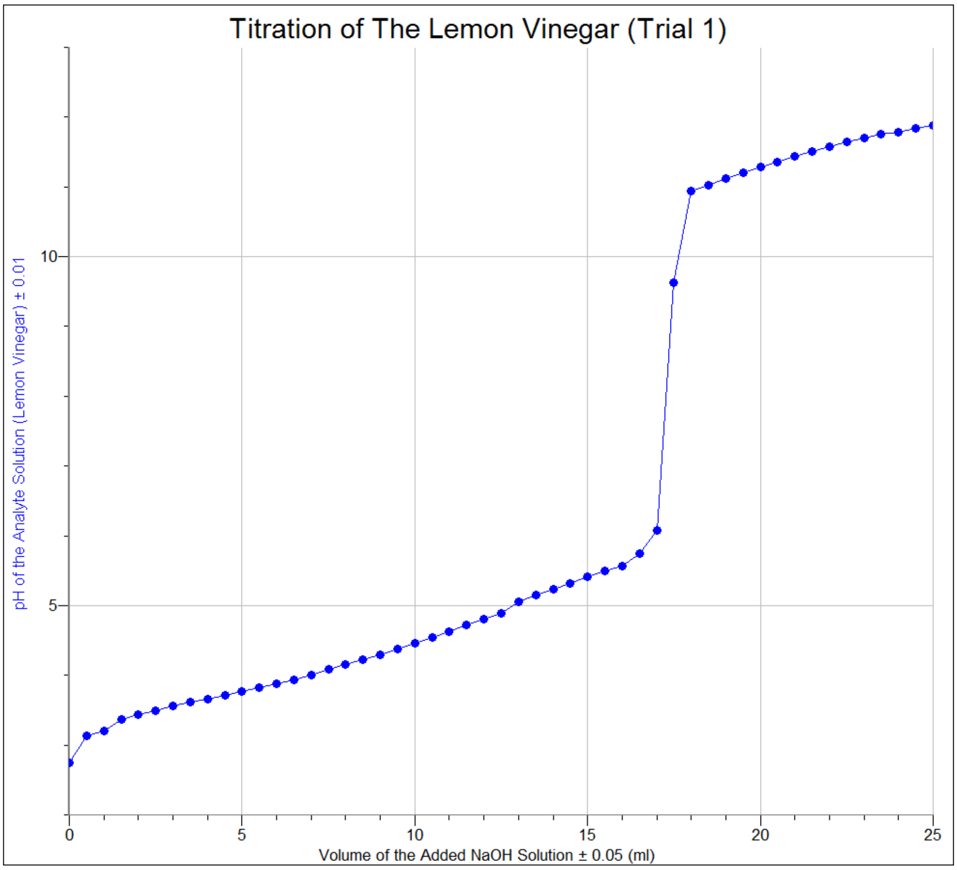
Volume of the Added NaOH Solution / ml (±0.05)	pH Readings / (±0.01)			Volume of the Added NaOH Solution / ml (±0.05)	pH Readings / (±0.01)		
	Trial 1	Trial 2	Trial 3		Trial 1	Trial 2	Trial 3
0.00	3.17	3.14	3.36	13.00	5.17	5.29	4.94
0.50	3.55	3.56	3.53	13.50	5.24	5.36	5.02
1.00	3.59	3.62	3.60	14.00	5.29	5.42	5.05
1.50	3.63	3.70	3.65	14.50	5.33	5.50	5.09
2.00	3.68	3.79	3.71	15.00	5.37	5.61	5.11
2.50	3.72	3.85	3.76	15.50	5.41	5.72	5.16
3.00	3.77	3.94	3.83	16.00	5.46	5.84	5.22
3.50	3.81	4.07	3.88	16.50	5.54	6.23	5.27
4.00	3.86	4.11	3.92	17.00	5.61	6.94	5.33
4.50	3.91	4.15	3.99	17.50	5.73	9.37	5.39
5.00	3.96	4.20	4.07	18.00	5.87	11.49	5.45
5.50	4.02	4.25	4.12	18.50	6.23	11.67	5.52
6.00	4.08	4.31	4.18	19.00	6.52	11.88	5.57
6.50	4.14	4.37	4.23	19.50	9.33	12.07	5.60
7.00	4.22	4.44	4.26	20.00	10.13	12.13	5.64
7.50	4.31	4.52	4.32	20.50	10.97	12.19	5.80
8.00	4.39	4.58	4.39	21.00	11.25	12.25	5.93
8.50	4.46	4.65	4.45	21.50	11.34	12.29	8.95
9.00	4.52	4.73	4.52	22.00	11.42	12.36	11.22
9.50	4.62	4.82	4.60	22.50	11.49	12.41	11.27
10.00	4.71	4.88	4.67	23.00	11.57	12.45	11.35
10.50	4.79	4.96	4.70	23.50	11.63	12.49	11.39
11.00	4.86	5.01	4.75	24.00	11.68	12.53	11.43
11.50	4.95	5.07	4.79	24.50	11.75	12.56	11.48
12.00	5.02	5.13	4.85	25.00	11.79	12.59	11.52
12.50	5.09	5.21	4.89				

Table A3: Data Collected for Grape Vinegar in Trials 1-2-3.

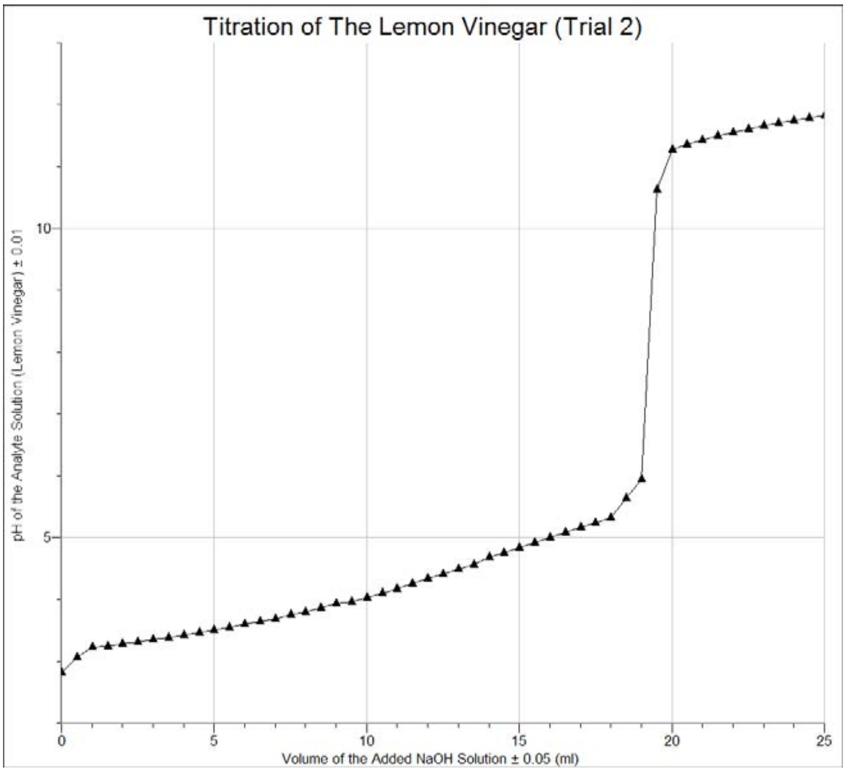
Graphs:

The graphs are sketched by Logger Pro 3.4.5., by using the collected data.

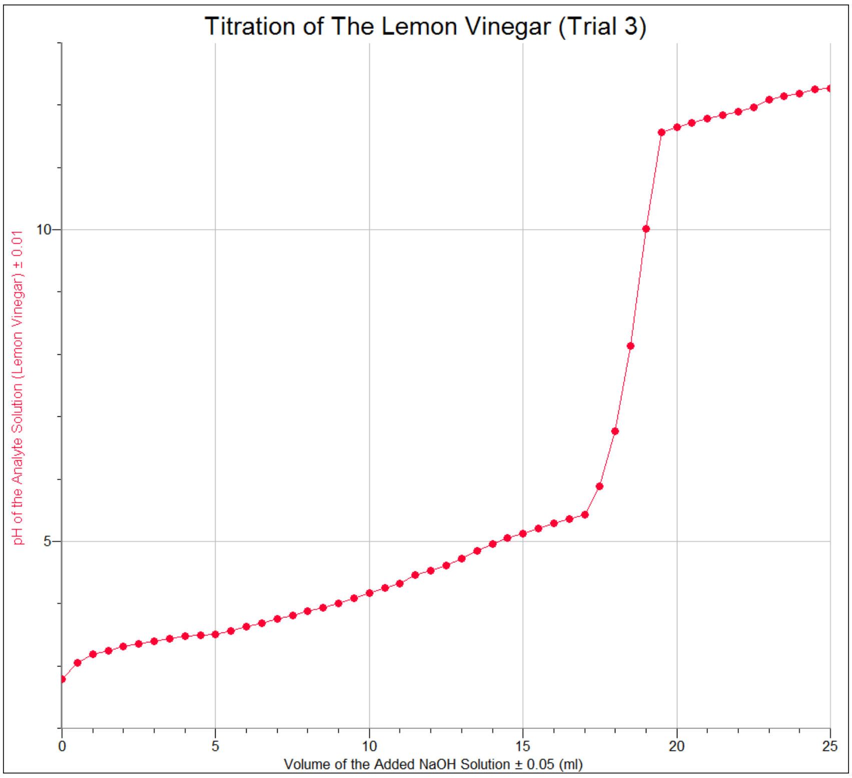
- Lemon Vinegar



Graph A1: pH of the Analyte Solution Versus Volume of the Added NaOH Solution for the Titration of The Lemon Vinegar (Trial 1)

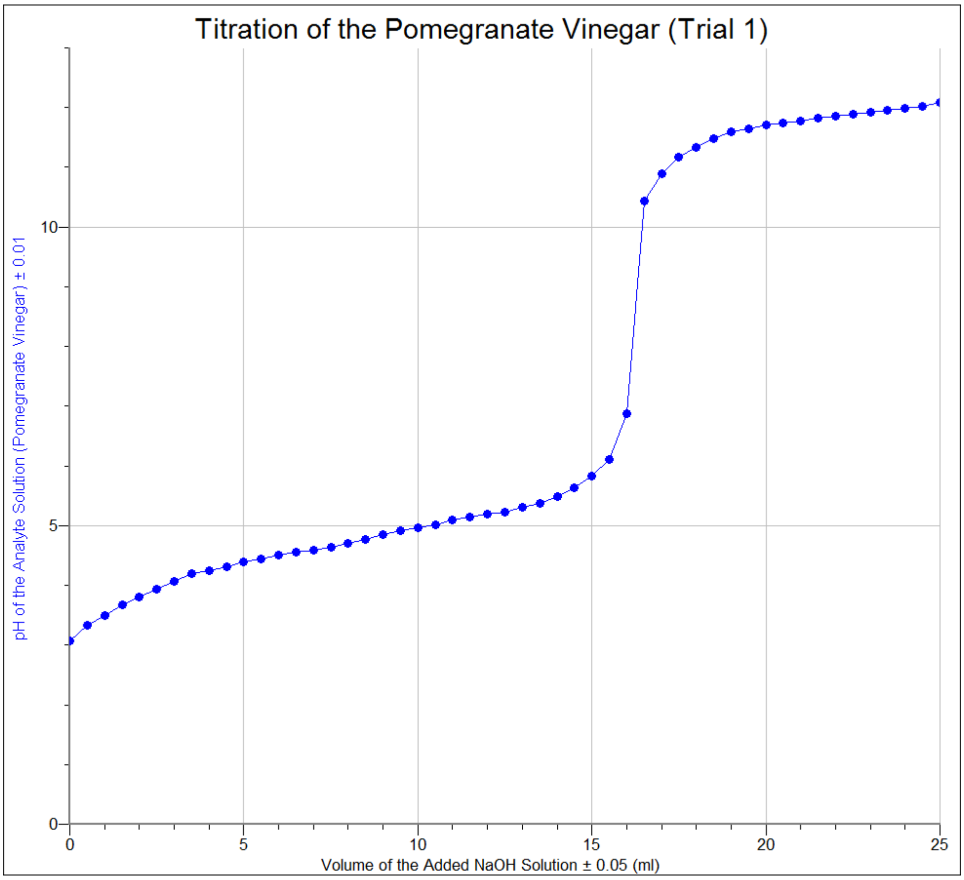


Graph A2: pH of the Analyte Solution Versus Volume of the Added NaOH Solution for the Titration of The Lemon Vinegar (Trial 2)

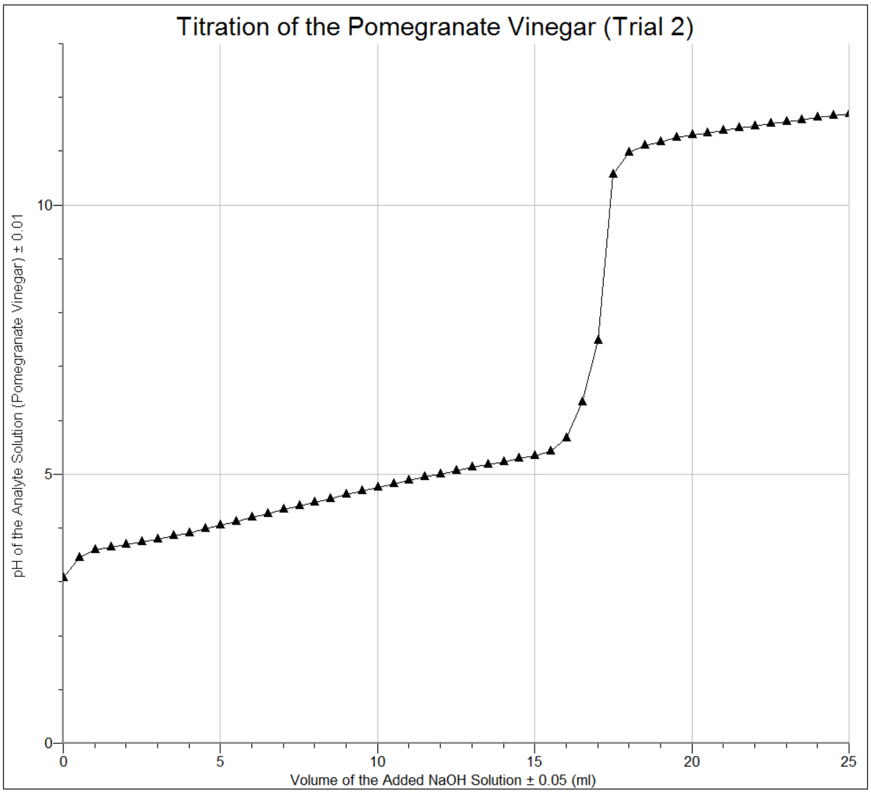


Graph A3: pH of the Analyte Solution Versus Volume of the Added NaOH Solution for the Titration of The Lemon Vinegar (Trial 3)

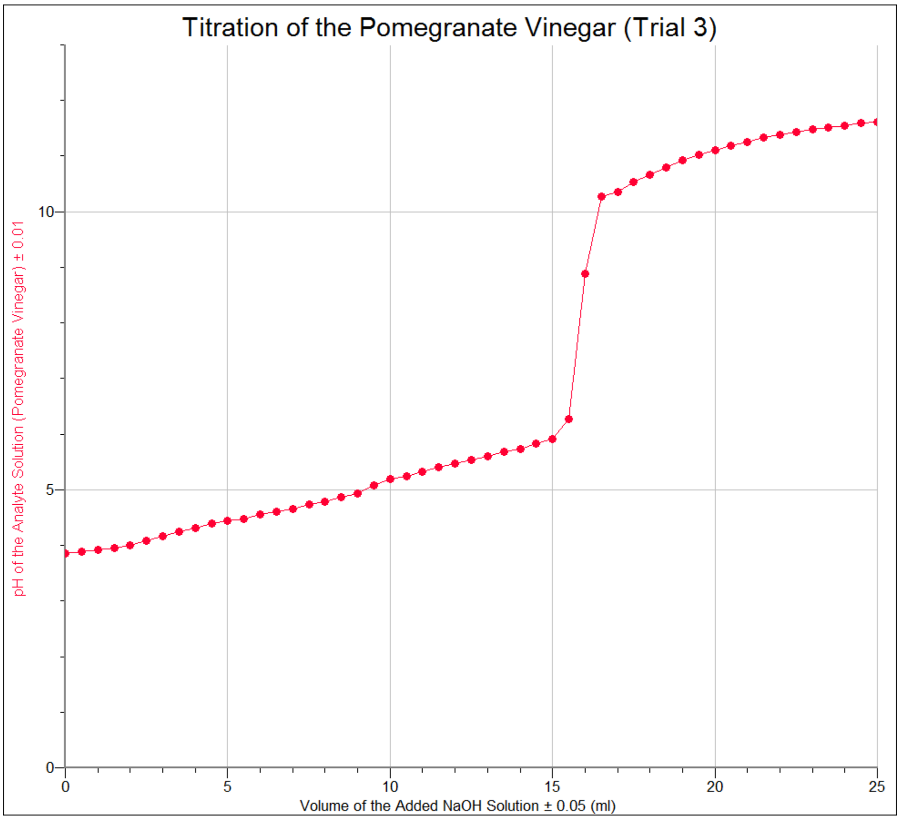
- Pomegranate Vinegar



Graph A4: pH of the Analyte Solution Versus Volume of the Added NaOH Solution for the Titration of The Pomegranate Vinegar (Trial 1)

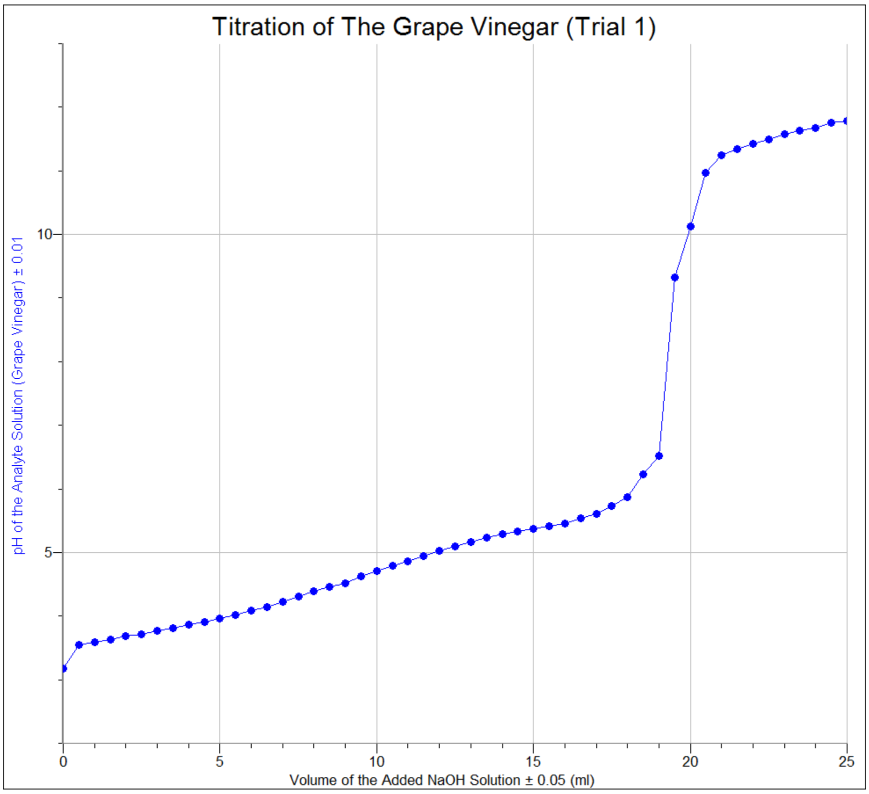


Graph A5: pH of the Analyte Solution Versus Volume of the Added NaOH Solution for the Titration of The Pomegranate Vinegar (Trial 2)

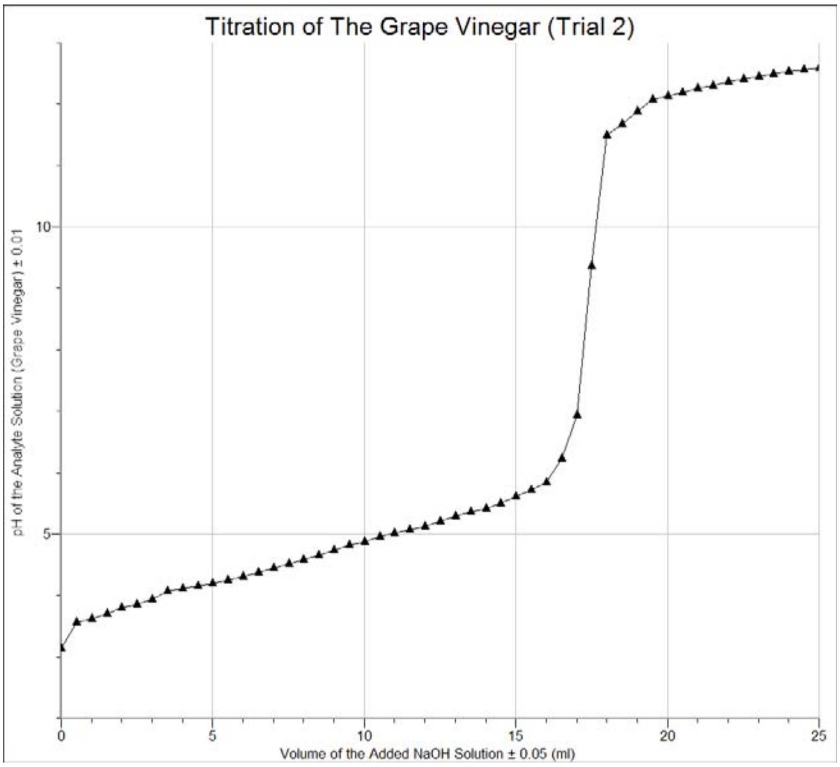


Graph A6: pH of the Analyte Solution Versus Volume of the Added NaOH Solution for the Titration of The Pomegranate Vinegar (Trial 3)

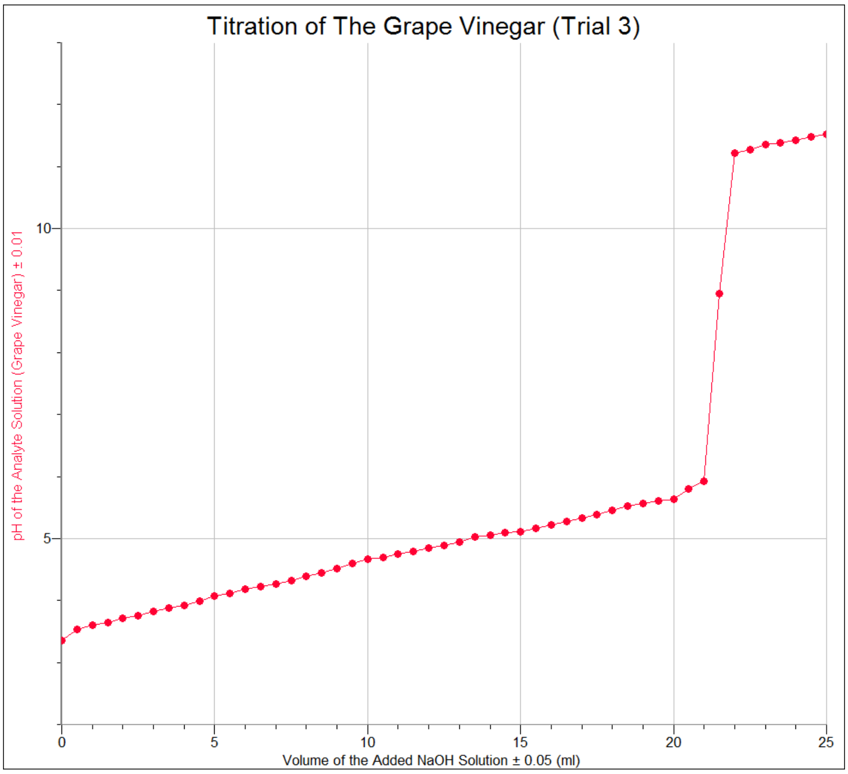
- Grape Vinegar



Graph A7: pH of the Analyte Solution Versus Volume of the Added NaOH Solution for the Titration of The Grape Vinegar (Trial 1)



Graph A8: pH of the Analyte Solution Versus Volume of the Added NaOH Solution for the Titration of The Grape Vinegar (Trial 2)



Graph A9: pH of the Analyte Solution Versus Volume of the Added NaOH Solution for the Titration of The Grape Vinegar (Trial 3)

Calculations:

$$V_{NaOH} \times M_{NaOH} = n_{NaOH}$$

$$n_{NaOH} = n_{CH_3COOH}$$

$$n_{CH_3COOH} \times m_{W(CH_3COOH)} = Amount\ in\ 30\ ml$$

$$Amount\ in\ 30\ ml \times \frac{100}{30} = Amount\ in\ 100\ mL$$

V_{NaOH}: Volume of used Sodium Hydroxide Solution in liters. These values are found from the mid points of the “S-curves” of the corresponding graphs plotted for each trial.

M_{NaOH}: Concentration of Sodium Hydroxide Solution in $molL^{-1}$

n_{NaOH}: Mole Number of used NaOH Solution

$n_{CH3COOH}$: Mole Number of Acetic Acid in 30 ml of Vinegar

$m_{W\ (CH3COOH)}$: Molar Mass of Acetic Acid in grams

Amount in 30 ml: Amount of Acetic Acid in 30 ml of Vinegar in grams

Amount in 100 ml: Amount of Acetic Acid in 100 ml of Vinegar in grams

- Lemon Vinegar:

<u>Trial 1:</u>

$$V_{NaOH} \times M_{NaOH} = n_{NaOH}$$

$$0.01743 \pm 0.29\% L \times 1.00 \pm 1\% molL^{-1} = 0.01743 \pm 1.29\% mol$$

$$n_{NaOH} = n_{CH_3COOH}$$

$$n_{CH_3COOH} \times m_{W\,(CH_3COOH)} = Amount\ in\ 30\ ml$$

$$0.01743 \pm 1.29\% mol \times 60.05\ g\ mol^{-1} = 1.041 \pm 1.29\% g$$

$$Amount\ in\ 30\ ml \times \frac{100}{30} = Amount\ in\ 100\ mL$$

$$1.041 \pm 1.29\% g \times \frac{100}{30} = 3.470 \pm 1.29\% g$$

<u>Trial 2:</u>

$$V_{NaOH} \times M_{NaOH} = n_{NaOH}$$

$$0.01926 \pm 0.26\% L \times 1.00 \pm 1\% molL^{-1} = 0.01926 \pm 1.26\% mol$$

$$n_{NaOH} = n_{CH_3COOH}$$

$$n_{CH_3COOH} \times m_{W\,(CH_3COOH)} = Amount\ in\ 30\ ml$$

$$0.01926 \pm 1.26\% mol \times 60.05\ g\ mol^{-1} = 1.157 \pm 1.26\% g$$

$$Amount\ in\ 30\ ml \times \frac{100}{30} = Amount\ in\ 100\ mL$$

$$1.157 \pm 1.26\% g \times \frac{100}{30} = 3.857 \pm 1.26\%$$

Trial 3:

$$V_{NaOH} \times M_{NaOH} = n_{NaOH}$$

$$0.01858 \pm 0.27\% \ L \times 1.00 \pm 1\% \, molL^{-1} = 0.01858 \pm 1.27\% \ mol$$

$$n_{NaOH} = n_{CH_3COOH}$$

$$n_{CH_3COOH} \times m_{W\,(CH_3COOH)} = Amount\ in\ 30\ ml$$

$$0.01858 \pm 1.27\% \ mol \times 60.05 \ g\,mol^{-1} = 1.116 \pm 1.27\% \, g$$

$$Amount\ in\ 30\ ml \times \frac{100}{30} = Amount\ in\ 100\ mL$$

$$1.116 \pm 1.27\% \, g \times \frac{100}{30} = 3.720 \pm 1.27\% \, g$$

- Pomegranate Vinegar:

Trial 1:

$$V_{NaOH} \times M_{NaOH} = n_{NaOH}$$

$$0.01620 \pm 0.31\% \ L \times 1.00 \pm 1\% \, molL^{-1} = 0.01620 \pm 1.31\% \ mol$$

$$n_{NaOH} = n_{CH_3COOH}$$

$$n_{CH_3COOH} \times m_{W\,(CH_3COOH)} = Amount\ in\ 30\ ml$$

$$0.01620 \pm 1.31\% \ mol \times 60.05 \ g\,mol^{-1} = 0.973 \pm 1.31\% \, g$$

$$Amount\ in\ 30\ ml \times \frac{100}{30} = Amount\ in\ 100\ mL$$

$$0.973 \pm 1.31\% \, g \times \frac{100}{30} = 3.243 \pm 1.31\% \, g$$

<u>Trial 2:</u>

$$V_{NaOH} \times M_{NaOH} = n_{NaOH}$$

$$0.01710 \pm 0.29\%\ L \times 1.00 \pm 1\%\ molL^{-1} = 0.01710 \pm 1.29\%\ mol$$

$$n_{NaOH} = n_{CH_3COOH}$$

$$n_{CH_3COOH} \times m_{W\,(CH_3COOH)} = Amount\ in\ 30\ ml$$

$$0.01710 \pm 1.29\%\ mol \times 60.05\ g\ mol^{-1} = 1.027 \pm 1.29\%\ g$$

$$Amount\ in\ 30\ ml \times \frac{100}{30} = Amount\ in\ 100\ mL$$

$$1.027 \pm 1.29\%\ g \times \frac{100}{30} = \mathbf{3.423 \pm 1.29\%\ g}$$

<u>Trial 3:</u>

$$V_{NaOH} \times M_{NaOH} = n_{NaOH}$$

$$0.01588 \pm 0.31\%\ L \times 1.00 \pm 1\%\ molL^{-1} = 0.01588 \pm 1.31\%\ mol$$

$$n_{NaOH} = n_{CH_3COOH}$$

$$n_{CH_3COOH} \times m_{W\,(CH_3COOH)} = Amount\ in\ 30\ ml$$

$$0.01588 \pm 1.31\%\ mol \times 60.05\ g\ mol^{-1} = 0.954 \pm 1.31\%\ g$$

$$Amount\ in\ 30\ ml \times \frac{100}{30} = Amount\ in\ 100\ mL$$

$$0.954 \pm 1.31\%\ g \times \frac{100}{30} = \mathbf{3.180 \pm 1.31\%\ g}$$

- Grape Vinegar:

<u>Trial 1:</u>

$$V_{NaOH} \times M_{NaOH} = n_{NaOH}$$

$$0.01937 \pm 0.26\%\ L \times 1.00 \pm 1\%\ molL^{-1} = 0.01937 \pm 1.26\%\ mol$$

$$n_{NaOH} = n_{CH_3COOH}$$

$$n_{CH_3COOH} \times m_{W\,(CH_3COOH)} = Amount\ in\ 30\ ml$$

$$0.01937 \pm 1.26\%\ mol \times 60.05\ g\,mol^{-1} = 1.163 \pm 1.26\%\ g$$

$$Amount\ in\ 30\ ml \times \frac{100}{30} = Amount\ in\ 100\ mL$$

$$1.163 \pm 1.26\%\ g \times \frac{100}{30} = 3.877 \pm 1.26\%\ g$$

<u>Trial 2:</u>

$$V_{NaOH} \times M_{NaOH} = n_{NaOH}$$

$$0.01736 \pm 0.29\%\ L \times 1.00 \pm 1\%\ molL^{-1} = 0.01736 \pm 1.29\%\ mol$$

$$n_{NaOH} = n_{CH_3COOH}$$

$$n_{CH_3COOH} \times m_{W\,(CH_3COOH)} = Amount\ in\ 30\ ml$$

$$0.01736 \pm 1.29\%\ mol \times 60.05\ g\,mol^{-1} = 1.042 \pm 1.29\%\ g$$

$$Amount\ in\ 30\ ml \times \frac{100}{30} = Amount\ in\ 100\ mL$$

$$1.042 \pm 1.29\%\ g \times \frac{100}{30} = 3.473 \pm 1.29\%\ g$$

<u>Trial 3:</u>

$$V_{NaOH} \times M_{NaOH} = n_{NaOH}$$

$$0.02144 \pm 0.23\% \; L \times 1.00 \pm 1\% \; molL^{-1} = 0.02144 \pm 1.23\% \; mol$$

$$n_{NaOH} = n_{CH_3COOH}$$

$$n_{CH_3COOH} \times m_{W\,(CH_3COOH)} = Amount\ in\ 30\ ml$$

$$0.02144 \pm 1.23\% \; mol \times 60.05 \; g\,mol^{-1} = 1.287 \pm 1.23\% \, g$$

$$Amount\ in\ 30\ ml \times \frac{100}{30} = Amount\ in\ 100\ mL$$

$$1.287 \pm 1.23\% \, g \times \frac{100}{30} = 4.290 \pm 1.23\% \, g$$

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