Preparation and Evaluation of Carbon Synthesized by Chemical Activation of Mango Seeds

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Abstract

This project aims to reduce mango waste and clean polluted water by using carbon adsorbents derived from mango seeds. Mango seeds were carbonized through chemical activation. First, mango seeds were mixed with phosphoric acid and heated to approximately 100°C. The temperature was later raised to 500°C in nitrogen. The resulting carbon was washed and dried. Methylene blue (MB) was used to represent a water pollutant. Concentrations of methylene blue in the water were monitored by a custom-made photometer. The photometer consists of an Arduino UNO microcontroller board, a colored LED, a light sensor, and an LCD display. The Arduino UNO was programmed through Arduino Web Editor - Arduino Create. Different concentrations of methylene blue were measured before test and after the test. The amount of methylene blue after the experiment was subtracted from the amount of methylene blue before the experiment, which results in the amount of methylene blue removed in total within the experiment. The total amount of methylene blue removed was divided by the initial amount of MB and multiplied by 100 to obtain the percent removal. The adsorption and the percent removal both show the effectiveness of carbonized mango seeds to clean water. The adsorption results from carbon prepared via chemical activation were compared with the carbon by thermal activation. It is apparent that the former has better adsorption capacity.

Keywords
mango seeds, carbon, chemical activation, adsorption, water, methylene blue, Arduino, photometer, luminosity

1. Introduction

Mangoes, one of the most important tropical fruits, are consumed by many people around the world. Global quantitative food losses and waste per year are roughly 40-50% for fruit.[1] Since mangoes are abundant in a multitude of countries and cannot be harvested in time or processed quickly enough, a large amount of waste, specifically the seed and peel, is produced and difficult to dispose of.[2]

Many areas do not have clean water and face economic issues. Deterioration of water quality can be due to human activities.[3] It would be helpful to remove pollutants from water using materials derived from mango seeds. This approach has a two-fold purpose. It reduces mango waste and clean water with natural resources. Many experiments conducted by scientists have involved the removal of methylene blue from water with materials different from natural products such as coconut shell, bamboo dust, and more.[4] Equilibrium adsorption, thermodynamic and kinetic study results were compiled and proved that these types of materials derived from a renewable resource can be used as adsorbents to remove methylene blue.

2. Materials and Methods

2.1 Photometer
A photometer was built for this project. The photometer consists of the Arduino Uno, a LED, a light sensor, and a LCD display. The Arduino Uno was used to control the LED, read data from the light sensor, and display data on the LCD. The Arduino Uno was programmed using the Arduino Web Editor - Arduino Create. The enclosure of the photometer was designed on an open source software, FreeCAD, and fabricated using a 3D printer. The photometer was programmed to sense the amount of light flowing through a sample of water and show the luminosity value on the LCD display. The luminosity values are used to calculate the amount of absorption in each solution. The

absorbance of standard solutions 2.60, 5.20, 10.5, 15.0, 20.0, 26.2mg/L was used to generate a calibration curve with the following equation:

$$y = 0.145x - 1.252$$

where y represents absorbance (the amount of red light that came through the vial) and x represents the concentration (mg/L).

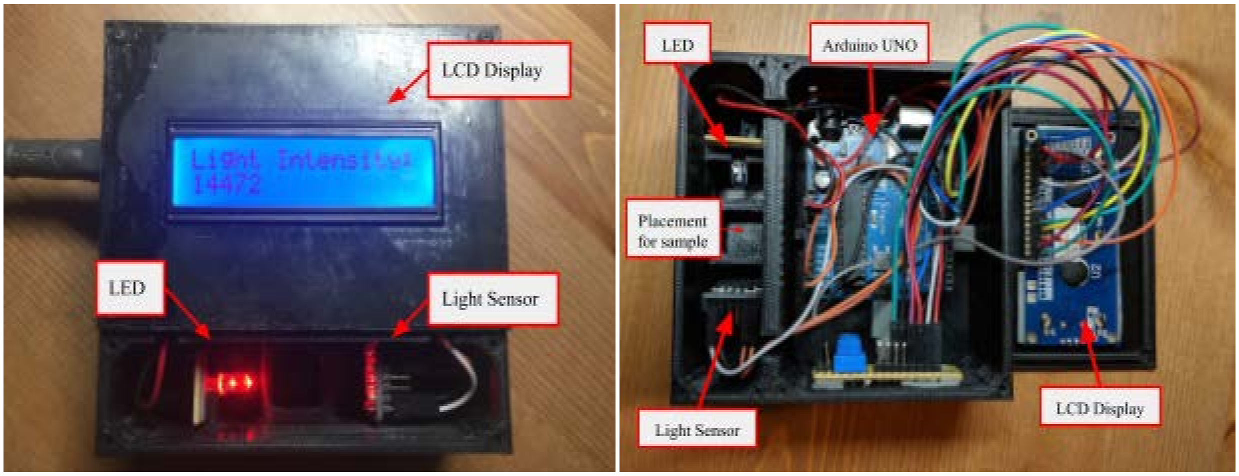

Figure 1. Photos of the photometer set up

2.2 Carbonization of Mango Seeds

The process of chemical activation was used to obtain carbonized mango seeds. Mango seeds were dried for three weeks, and then grinded. 81.7g of mango seeds were mixed with 144.2g 85% phosphoric acid, which actually contains 122.57g of phosphoric acid. The mango seeds were dried in an oven at 102°C for twenty four hours, then placed into a tube furnace at 500°C for two hours. The product was cooled and washed with DI water to remove acid residue, followed by drying carbon at 110°C.

2.3 Adsorption Equilibrium

Four beakers filled with 50 mL of 2.6, 5.2, 10.5 and 26.2mg/L blue solutions each contained 0.20g of carbon in it. The beakers were placed onto the stirrer, where it was stirred with a Teflon-coated magnetic bar for forty eight hours. The mixing helps the molecules of the methylene blue diffuse from high concentrated to low concentrated area, allowing the molecules to approach the pores of the carbon adsorbents and adsorb inside to the active site. After mixing, the 10 mL samples were put into a centrifuge to separate the carbon and methylene blue solution. The solutions later were transferred into vials. Each vial was placed into the absorption measurement setup and the photometer measured the light luminosity, which shows how much red light from the LED passes through the solution. The equilibrium concentration for each solution was calculated from the absorbance using the Calibration Curve equation. The equilibrium amount of methylene blue adsorbed per unit mass of carbon (Qe) values was calculated with the following equation:

$$Q_e = \frac{C_0 - C_e}{m} \times V$$

where C_0 (mg/L) represents the concentration before the adsorption, while C_e (mg/L) represents the concentration after adsorption, m (g) represents mass of carbon, and V (L) represents the volume of methylene blue solution.

2.4 Amount of Adsorbent

This experiment follows exact procedures as described in section 2.3. The six beakers each contained 50mL of methylene blue solution with a concentration of 10.5 mg/L with different amounts of the carbon adsorbent in each:

0.05, 0.10, 0.15, 0.20, 0.30 and 0.40g. The percent removal of the methylene blue was calculated using the equation below:

$$\% \, removal = \frac{C_0 - C_e}{C_0} \times 100$$

3. Results and Discussions

3.1 Development of Photometer

Arduino is an open-source platform used for building electronics projects. It consists of a physical circuit board and an integrated development environment (IDE) that is used to write and upload computer code to the circuit board. Because Arduino is low-cost and easy to learn, it is very popular with people just starting out with electronics and in need to quickly develop a prototype. The UNO is the most used and documented board of the whole Arduino family. It is the best board to get started with on electronics and coding. To program the software, some of Arduino's built-in Adafruit sensor and digital luminosity sensor libraries were used and more code was added. Orange colored Light Emitting Diodes made by Chanzon with a VF of 2.0-2.5V were purchased from Amazon. The LCD display was a Standard LCD 16x2 (White on Blue) ID:181. The light range sensor was an Adafruit TXL2591 High Dynamic Range Light Sensor ID:1980.

3.2 Process of Carbonization

In chemical activation, the most frequent proportion of phosphoric acid/precursor is a 1.5 ratio.[5] In this experiment, the ratio used was calculated by finding how much phosphoric acid was present in a 144.2g solution of 85% phosphoric acid, which was 122.57g. The amount of phosphoric acid present in the solution was divided by the amount of raw material used, which was 81.7g of mango seeds. The calculation resulted in a precise 1.50 ratio of phosphoric acid/precursor. If the ratio was too low, then that would mean there is not enough chemicals to have the experiment to work, but if the ratio was too high, then chemicals could have been wasted. During activation, holes or pores are formed on each activated carbon particle. The active sites allow methylene blue to be adsorbed into it whereas water would pass through. The holes increase the surface area of the carbon, allowing the carbon to adsorb more methylene blue. If each carbon adsorbent has its active sites occupied, it can no longer absorb more methylene blue.[6]

3.3 Calibration Curve

The solutions that were used to create the calibration curve are shown in Table 1. The calibration curve was later used to determine the concentration of methylene blue after the carbon adsorbents were mixed in. As seen in both Table 1 and Figure 2, the concentration of the methylene blue and its absorbance are directly related: the higher the concentration, greater the absorbance value as less red light passes through darker, more concentrated solutions. The linear relationship between absorbance and concentration proves the Beer Lambert's law. As seen in the linear regression model, the calibration curve has a high R^2 value of 0.998, which is relatively accurate, as a really accurate graph has an R^2 value of 1. Since 20.0 and 26.2 mg/L were outliers, they were not used in the creation of the calibration curve.

Table 1. Calibration Curve

Solutions	1	2	3	4	5	6
Concentrations (mg/L)	2.60	5.20	10.5	15.0	20.0	26.2
Absorbance	0.145	0.495	1.22	1.95	2.05	2.06

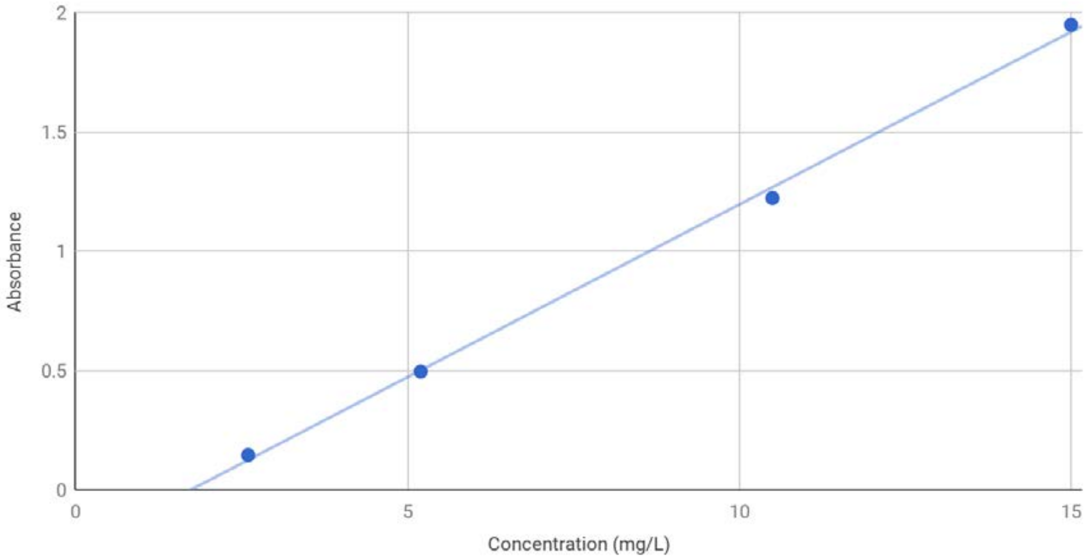

Figure 2. Calibration curve displaying the relationship between absorbance and concentration

Since the chemically activated carbon was extremely effective, solutions with higher concentrations were created: 100.0, 90.0, and 78.7 mg/L. The lower concentrations of methylene blue after carbon were almost clear; therefore, we had to increase the concentrations to get readings.

3.4 Adsorption Equilibrium

Before and after the carbon adsorbents were mixed in, the finishing solution is always lighter because the carbon was able to adsorb the methylene blue. After adding a constant amount of carbon adsorbent, a solution with a higher concentration would result in a darker color than one with a lower concentration. The initial absorbance values seen in Table 2 are higher than the final absorbance values after the carbon adsorbents were added, due to more orange light entering through the solution. The concentrations of the solution after the carbon adsorbents were added were close to methylene blue's concentration of 0, showing the effectiveness of the adsorbents. Figure 3 graphs the relationship between the C_e and Q_e values by a regression. This shows that the activated carbon can still continue to absorb more methylene blue because it has not reached equilibrium (its saturation point) yet. Since the values were almost equal to the blank sample of water after the experiment, the experiment was performed a second time with higher concentrations of methylene blue: 100.0, 90.0, 78.7 mg/L.

Table 2. Lower Concentrations of Methylene Blue

Solution Number	1	2	3
Initial Concentration (mg/L)	5.2	10.5	26.2
Initial Absorbance	0.495	1.22	2.06
Initial Light Luminosity	5876	1053	156
Final Absorbance	0.00760	0.00813	0.0107

Table 3. Higher Concentrations of Methylene Blue

Solution Number	1	2	3
Initial Concentration (mg/L)	100.0	90.0	78.7
Initial Light Luminosity	108	108	108
Initial Absorbance	2.233	2.232	2.228
Light Luminosity	16401	16407	16442
Absorbance	0.019017	0.018852	0.017933

Table 4. C_e and Q_e values

Solution Number	1	2	3	4	5	6
C_0 (mg/L)	100.0	90.0	78.7	26.2	10.5	5.20
C_e (mg/L)	1.8691	1.8679	1.8616	1.8116	1.7940	1.7904
Q_e (mg/g)	24.53	22.03	19.21	6.09	2.17	0.85

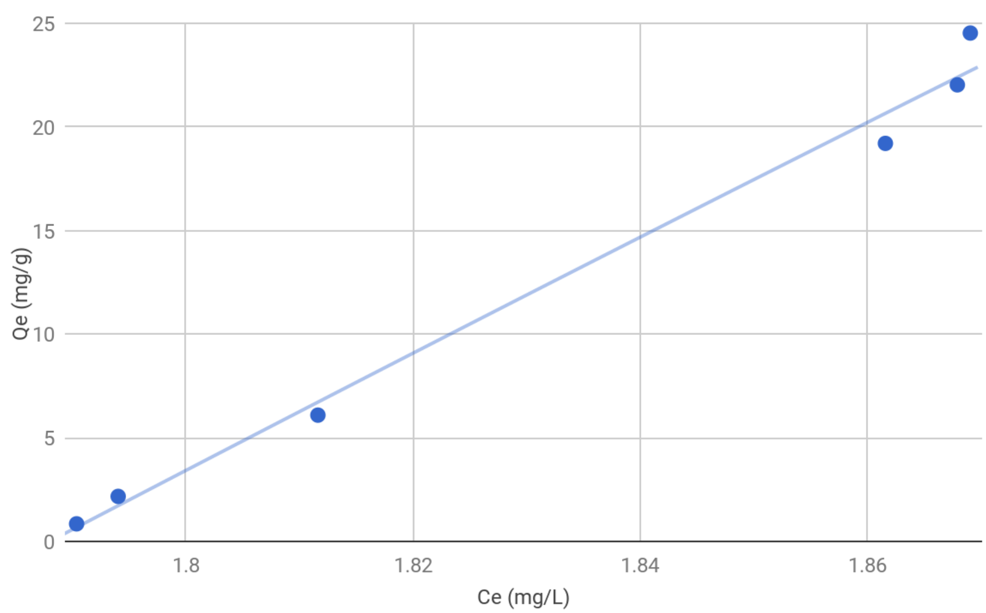

Figure 3. Relationship between Final Concentration and Methylene Blue Adsorbed Per Gram of Carbon

3.5 Effect of Amount of Adsorbent

A trendline relating the amount of carbon adsorbent and the absorbance, as well as Table 5 were used to show the absorbance values descending as more carbon were mixed in. With a larger amount of carbon, more methylene blue is able to be adsorbed, shown by a greater light luminosity and smaller absorbance value. This results in a clearer solution that is similar to water. When the concentration was too high, the solution was diluted to fall in the range of the calibration curve.

Table 3 displays the light luminosity values and the absorbance values for 78.7 mg/L of methylene blue solution with different amounts of carbon. As more carbon is placed into the solutions, the light luminosity values increase and the absorbance values decrease. The values from Table 5 were used to form Figure 3, an exponential trend line. Although the outlier does not follow the linear relationship, the line shows that the solutions become clearer as greater amounts of carbon are placed.

As shown in Table 6, the percent removal values increase as the amount of carbon increase. The carbon removes more methylene blue. The percent removal values gathered in Table 6 are used to create a trendline showing the relationship between the amount of carbon adsorbents and their percent removals shown in Figure 4. The graph begins to show a rise in the percent removal as carbon is added. As the amount of carbon increases, the surface area increases and the carbon adsorbents are able to adsorb more molecules of methylene blue. However, when approximately 0.04 grams of carbon adsorbent is added, the percent removal values begins to plateau. The amount of methylene blue the carbon is able to adsorb increases as more adsorbent is added, but the concentration of methylene blue continues to stay constant. When amounts of carbon greater than 0.04 grams are added, they are able to adsorb all the methylene blue, but still have enough capacity to adsorb more.

Table 5. Amount of Adsorbent

Solution Number	1	2	3	4
Amount of Carbon (g)	0.025	0.030	0.040	0.050
Light Luminosity	159.4	5405	16683	18870.6
Absorbance	1.485	0.5035	0.03644	-0.03939

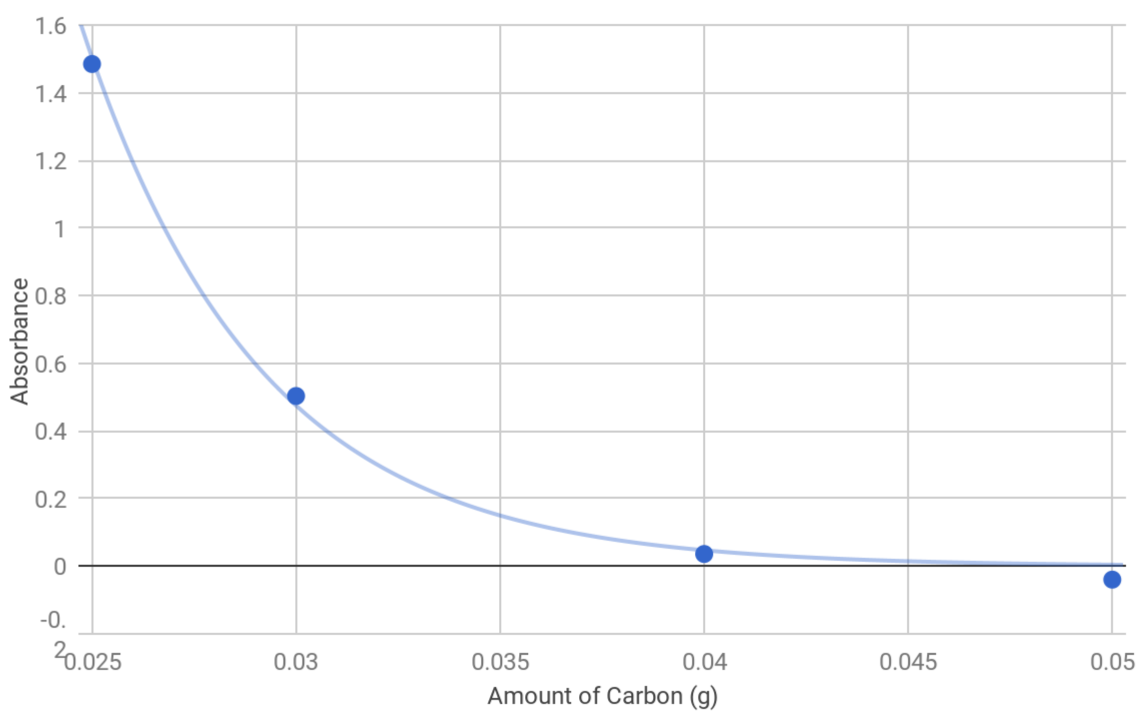

Figure 3. Absorbance in Relation to the Amount of Carbon

Table 6. Percent Removal of Methylene Blue

Solution	1	2	3	4
Concentration After Carbon (mg/L)	11.98	5.211	1.989	1.466
Percent Removal (%)	84.78	93.38	97.47	98.14

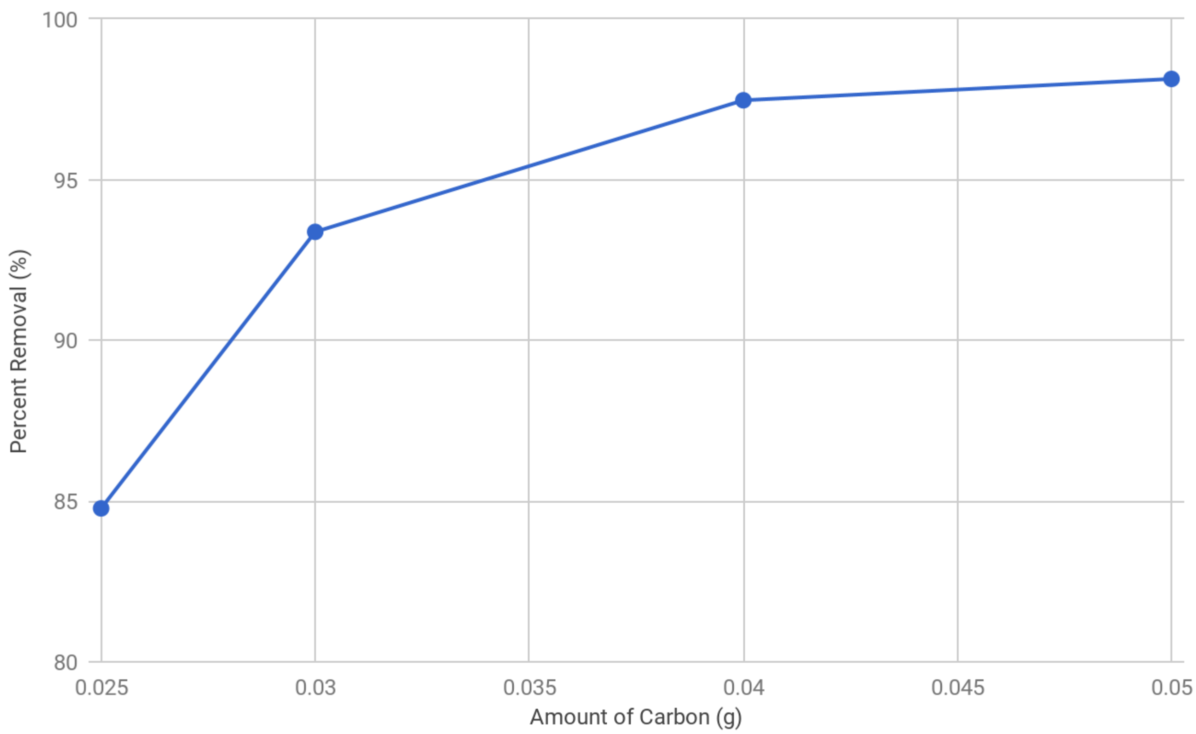

Figure 4. Trendline for relationship between percent removal and amount of carbon added

4. Conclusion

The chemical activation was used to carbonize the mango seeds. The mango seeds were mixed with phosphoric acid then underwent heat treatment to produce the porous structure.

Two experiments were conducted to test the efficiency of the chemically activated carbon adsorbent. In the Adsorption Equilibrium experiment, the concentration of methylene blue in each solution increased whereas the amount of carbon adsorbent stayed constant. All the tested solutions were not concentrated enough, allowing the carbon adsorbent to adsorb almost all of the methylene blue. Hence, the experiment was conducted again but with much higher concentrations. The amount of methylene blue each unit mass of carbon could adsorb was calculated and graphed. The graph compared the amount of methylene blue adsorbed per unit of carbon and the concentration after adsorption. It showed that as the concentration of methylene blue increased, the amount of methylene blue adsorbed still increased, meaning that the adsorbents still had the capacity to adsorb even more methylene blue. While solutions with lower concentrations of methylene blue result in a clear color similar to water, those with an extremely high concentration should not because the carbon adsorbents can only adsorb a certain amount before it can no longer furthermore adsorb.

In the Amount of Adsorbent experiment, the amount of carbon adsorbent added to the solution was changed, and the concentration of methylene blue stayed constant. The amount of carbon added per solution and the resulting solutions' absorbance values were graphed. The more carbon added resulted in a lower absorbance value. Since it got clearer and less orange light was able to be absorbed by the solution, the absorbance values decreased and the light luminosity values increased. The percentage of methylene blue removed with each increasing amount of carbon was calculated and graphed. It showed that as greater amounts of carbon were added, the percentage of methylene blue was removed within the 78.7 mg/L methylene blue solution was getting closer to almost 100%. Approximately 0.04 grams are required to remove a majority of the methylene blue in the 78.7 mg/L solution.

Acknowledgements

We would like to thank our families for supporting us throughout the entire experiment. We would especially like to thank Dr. Ru Chen at UltraCell LLC for his support throughout and allowing us access to UltraCell's lab.

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Biography

Alicia H. Chen is a junior at Dublin High School. She holds a large interest in the STEM field and wishes to enter either the medical or technology field. She is a founding member and co-Webmaster of the IEOM Society Bay Area Student Chapter and is a board member of her school's Interact club. She is also an Engineering Academy student at her school. She enjoys doing volunteer work in her community some of which include volunteering at a local hospital and volunteering for the city for summer camps. On her free time, she enjoys listening to music, dancing, reading, drawing, and socializing.

Emily L. Chen is a sophomore at Dublin High School. She desires to pursue a career in public health. She became an IBM Certified Specialist of SPSS Statistics level one in January 2017. She is a founding member and currently holds a position as co-Webmaster of the IEOM Society Bay Area Student Chapter. She is involved in her school's Interact club, and holds a position as a board member. She is currently working part time as a lifeguard. On her free time, she loves to swim and play her violin. She also enjoys cooking, traveling the world, and sightseeing.