TEAM PROJECT REPORT

Availability of Safe Drinking Water: A Research Experience and Classroom Implementation Plan

Submitted To

The RET Site

For

**"Sustainable Engineering for Urban Needs:
Research Experiences for Middle and High School Teachers"**

Sponsored By

The National Science Foundation

Grant ID No.: EEC-0808696

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Reporting Period: June 20 – July 29, 2011

Abstract

It is a well-known fact that humans cannot survive very long without water. But how is it possible to determine that the water is clean and safe to drink? Contaminants come from a variety of seemingly innocuous sources to pollute and contaminate available drinking water. There exists an overwhelming need to address or even eliminate these rising contaminant levels. Water treatment facilities strive to determine the best ways to remove contaminants from drinking water and to study the ways that contaminant adsorption may be affected. The main objective of this research was to examine the impact of nanoparticles (NPs) in an aquatic environment on the removal of trichloroethylene (TCE) by granular activated carbon (GAC) in the presence of humic acid. In order to complete these studies, three experimental models, adsorption isotherm, adsorption kinetics, and column breakthrough studies, were used. In the isotherm studies, NPs were found to be in competition with TCE at high concentrations for adsorption by the GAC. In the kinetic studies, no difference was found in the presence and absence of NPs. Finally, from the column breakthrough studies, it was found that the rapid small column test could be used to model the large scale column to reduce time and money. By studying the impact of nanoparticles on the adsorption of TCE by GAC in a laboratory created model of a traditional water environment, it is possible to better predict the duration that GAC will retain its adsorption properties in a large scale bed such as those found in water treatment facilities.

Goal and Objectives

The goal of the project was for teachers to have an authentic research experience in environmental engineering pertaining to water quality in order influence their classroom teaching. The research objective was to study the impact of the presence of nanoparticle (NP), in the water environment, on the removal of the trichloroethylene (TCE) by granular activated carbon (GAC) in the presence of humic acid. In order to complete the study, the most appropriate method to complete the research had to be determined. The classroom objective was to create a classroom implementation plan to embed the research experience into the classroom environment.

Research Tasks

The research involves the quantification of TCE and humic acid in the water environment. TCE was detected using gas chromatography and humic acid was detected using UV/Vis spectroscopy. Before using these instruments, they had to be calibrated for these specific substances. After calibration was completed, the most appropriate method for studying the impact of the silica NP on the removal of the TCE by GAC in the presence of humic acid was determined. Three known methods for studying charcoal adsorption were used, which included adsorption isotherms, adsorption kinetics, and breakthrough studies utilizing rapid small column tests (RSCT). Through the use of these methods with and without the presence of the NPs, the results were analyzed to determine the effects of NPs in the water environment on the adsorption of TCE by GAC.

Methodology Used

TCE Calibration of GC: The calibration of the GC for TCE was completed by a serial dilution of TCE 20.0 mg/L stock solution. First, the 20.0 mg/L TCE solution was prepared with 200.0 µL of the 25.0 g/L TCE stock solution diluted to 250 mL with buffered water. Then a serial dilution was performed from this stock solution to prepare nine samples. The internal standard used for this calibration was PCE, and the total volume of each of the solutions was 50 mL by diluting with buffered water. **Table 1** provides the specifications for each of the nine solutions. Once prepared, the samples were transferred into 43 mL vials. These vials were placed in the auto sampler and set to run through the purge and trap and then finally the GC as described in the Materials section.

Table 1. Solution Preparation for TCE Calibration of GC

[TCE] µg/L	Volume (µL) of 20.0 mg/L TCE	Volume (µL) of 60.0 mg/L PCE
400	1000.0	24.0
300	750.0	24.0
200	500.0	24.0
150	375.0	24.0
100	250.0	24.0
50	125.0	24.0
30	75.0	24.0
15	37.5.0	24.0
5	12.5	24.0

Humic Acid Calibration of UV/Vis: The calibration of the UV/Vis for humic acid was completed by a serial dilution of the humic acid stock solution. A serial dilution was performed from this stock solution to prepare six samples as shown in **Table 2**. Once prepared, the samples were taken to the UV/Vis. The UV/Vis was set to 254 nm and zeroed with nanopure water. The first sample was transferred into the cuvette. The cuvette was placed in the UV/Vis and the absorbance was recorded. Then the remaining five samples were run in the same manner.

Table 2: Humic Acid Concentration for Calibration

Sample #	[Humic Acid] (mg/l)
1	10
2	7.5
3	5
4	2.5
5	1
6	0.5

Adsorption Isotherms: The adsorption isotherm experiments were used to determine the effects of nanoparticles on TCE adsorption by activated carbon under equilibrium conditions. In order to carry out this type of experiment, the bottle point technique was used. In the first experiment, no TiO_2 NPs were added and in the second experiment it was run in the presence of the TiO_2 NPs. In each of the experiments, three different initial concentrations of TCE were tested: 450 μg/L, 900 μg/L, and 1800 μg/L. Each of the samples was prepared by diluting the 25.0 g/L stock solution of TCE in 4.0 L using the following amounts, respectively: 72 μL, 144 μL, and 288 μL. Humic acid was also added to prepare 5.0 mg/L humic acid from the 10.0 g/L stock solution. At this point 50.0 mL of each solution was removed to prepare blanks with only TCE and humic acid. Then, for the second experiment, to each of the remaining 3.50 L solutions, a volume of 3.5 mL of the TiO_2 nanoparticles stock solution of 1.0 g/L was added to prepare 1.0 mg/L solutions of TiO_2. The mass of PAC was varied, including the use of four blanks. The information about each of the bottles is presented in **Error! Reference source not found.3**.

Once the 250 mL bottles were prepared, capped, and covered with Parafilm, they were placed in a bottle rotator for sixteen days (see **Figure 1**).

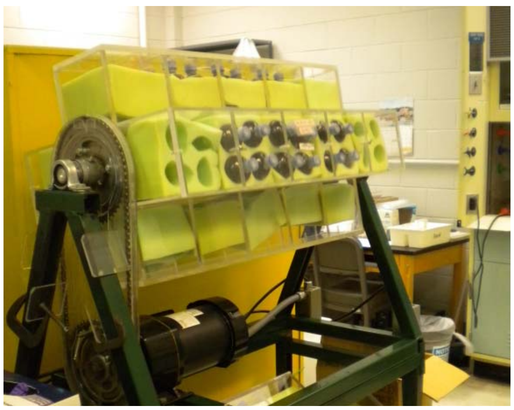

Figure 1. Bottle Rotator During Isotherm Experiment

Figure 2. 4.0L Flask Used for Filling Bottles

Figure 3. Large Column

Figure 4. Column Breakthrough Study Experimental Design

At the end of the sixteen days, the rotator was stopped, and the samples were filtered with a 0.45 micron filter. The samples used to test for TCE on the GC were diluted to according to the dilution factor in **Table 3** in 50 mL amounts, and then 24.0 µL of PCE stock solution was added. Then the solution was placed in 43.0 mL vials. These vials were placed in the auto sampler and set to run through the purge and trap and then finally the GC. The computer connected to the GC was set to record peak areas at retention time 10.3 minutes for the TCE and retention time 11.1 minutes for PCE and to print the results of each vial. The samples used to test for humic acid were taken from the experiment bottles and only filtered with the 0.45 micron filter and placed in vials to be tested on the UV/Vis. The UV/Vis was set to 254 nm.

Table 3: Adsorption Isotherm Set-up

Sample #	[TCE]o (ug/L)	Amount of Carbon (g)	$[TiO_2]$ mg/L	Dilution Factor for GC
450-1	450	0.0019	1.0	2
450-2	450	0.0029	1.0	2
450-3	450	0.0044	1.0	2
450-4	450	0.0059	1.0	1
450-5	450	0.0080	1.0	1
450-6	450	0.0110	1.0	1
450-7	450	0.0156	1.0	1
450-8	450	0.0254	1.0	1
450-9	450	0.0000	1.0	2
450-10	450	0.0000	1.0	2
450-11	450	0.0000	0	2
450-12	450	0.0000	0	2
900-1	900	0.0025	1.0	5
900-2	900	0.0041	1.0	5
900-3	900	0.0059	1.0	5
900-4	900	0.0082	1.0	5
900-5	900	0.0110	1.0	1
900-6	900	0.0151	1.0	1
900-7	900	0.0213	1.0	1
900-8	900	0.0351	1.0	1
900-9	900	0.0000	1.0	5
900-10	900	0.0000	1.0	5
900-11	900	0.0000	0	5
900-12	900	0.0000	0	5
1800-1	1800	0.0035	1.0	10
1800-2	1800	0.0055	1.0	10
1800-3	1800	0.0080	1.0	10
1800-4	1800	0.0112	1.0	5
1800-5	1800	0.0152	1.0	5
1800-6	1800	0.0209	1.0	2
1800-7	1800	0.0293	1.0	2
1800-8	1800	0.0482	1.0	1
1800-9	1800	0.0000	1.0	10
1800-10	1800	0.0000	1.0	10
1800-11	1800	0.0000	0	10

1800-12	1800	0.0000	0	10

Adsorption Kinetics: The purpose of the adsorption kinetics experiment was to study the rate at which the adsorption of TCE by carbon takes place without and with the presence of humic acid and different NP's. In order to determine the behavior, four separate experiments were run. Each experiment included the following set-up. The volume of the bottles used in the experiment was 250 mL. The initial concentration of TCE was 1800 μg/L, which was again prepared by diluting the 25.0 g/L stock solution of TCE in 4.0 L using 288 μL with nitrogen gas in the head space. The mass of carbon in each bottle was 0.0150 g +/-0.003 g. **Error! Reference source not found.4** contains information about variations in spinning time and dilution factors. In the experiments with humic acid and humic acid with different NP's, 2.0 mL of the 10.0 g/L humic acid stock solution was also added to prepare 5.0 mg/L humic acid in the 4.0 L solution. For the experiment with TiO_2 NP's, 4.0 mL of the 1,000.0 mg/L TiO_2 stock solution was added to make the 4.0 L. For the experiment with Fe_2O_3 NPs, 4.0 mL of the 1,000 mg/L stock solution was added to make 4.0 L. **Figure 3** on page 4 shows a solution prepared for this experiment with the tubing connecting the N_2 gas.

Table 4: Adsorption Kinetics Experiment Set-up

Sample Name	Time Spinning (hrs)	Dilution Factor
Blank (No Carbon)	0.00	10
1	0.02	5
2	0.17	5
3	0.50	5
4	1.00	5
5	1.50	5
6	2.00	5
7	2.50	5
9	3.00	5
10	72.00	5

Once the bottles were prepared in each experiment, capped, and covered with Parafilm, they were placed in a bottle rotator for the amount of time listed in **Table 4**. At the end of the time for each bottle, the rotator was stopped, and the sample was filtered with a 0.45 micron filter. A portion of the sample was diluted according to the dilution factor in **Table 4** in 50 mL amounts, and then 24.0 μL of PCE stock solution was added. Then a portion of the solution was placed in 43.0 mL vials. These vials were placed in the auto sampler and set to run through the purge and trap and then finally the GC. A second portion of the sample was also filtered with the 0.45 micron filter and placed in vials to be tested on the UV/Vis. The UV/Vis was set to 254 nm.

Breakthrough Studies utilizing Rapid Small Column Tests: The rapid small column test (RSCT) method is used to simulate the behavior of a large scale GAC bed (Vidic et al. 1992). The RSCT method is reliant upon keeping the dimensionless parameters in the mathematical model constant. The mathematical model describes the adsorption of the contaminant in both the large and small column, in the case of this research, TCE (Vidic et al. 1992). The three dimensionless parameters to note are the kinetic behavior of the TCE with the GAC, the surface diffusion modulus, and the Reynolds number. These three dimensionless parameters must remain constant for both the large and small column. This led to Equations (1) and (2) given below:

$$\frac{EBCT_{SC}}{EBCT_{LC}} = [\frac{dp_{,SC}}{dp_{,LC}}] \quad (1)$$

$$\frac{V_{SC}}{V_{LC}} = \frac{d_{LC}}{d_{SC}} \quad (2)$$

The $EBCT_{sc}$ and $EBCT_{LC}$ refer to the empty bed contact time of the small and large column respectively. The $dp_{,SC}$ and $dp_{,LC}$ refer to the diameter of the particle size in the small and large column respectively. The variables V_{SC} and V_{LC} refer to the velocity of the small and large column respectively, and finally the d_{SC} and d_{LC} refer to the diameter of the small and large column respectively. Based on Equations (1) and (2), the parameters of the large and small columns were determined and are presented in **Error! Reference source not found. 5**.

Table 5: Large and Small Column Parameters

	Large Column	Small Column
Carbon Granular Size	16x20 micron	35x40 micron
Length of Carbon	6.5 cm	6.5 cm
Mass of Carbon	15.9 g	3.7 g
Sand Granular Size	16x20 micron	16x20 micron
Column Diameter	25.0 mm	11.0 mm
Empty Bed Contact Time	2.8 min	0.43 min

The columns were packed with stainless steel mesh at each end and in between each layer. As shown in **Figure 3** on page 4, sand was added first, then the prescribed amount of carbon, and finally another layer of sand to the top.

The large and small column studies were conducted using the buffered solution by adding 8.44 g $KHPO_4$ to the 62.0 L tank filled with nanopure water. The buffered solution was brought to pH 7 by adding 3.4 mL of 10 N NaOH per tank. Once the tank was filled, sealed, and N_2 connected to fill the head space, the TCE was added through the septa port to a concentration of 2.2 mg/L by adding 5.5 mL of the TCE stock solution. Silica NPs were also present in the experiment in a concentration of 1.0 mg/L by adding 160 µL by adding the SiO_2 stock solution. The tank was continuously stirred by a magnetic stir bar. Two identical tanks were rotated and prepared daily to ensure solution continuously flowed through the columns. The flow rate was maintained at 15 mL/min and checked daily. **Figure 4** on page 4 for the entire experimental design.

Training Received

Though some prior knowledge existed, Mr. Hafiz Salih, Graduate Student Mentor, provided training on several of the instruments and techniques used in the laboratory. The first training received was on the instrumentation used in this report. Mr. Salih taught how to run the autosampler, purge and trap, and GC. He also taught how to prepare and run samples in the UV/Vis Spectrometer. Another important portion of training was the handling of TCE. Finally, Mr. Hafiz taught the correct technique for applying Parafilm to the vials.

Research Findings

TCE Calibration of GC: The data obtained from the GC was then compiled and analyzed (**Table 6**) and graphed (see **Figure 5**). The internal standard was made use of by calculating the quotient of the TCE Area by the PCE Area was calculated in order to decrease any instrumental error. The R^2 value was greater than 0.95 and therefore considered a good calibration of the GC. The value of the slope will be used in conjunction with the TCE Area/PCE Area to determine the [TCE] of future results.

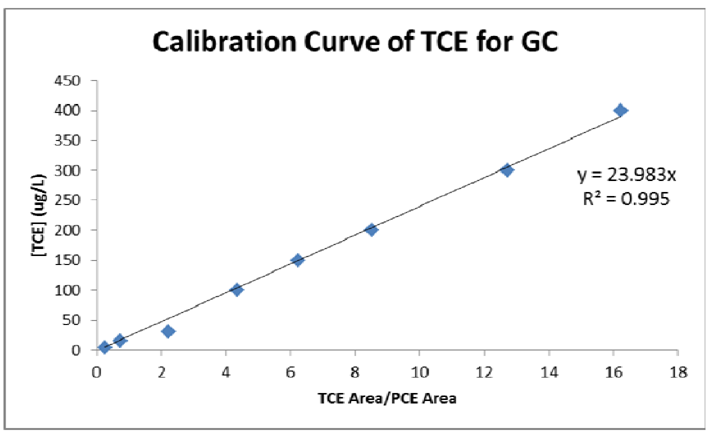

Figure 5. Calibration Curve for GC

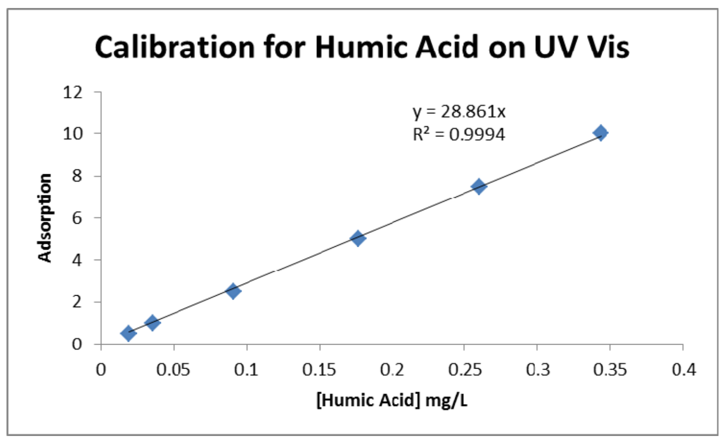

Figure 6. UV Vis Calibration Curve

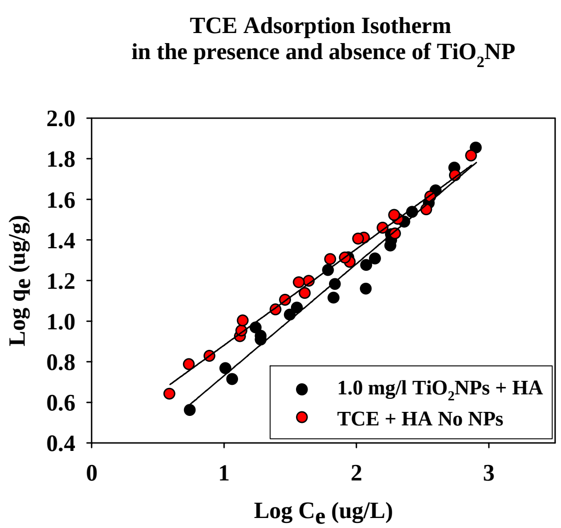

Figure 7. Log q_e vs. Log C_e for TCE

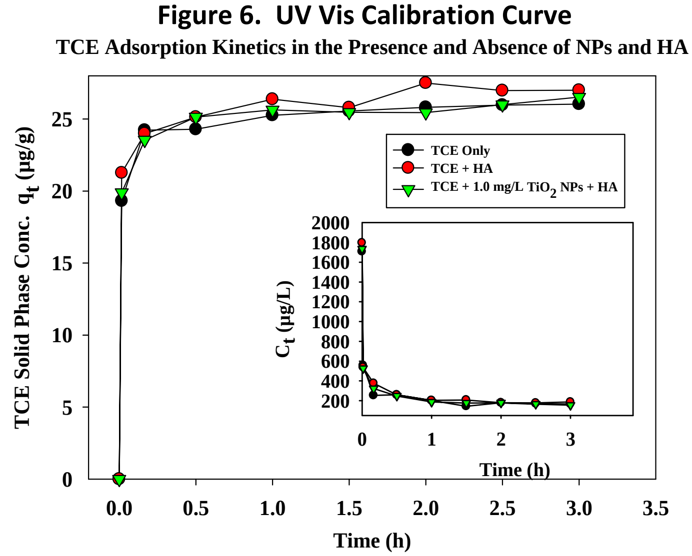

Figure 8. Adsorption Kinetics for TCE

Table 6. Calibration Curve Data and Analysis

Concentration TCE (ug/L)	TCE Area (pA*s)	PCE Area (pA*s)	TCE Area/PCE Area
5	3.05113	12.52067	0.24369
15	8.66012	11.95642	0.72431
30	27.15236	12.18261	2.228780
100	58.80345	13.54115	4.342574
150	86.50177	13.87612	6.233859
200	116.00013	13.61608	8.519348
300	174.12532	13.69967	12.71018
400	235.67941	14.50386	16.24943

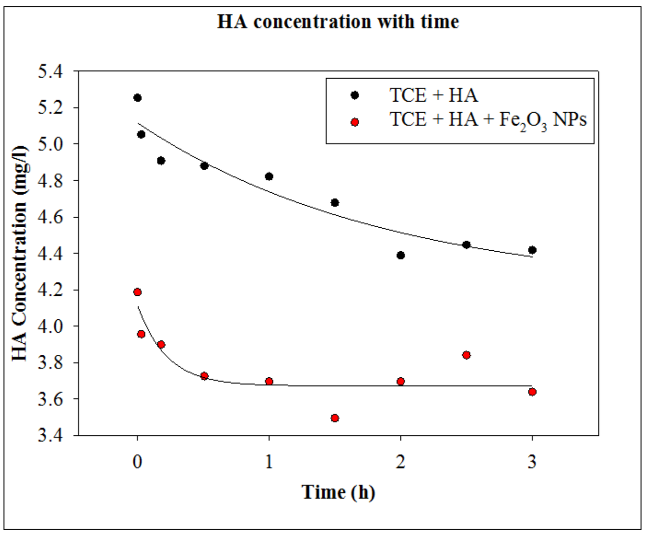

Figure 9. [Humic acid] With Time

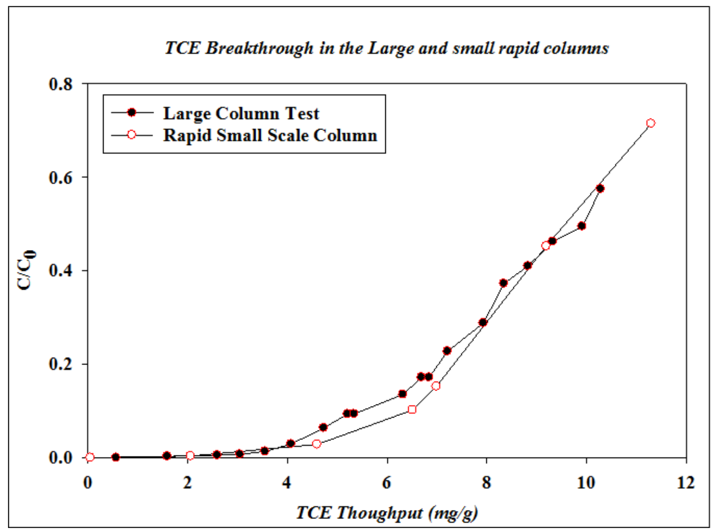

Figure 10. Large and Small Column TCE for Breakthrough

Humic Acid Calibration of UV/Vis: The data obtained from the UV/Vis was then compiled and analyzed (**Error! Reference source not found.**) and then graphed (**Figure 6** on page 8). The R^2 value was greater than 0.95 and therefore considered a good calibration of the UV/Vis for humic acid. The value of the slope will be used in conjunction with the adsorption data to determine the [Humic Acid] of future results.

Table7. UV/Vis Calibration Data

[Humic Acid] mg/L)	Absorption
10.0	0.343
7.5	0.26
5.0	0.177
2.5	0.091
1.0	0.036

0.5	0.02

Adsorption Isotherms: At the conclusion of the sixteen days, each of the solutions in the adsorption isotherm experiment was analyzed for the presence of TCE and humic acid. For the analysis of TCE, the equilibrium quotient (given by Equation (3) on next page), was used to show the amount of TCE adsorbed per milligram of carbon used, where q_e is the equilibrium quotient, C_o is the initial concentration of TCE, C_e is the equilibrium concentration of TCE, V is the volume of the bottle, and m is the mass of carbon. This equation is useful for comparing experiments due to the volatility of TCE. The Fruendlich Isotherm Equation is shown in Equation (4) below. The constants k and 1/n in this equation are called the Fruendlich Model Equation Parameters, and they are often used in mathematical modeling of different types of contaminants by activated carbon (Salih, H. H., Patterson, C. L., Sorial, G. A., Sinha, R., and Krishnan, R. "The fate and transport of the SiO2 nanoparticles in a granular activated carbon bed and their impact on the removal of VOCs." J.Hazard.Mater., In Press, Accepted Manuscript). By taking the logarithm of each side of Equation (4), the result is the Equation (5) given below. The equations mentioned in this paragraph are given below:

$$q_e = \frac{(C_0 - C_e)V}{m} \qquad (3)$$

$$q_e = kC_e^{\frac{1}{n}} \qquad (4)$$

$$\log q_e = \frac{1}{n}\log C_e + \log k \qquad (5)$$

The results of the isotherm experiment, in terms of Equation (5), are shown in **Figure 7** on page 8. There exists a difference in the plots at high concentrations (low q_e, low C_e) between the lines of no NPs and the line with 1.0 mg/L TiO_2 NPs and humic acid. This shows that the NPs and humic acid were competing with TCE for adsorption sites. This can also be demonstrated in the change in parameters of both log k and 1/n (see **Table 8**). The analysis of humic acid for this experiment was that 0.01 mg of humic acid was adsorbed on the carbon for each of the different carbon dosages. This shows that there is no difference in the amount of humic acid adsorbed for the amount of carbon used.

Table 8. Parameters from Fruendlich Isotherm Equation

	Log k	1/n	R^2
TCE + HA No NPs	0.40	0.48	0.99
1.0 mg/L SiO_2 NPs and HA	0.20	0.55	0.97

Adsorption Kinetics: Due to findings at high concentrations of the adsorption isotherm experiment, three kinetics experiments were run at high concentrations of TCE (1800 µg/L) at constant mass of carbon (0.0150 ± 0.0003 g). In order to analyze and compare the three different experiments, the kinetics quotient (q_t) was used, given by Equation (6) below, where C_o is the initial concentration, C_t is the concentration at time t, V is the volume of the bottle, and m is the mass of carbon used.

$$q_t = \frac{(C_0 - C_t)}{m} \quad (6)$$

Similar to the isotherm equilibrium quotient, q_t is a quotient with amount adsorbed per milligram of carbon and is useful for comparing experiments due the volatility of TCE. **Figure 8** on page 8 shows the data for the three adsorption kinetics experiments conducted. The inside graph shows the TCE concentration at time t, C_t, versus time. The outside graph shows q_t versus time where q_t was calculated using Equation (6).

The effects of NPs on the adsorption of TCE in the presence of humic acid showed no significant difference. From the kinetics studies, the influence of different nanoparticles on the adsorption of TCE was not seen.

The data for the concentration of humic acid with time in the kinetics experiment is shown in **Figure 9** on page 9. Compared with the TCE kinetics data, humic acid is adsorbed at a much slower rate than the TCE.

<u>Breakthrough Studies utilizing Rapid Small Column Tests (RSCT)</u>: The large and small columns were analyzed in terms of the effluent and influent on a daily basis. In order to determine if the RSCT adequately predicted the breakthrough activity of the small column, C/C_o was graphed versus the TCE throughput per mg of GAC (see **Figure 10** on page 9). C refers to the concentration of the effluent and C_o refers to the influent and by taking their quotient, this normalizes the data. The throughput per mg of GAC refers to the initial concentration times the flow rate and divided mass of GAC.

According the results and the limits of the data, the behavior of the large column can be predicted by the small column up to 60% removal as a breakthrough point. The small column was run for 5 days whereas the large column was run for 20 days. By using the RSCT in the future for this experiment, time and money will be saved and the same results will be achieved through this modeling experiment.

Classroom Implementation Plan

This lesson is part of an extensive developed unit relating to the chemistry of water. Students will begin the unit by learning about the molecular structure and unique characteristics of water. As a homework assignment on the evening of this direct instruction lesson, students will be completing a survey to determine the volume of water they personally use on a daily basis. For example, from the time they leave class with the assignment on Monday, students will keep track of how much water they use until they return to class again on Tuesday. After a comparison of the results and a class discussion relating to the importance of having a large supply of clean drinking water readily available, a dialogue about how water is made clean and safe to drink will begin. Because this lesson is being taught in Biology and Chemistry courses with two very different curricula, additional adaptations and modifications may be made by each teacher in order to better suit the needs of her students and goals of the course being taught.

After students show mastery of the chemical characteristics of water (to be presented through previous lessons in the unit), a move toward more inquiry based learning activities is made. The main activity of the unit involves students working in groups to design a water filter. Students will be given the instructions that they are trying to make the “cleanest” water possible combined with the most efficient filter design, and that they will be scored on a number of factors related to their filter design and efficacy. The goal for the students is to earn the maximum number of points possible in each of five categories. Students will be placed into heterogeneous groups where different interests and abilities are combined. The goals of the lab will then explained to the students, and then the process of designing, building, and testing the filter will get underway.

Students will be provided a bevy of various common materials that they could choose to use in their filter. Some parameters will be given; such as the filter must be housed in a plastic water bottle with the end removed, and filtration materials must not go closer than 8cm from the opening of the bottle. But the amount and order of the materials used by students in the filter will be entirely up to the group, but they do have to record the quantity of each material used to help determine their filter cost. Arbitrary prices have been assigned to each possible material students may use in their filter, and they must keep track of their materials and be cognizant of the overall cost during the design process. The criterion to be used for determining water cleanliness (and their overall score) are lowest turbidity, pH closest to 7, maximum amount of water retained through the filtration process (percent recovery), and cost to build. Filter designs are to be described and illustrated on the student handout, and then receive teacher approval before construction begins.

After the filter is constructed, students will be provided with an amount of Deionized water only substantial enough to wet the materials of the filter completely to increase the percentage of sample recovered through filtration. Each group will then be provided a 100 milliliter sample of local river water (samples were taken from the Ohio River or the Great Miami River for these experiments). Students test the water using some quantitative data criteria such as volume, temperature, pH, and turbidity. To collect this data, specific probes and software (such as Vernier or PASCO) will be used, along with graduated cylinders for measurement. Students first measure the volume using a graduated cylinder, and then proceed to work through the other quantitative data collection, recording their results on the student data table as they go. Students also test the water using some qualitative criteria such as odor and color or appearance, again recording results on their data table.

The river water sample will be tested for all qualitative and quantitative criteria before filtration and after filtration, using the same order for testing each criterion. A detailed comparison of the results will enable students to analyze the efficacy of their designed filter and to identify ways to improve the initial filter design. In their own groups, students will discuss the pros and cons of their filter design and analyze what they learned from testing. Once this is completed, a class-wide discussion will commence. As a class, students will compared the results of all classroom groups and brainstorm ways to combine the best results from each

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Appendix: Lesson Plan

1A. Lesson Name: __Water Unit__________________ Teacher Name: __Rachel Rice/Kathryn Nafziger___
Subject: __Biology/Chemistry_____________ Grade Level: __10-12________ Duration: _Seven 45 minute classes

1B. Analyze Learners:
Overview & Purpose (Engineering theme)

- What will be learned and why it is useful.
- **A :** Address the necessity for clean, readily available drinking water
- **C :** Environmental Engineer, Civil Engineer, Hydrogeologist, Water Resources Policy Management, Hydrologist, Environmental Lawyer, Government Policy Maker, Water Quality Consultant, Limnologist, Freshwater Biologist, Sustainability Consultant
- **S :** Maintaining a supply of safe drinking water to meet the growing demands of society will be a long term challenge

2. Education Standards Addressed

Ohio Academic Content Standards

- **Earth and Space Sciences D:** "Describe the finite nature of Earth's resources and those human activities that can conserve or deplete Earth's resources."
- **Physical Sciences A:** "Describe that matter is made of minute particles called atoms and atoms are comprised of even smaller components. Explain the structure and properties of atoms."
- **Physical Sciences B:** "Explain how atoms react with each other to form other substances and how molecules react with each other or other atoms to form even different substances."
- **Physical Sciences C:** "Describe the identifiable physical properties of substances. Explain how changes in these properties can occur without changing the chemical nature of the substance."
- **Science and Technology A:** "Explain the ways in which the processes of technological design responds to the needs of society."
  Science and Technology B: "Explain that science and technology are interdependent: each drives the other."

Quality Core

I. UNDERSTANDING CHEMISTRY AS INQUIRY
A. Foundations
1. Scientific Inquiry
   a. Identify and clarify research questions and design experiments
   c. Collect, organize, and analyze data accurately and use techniques and equipment appropriately
   d. Interpret results and draw conclusions, revising hypotheses as necessary and/or formulating additional questions or explanations
   e. Write and speak effectively to present and explain scientific results, using appropriate terminology and graphics

II. EXPLORING THE PHYSICAL WORLD
A. Introduction to Chemistry
2. Elements, Atomic Mass, and Nomenclature
   a. Use the IUPAC symbols of the most commonly referenced elements

b. Compare the characteristics of elements, compounds, and mixtures

IV. BUILDING MODELS OF MATTER
A. Microscopic Nature of Matter
1. Structure of Liquids and Solids
a. Describe differences between solids, liquids, and gases at the atomic and molecular levels
b. Describe and perform common separation techniques (e.g., filtration, distillation, chromatography)

3. Goals (learn/understand) (Specify skills/information that will be learned.)

- Students will learn the steps in water treatment
- Students will understand the importance of the availability of safe drinking water

Objectives (measurable)

- Students will be able to build a filtration device for a river water sample
- Students will be able to explain the rationale for the items utilized in their filter creation
- Students will be able to test water samples (both filtered and unfiltered) for temperature, pH, turbidity and explain the implications of these results.

4. Misconceptions about this topic:

Most students will not know where their drinking water comes from or how complicated the process is to make it safe to drink. Students are also unlikely to understand how great an impact on the environment they have simply through the products that they use (and often discard) on a daily basis.

5. Materials Needed

- Paper
- Pencil
- PASCO or Vernier sensors for temperature, pH, and turbidity(enough for lab stations)
- Class set of laptop computers for analyzing data
- Sand
- Gravel
- Filter paper or coffee filters
- Rubber Bands
- Funnels
- Distillation tube
- River water (100 mL per group)
- Charcoal (activated carbon)
- Cotton
- Cheesecloth
- Alum
- Plastic water bottles with bottoms cut off (to house filters)
- Beakers to catch filtrate
- Disposable pipets for transferring samples for testing.
- Graduated cylinders
- Rulers

- Deionized water (enough to wet filter for each group)

6. Select Instructional Strategies – (Give and/or demonstrate necessary information)

- Direct instruction : Teacher will provide information about atoms, molecules, water filtration
- Inquiry lesson
- Hands on lesson
- Activity

7. Utilize Technology

Technology will be utilized in that specially calibrated probes designed for data collection of various different types will be used by students in all aspects of this lesson plan. Students will also use technology in the form of laptop computers and data analysis software (such as Excel) to collect, compare, and draw conclusions from the data they collect. In addition, SMART boards can be utilized in the classroom to keep a real-time log of the data collected by each lab group.

8. Require Learner Participation

After students show mastery of the chemical characteristics of water (to be presented through previous lessons in the unit), a move toward more inquiry based learning activities is made. The main activity of the unit involves students working in groups to design a water filter. Students will be given the instructions that they are trying to make the "cleanest" water possible combined with the most efficient filter design, and that they will be scored on a number of factors related to their filter design and efficacy. The team that can score the highest in each of the categories will win the day. Students will be placed into heterogeneous groups where different interests and abilities are combined. The goals of the lab will then explained to the students, and then the process of designing, building, and testing the filter will get underway.

Students will be provided a bevy of various common materials that they could choose to use in their filter (see list of materials from #5). Some parameters will be given; such as the filter must be housed in a plastic water bottle with the end removed, and filtration materials must not go closer than 8cm from the opening of the bottle. But the amount and order of the materials used by students in the filter will be entirely up to the group, but they do have to record the quantity of each material used to help determine their filter cost. The criterion to be used for determining water cleanliness (and their overall score) are lowest turbidity, pH closest to 7, maximum amount of water retained through the filtration process (percent recovery), and cost to build. Filter designs are to be described and illustrated on the student handout, and then receive teacher approval before construction begins.

After the filter is constructed, students will be provided with an amount of Deionized water only substantial enough to wet the materials of the filter completely to increase the percentage of sample recovered through filtration. Each group will then be provided a 100 milliliter sample of local river water (samples were taken from the Ohio River or the Great Miami River for these experiments). Students test the water using some quantitative data criteria such as volume, temperature, pH, and turbidity. To collect this data, specific probes and software (such as Vernier or PASCO) will be used, along with graduated cylinders for measurement. Students first measure the volume using a graduated cylinder, and then proceed to work through the other quantitative data collection, recording their results on the student data table as they go. Students also test the water using some qualitative criteria such as odor and color or appearance, again recording results on their data table.

The river water sample will be tested for all qualitative and quantitative criteria before filtration and after filtration, using the same order for testing each criterion. A detailed comparison of the results will enable students to analyze the efficacy of their designed filter and to identify ways to improve the initial filter design. In their own groups, students will discuss the pros and cons of their filter design and analyze what they learned from testing. Once this is completed, a class-wide discussion will commence. As a class, students will compared the results of all classroom groups and brainstorm ways to combine the best results from each team into the most effective and most economical filter design.

9. Evaluate (Assessment)

i. Pre Test
ii. Lab Papers
iii. Exit Slip on Reflection of Filter Design
iv. Post Test

10. Essential/Review questions are outlined

1. Evaluate the following filter design for cleaning river water for human consumption

Filter paper placed over the mouth of a water bottle and secured with a rubber band.

A. The water is CLEAN because all contaminants have been removed from the water.
B. The water is CLEAN enough for humans because all large contaminants have been removed from the water.
C. The water is UNCLEAN because all contaminants have NOT been removed from the water.
D. The water is UNCLEAN because harmful contaminants have NOT been removed from the water.

2. Hydrogen is a _______ and water is a _________.

A. Atom, molecule
B. molecule, atom
C. molecule, element
D. atom, mixture

3. If you were to create a filter design, which of the following would be the best?

A. Filter paper placed over the mouth of a water bottle and secured with a rubber band.
B. Filter paper placed over the mouth of a water bottle and secured with a rubber band with sand and gravel packed in the bottle.
C. Filter paper placed over the mouth of a water bottle and secured with a rubber band with charcoal, sand, and gravel packed in the bottle.
D. Filter paper placed over the mouth of a water bottle and secured with a rubber band with cotton balls packed into the water bottle.

Defend your response:

4. Analyze the following data on the percent recovery of water from a filtration.

	Volume Before Filtration	Volume After Filtration	Percent Recovery
Trial 1	100 mL	50 mL	50%
Trial 2	100 mL	80 mL	80%

Which statement is true about the best trial?

A. Trial 1 is the best trial because it has the lowest percent recovery.
B. Trial 1 is the best trial because it has the highest percent recovery.
C. Trial 2 is the best trial because it has the lowest percent recovery.
D. Trial 2 is the best trial because it has the highest percent recovery.

5. Calculate the percent recovery for the following filtration information.

Volume Before Filtration	Volume After Filtration
50 mL	40 mL

A. 90%
B. 80%
C. 50%
D. 40%

11. Pre/Post Test Questions:

1. Evaluate the following filter design for cleaning river water for human consumption

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D. Trial 2 is the best trial because it has the highest percent recovery.

5. Calculate the percent recovery for the following filtration information.

Volume Before Filtration	Volume After Filtration
50 mL	40 mL

A. 90%
B. 80%
C. 50%
D. 40%

6. What is the molecular formula of water?
A. OH
B. H_2O
C. CO_2
D. H_3O

7. Where does your tap water come from?
A. Ground water
B. Surface water (rivers, lakes, etc.)
C. Aquafina plant
D. Both A and B

8. Which one of the following steps is not a step in the water treatment process?
A. Sedimentary Tanks
B. Activated Carbon
C. Large filter paper
D. Pumping from water source

12. Reflection on Lesson:

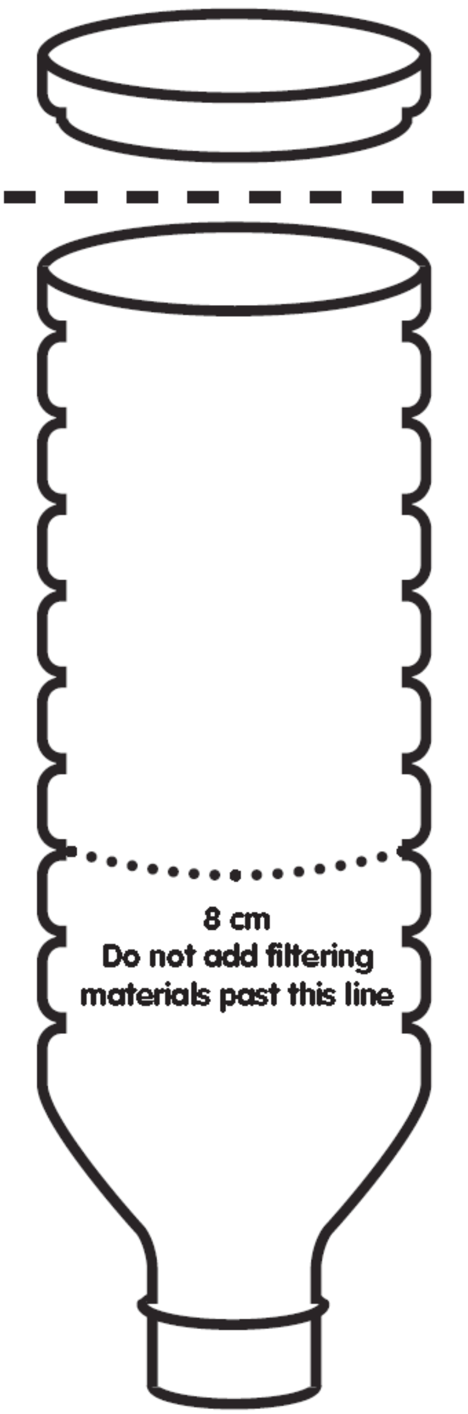
If there is time and adequate supplies, it would be very beneficial to provide students with a second opportunity to create a filter based on what they learned from their first attempt and discussions with the class.

Student Handout

Group Members
____

Filter Design

The filtration materials will be layered inside the bottle. Use the diagram (left) to design your filter. Draw in and label which Filtration materials you think will best filter the dirty water. Remember, you may use **some or all** of the available filtration materials.



Describe how each material you use in your filter will help your group to clean the water and why you think your filter will work.

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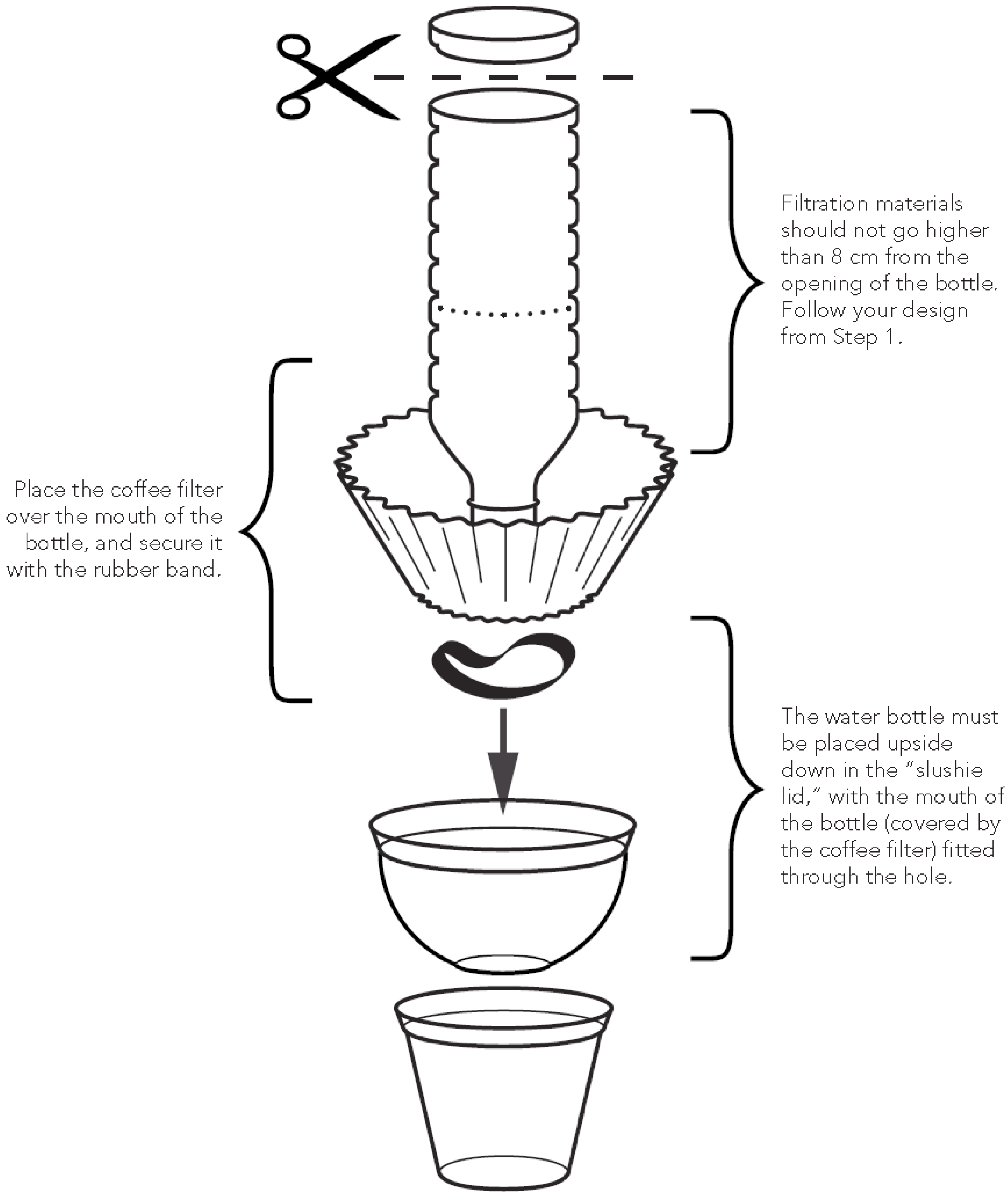
Procedure Step 2: Build your filter

Have one or two team members obtain the Filtration and Structure materials needed to build your filter. Build your filter according to your approved design from Step 1. Be careful not to fill the bottle higher than 8 cm from the mouth of the bottle with the Filtration materials.

Wear your safety goggles at all times.



Group Members ____

Water Filtration Experiment Data Sheet

Cost List

	Cost
Water Bottle	$10.00
Sand (1 spoonful)	$0.50
Gravel (1 spoonful)	$0.50
Filter paper/coffee filter (1)	$1.00
Rubber Band (1)	$0.10
Charcoal (1 spoonful)	$1.00
Cotton Ball (1)	$0.50
Cheesecloth (10 cm x 10 cm)	$1.00
Alum (1 spoonful)	$1.00
River water (100 mL per group)	Free
Replacement River Water (10 mL)	$5.00
Extra Lab Paper	$10.00
Borrow Pen or Pencil	$5.00

Materials List

Name of Material	Quantity of Material	Cost of Material (per unit)	Total Cost (per material)
GRAND TOTAL	XXXXXXXXXXXXXX	XXXXXXXXXXXXX	

Filtration Data Table

	Pre - Filtration	Post - Filtration	Notes / Comments
Volume (mL)			
Temperature (°C)			
Turbidity (NTU)			
pH			
Appearance / Color			
Odor			

Scoring Rubric

	10	8	6	4	2	0	Score
Volume (mL)	90-100	80-89.9	70-79.9	60-69.9	50-59.9	Less than 50	
pH	7.0	6.5-6.9 Or 7.1-7.5	6.0-6.4 Or 7.6-8.0	5.5-5.9 Or 8.1-8.5	5.0-5.4 Or 8.6-9.0	Less than 5 or Greater than 9	
Turbidity (NTU)	Less than 10	10.1-25.0	25.1-45.0	45.1-70.0	70.1-99.9	Greater than 100	
Temperature	±0°C	±0.5°C	±1.0°C	±1.5°C	±2.0°C	±2.1°C or more	
Cost	Less than $15	Less than $17.50	Less than $20	Less than $22.50	Less than $25	Less than $27.50	
						Total Score	