SIWI STOCKHOLM
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WATER PRIZE

An Approach to Water and Wastewater Treatment with Solar-power:

Removal of Cyanobacterial Contaminants via Electrocoagulation-Sand Filtration

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Figure 1.1

Abstract

The availability of drinkable water diminishes with the increase of cyanobacterial blooms. This study set to determine the: (1) feasibility of solar-powered electrocoagulation (EC) on *Anabaena*, (2) effects of pH on the EC, and (3) effectiveness of sand-filtration as a polishing step. EC works by charging particulate matter in solution causing it to clump, as hydrogen ions float this "floc" to the top. Research has been done on EC, but few studies have been done using slow-sand filtration, solar energy, and cyanobacteria. It was hypothesized that treatment would be most effective at a pH of 2 and slow-sand filtration would be less effective than EC, but an ideal post-treatment step. It was determined that solar EC was not feasible in Wisconsin winter, but it could be effective at sunnier times. Of the pHs tested (2, 4 [control], 6, and 8), the control produced the greatest decrease in turbidity and green absorbance levels according to the scanning spectrophotometer. Although the sand filter did not affect turbidity much, it did produce a qualitative drop in absorbance, making it perfect for post-treatment clarifications.

Introduction

About 783 million people worldwide do not have access to clean water for not only drinking purposes, but also everyday usage, according to UN Water [1]. Surely, this significant figure highlights a social responsibility to the better-off. It also inherently emphasizes to the world that eco-friendly, effective, and/or cheap methods for turning wastewater and other contaminated water sources alike into potable/semi-potable water has been extremely difficult for many communities to salvage, especially as centralized systems in developing countries. Regrettably, this struggle of an endeavor to save this precious commodity of water can still be seen today, even in the most urban of areas – during the continuous research and studies for this experiment, trips to some thriving cities in coastal countries like Mexico and Puerto Rico, where water definitely plays a capitalizing and important role, were made to further explore and observe the harsh and critical conditions of poverty and environmental impacts of a lack of sanitary water sources (see Figure 2.1, 2.2, 2.3 and 2.4 below). For example, some of the challenges in developing countries like Mexico alone include drinking water scarcity and inadequate water service quality.

In fact, according to some studies done by the 2000 census, 55% of Mexicans receive water only intermittently ("Water" 2017). Poor technical and commercial use, such as from paper mills, and after-use of most utilities contribute to polluted waterways and ever-growing, unsustainable or untreatable wastewater bodies (only 36% of wastewater received treatment in 2006 alone).

Novel methods

There are some fairly new methods that have generated a lot of attention due to their potential cost-benefit possibilities, despite the lack of controlled testing for optimization and/or efficacy. One of the most promising wastewater and water treatment techniques in this day and age is that of electrochemical coagulation, or in short, "electrocoagulation" (EC), where an

L-R: Figure 2.1, 2.2, 2.3 and 2.4 show various areas around the cities of Cancún, Mexico, and San Juan, Puerto Rico, stressing the poorest of areas, even in seemingly "urban" civilizations. An emphasis on the importance of water (as coastal countries) in these extremely hot and dry areas is extended as well.

anode and cathode (with a direct current flowing through) are used to stimulate removal of eventually hydrogenated suspended solids that coagulate into flocs. The flocs (usually contaminants that would not have been able to be seen with the naked eye or are too hard to remove without some kind of energized heat source) are then subsequently removed (see Figure 2.5).

Although relatively new, the method indeed has a promising future as it has just started to be used in some contemporary research, like in a study done by Pirkarami in 2013 [2]. The method is more reliable and produces less waste than chemical coagulation. However, the process does have one downfall – some of the pollutant not electrocoagulated out, often referred to as "sludge," sinks to the bottom of the effluent, and this calls for the means of additional polishing. This is why secondary or post-treatment is often needed, and this is also where processes like filtration and flotation tend to get ridiculously expensive.

Fortunately, both rapid-sand filtration and slow-sand filtration have recently been on the rise as a very cheap way to remove microbial contaminants from water sources. Slow-sand filtration, for example, with a high flow rate of up to 0.6 liters per minute, is simple to use, especially on a local, decentralized scale (implemented on the household level) and its acceptability is key to its success. There is often visual improvement of the water, as turbidity decreases, and there is "proven reduction of protozoa" and almost all bacteria ("Slow" 2014). Rapid-sand filters, on the other hand, are also effective. With a one-time installation and low maintenance cost requirements, it proves to be economically viable as most sand filters range from $10-60, and, obviously, quick for usage ("2.5 Filtration" n.d.). Scalability-wise, by the CDC, both sand filters have long lives (estimated >10 years), with no recurrent expenses in the slow-sand filter. It ultimately constitutes a great decentralized system.

Not a lot of studies exist that encompass the combination of some sustainable treatment methods (like the combination EC-sand filtration), as well as solar aspects, especially for rural regions that are in critical need for them but cannot afford traditional, technological systems that would be seen in the United States for maximum and affordable effectiveness.

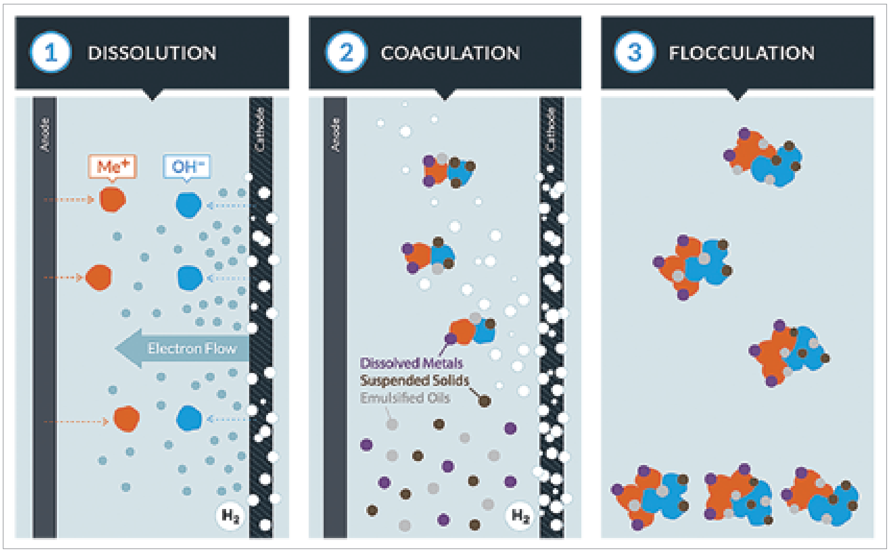

Figure 2.5: The schematics for EC (WaterTectonics, n.d.)

Cyanobacteria and algae in water and wastewater treatment

Blue-green algae, more commonly known as cyanobacteria, are found in all aquatic systems ("Cyanobacteria" 2016). It is often confused with green algae, which are known for their algal blooms. According to the EPA (2014), these typically occur from excess nutrients in the watershed. As the algae multiply at exponential rates in water, dissolved oxygen, pH, nitrate, and phosphate levels turn to levels that are unable to sustain fish or insect life. The resulting effect is a dead zone as a result of chemical-heavy fertilizers, treatment plants waste, and overall increased globalization and industrialization. Since both green algae and cyanobacteria can produce dense growth in water systems and cause odor and dissolved oxygen depletion, for the purpose of this research, they will be used comparably when it comes to considering the possible environmental impacts.

Unlike green algae, unmanaged cyanobacteria overgrowth (usually found in wastewater or commonly used yet polluted "water-holes" in some third-world countries) often can become poisonous and start releasing detrimental and hazardous cyanotoxins that can seriously damage human health and possibly lead to death when ingested. These toxins can be produced by a multitude of planktonic cyanobacteria in eutrophic water bodies, such as the strain *Anabaena*, which was used in this research, since most studies have focused on *Microcystis*.

Unfortunately, due to the extremely poor, inefficient, or unsanitary practices (or a lack thereof) for retrieving and cleansing water to drink, a great portion of the human population cannot access drinking water sources within the proximity.

Rationale and hypothesis

The rationale of this lab was to determine which pH would provide the most optimal results for cleaner wastewater (cyanobacteria-contaminated) via solar-powered electrocoagulation and subsequent sand filtration. However, due to weather conditions, instead of a 10W polycrystalline solar panel, a 12V battery (that could produce the same energy output) was used instead. In a broader sense, this experiment had an intent to find a more sanitary, cheap, and sustainable method to possibly convert wastewater into potable water as a decentralized system. This would insure a safer future for an ecological community, allowing people to have more access to one of the world's scarcest natural resources.

It was hypothesized that, both solar-powered electrocoagulation and electrocoagulation through DC power itself

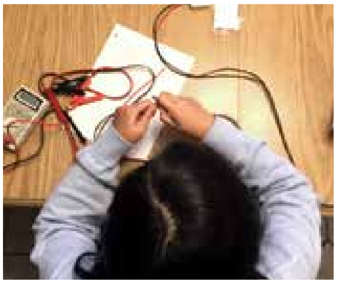

Figure 3.1

Figure 3.1.1

Figure 3.1.2

Figure 3.1.3

will be most optimal at a pH of 2 due to more hydrogen ions available to aid in the coagulation process. Additionally, it was hypothesized that simple slow-sand filtration will be less effective than EC, but still beneficial, as either secondary or primary treatment before electrocoagulation.

Methods

Solar-powered Electrocoagulation (SPEC) Setup

1. One 10W polycrystalline solar panel was obtained from a local science department store. The instructions located inside the box were followed to hook up the solar panel and load (multimeter) to their respective slots, using a small flathead screwdriver, on the given solar charge controller for initial voltage readings (see Figure 3.1).
2. On a partly sunny day with an outside temperature of 26°C, the panel was put outside in a constant spot (for each time this was tested) on an angle where sunlight was determined to be the most optimal. A warming period of 10 minutes was used.
3. After the warming period, readings of voltage and amperes were recorded, with the multimeter on the DC setting each time.
4. *It should be noted that due to winter weather conditions, the solar panel could not be utilized for the actual electrocoagulation. The usage and set-up is just a proof-of-concept. However, a 12V battery (methods below) was used in its place as both produce the same amount of output of energy.*

12V Battery EC

1. A 12V 50Ah lead-acid battery was purchased and kept until the start of experimentation in a room at a constant 21°C.
2. 150 mL of *Anabaena*-contaminated water and 50 mL of distilled water were added to a 250 mL beaker. (In the case of non-control (not pH of 4) trials, 0.05 M NaOH and 0.05 M HCl solutions were created via dilutions to buffer certain experimental solutions to a desired pH.)
3. A small sample (~10 mL) was removed to be sent through the turbidity meter and scanning spectrophotometer for initial readings (following the respective instructions). After these readings were taken the solution was returned to the beaker.
4. The beaker was placed on stirring plate set on lowest setting available and a magnetic stirring bar was placed in the solution at the bottom of the glassware in order to start the mixing.
5. Pre-cut aluminum electrodes (placed 2 cm apart in a cardboard template) were put on top of and into the beaker.
6. The cathode and anode were connected to positive and negative ends of the 12V battery through alligator wires and allowed to run for 15 min. before being removed from power source to take final data readings of the test water for turbidity and absorbance levels.

Sand filtration

1. Before the measurements could be taken the sand filter was constructed by layering large rocks, then smaller stones, then coarse sand, followed by extra fine sand in a cleansed juice jug with 2 coffee filters at the bottom.
2. 2 L of spring water were used to cleanse the filter prior to use.
3. The same type of 200 mL contaminated solution described in the EC section was tested for turbidity and sent through the scanning spectrophotometer before being sent through the filter until enough solution was available for filtration.
4. Turbidity and spectrophotometric data was taken once again.
5. Between trials, 2 liters of spring water were sent through again in order to cleans the technology. See sand filter in Figure 3.1.1 and EC setup in 3.1.2 (solar panel power source) and 3.1.3 (12V battery power source).

Turbidity meter usage

1. The turbidity meter was calibrated according to the instructions provided using 0 ntu and 100 ntu solutions.
2. A container provided with the set was filled with 10 mL of the solution in question and was placed in the meter before pressing the test button.
3. The data was then recorded in the spreadsheets created for information collection.

Scanning spectrophotometer usage

1. The machine was calibrated with a "blank cuvette" full of distilled water according to the instructions provided inside the kit.
2. Enough solution was collected to practically fill the cuvette before being capped and wiped down with a lens cleaning cloth and placed in the slot.
3. The "record data" button was pressed and the graph produced was then transferred into a spreadsheet which was exported to the computers.

Results

Solar-powered Electrocoagulation*

In order to power an electrocoagulation unit, at least 0.1 A of power was needed. However, the maximum amount of power that was able to be produced was 0.04 mA. Although this is not sufficient, it is clear that if the climate were more

forgiving, solar would not only have been feasible but also more effective. *Unfortunately the harsh Wisconsin winters did not comply with the data collection.

12V Battery EC

CONTROL GROUP

The pH was measured and there was a pH of 4. See Figure 4.1 for spectrophotometer graph readings for trial 1 (initial and final).

EXPERIMENTAL GROUPS

The experimental groups consisted of cyanobacterial-test water that was buffered to a pH of 2, 6, and 8, respectively. Using the same methods as the control group, turbidity and spectrophotometer readings were determined. See Figure 4.2 (located near the end of results) for all turbidity data. Only trial 1 results are displayed due to the lengthy data for conciseness.

- **pH of 2:** See Figure 4.3 for spectrophotometric absorbance levels for each "trial 1," initially, and finally, respectively. Note the drop in 400-500 nm levels, reflecting chlorophyll A levels and therefore cyanobacterial content.
- **pH of 6:** See Figure 4.4 below
- **pH of 8:** See Figure 4.5 below.

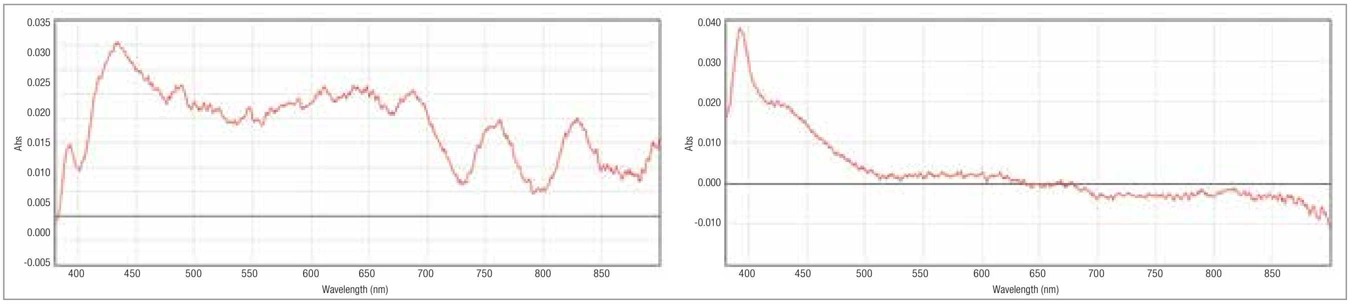

Figure 4.1: Control group's initial and final data, trial 1

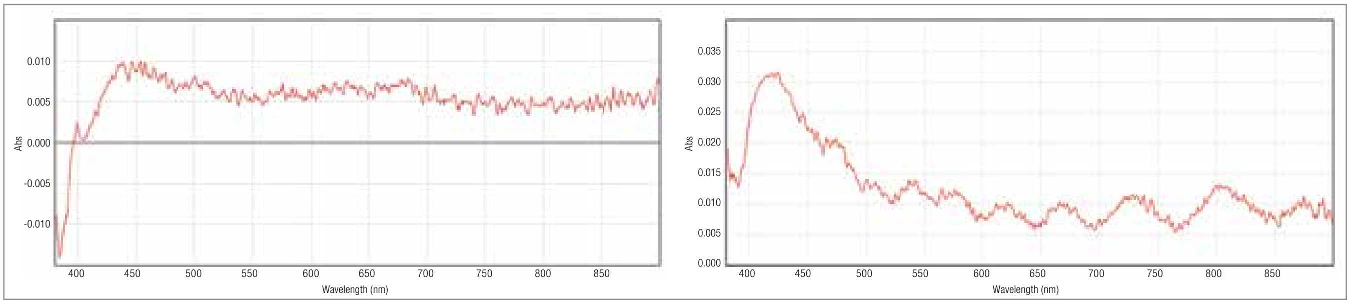

Figure 4.3: Trial 1

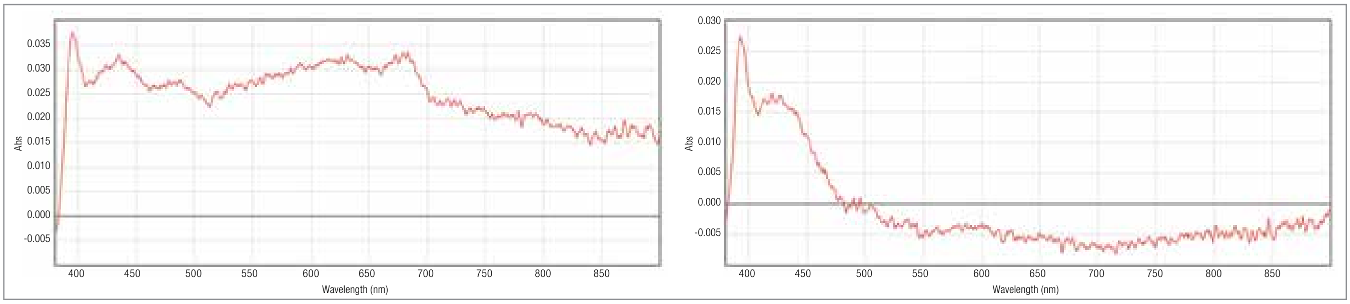

Figure 4.4: Trial 1

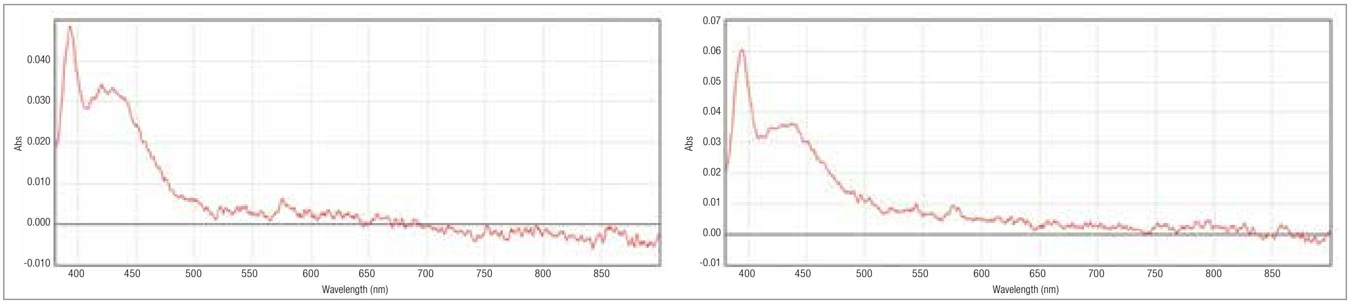

Figure 4.5: Trial 1

TURBIDITY RESULTS

(see Figure 4.2 below)

Sand Filtration

TURBIDITY RESULTS

See Figure 4.6 below for turbidity results for all 3 trials of the sand-filter and control group, initially and finally.

SCANNING SPECTROPHOTOMETER RESULTS

The absorbance levels in green wavelengths' range (~400-500 nm) did see a decrease, as reflected in both Figure 4.7 (initial) and 4.8 (final), for Trial 1.

It is clear from the outcome of the turbidity data (Figure 4.6) that the sand filter was not as effective as the electrocoagulation. In fact the change in turbidity was, statistically speaking, null. However, from the graphs above there was a decrease in the absorbance levels for green wavelengths – meaning that some clarification did happen. This means it would be an effective polishing step to remove the larger chunks of floc that may not have been removed by hand or electrocoagulation itself.

Discussion

The problem at hand was that millions of people worldwide have no access to drinkable and clean water. Therefore, the experiment sought to find a cost-effective and attainable method of wastewater and water treatment.

The results of the experiment are significant since they demonstrate that electrocoagulation, a cost-effective method for water sanitation, could be powered by solar energy (although not in this climate), creating a stepping stone in a highly environmentally friendly and sustainable option to achieve a means of drinking water from contaminated water sources. Additionally, it provides a helpful secondary process which would further the effects of filtration in many water treatment systems.

Compared to other similar research, it makes sense that a lower pH would result in the greatest effectiveness in EC. Additionally, although there have been few comparisons of sand filtration and EC, it can be assumed that the results would be fairly similar, although changes in filter design could have improved the results of the sand filter. The novelty of the project comes from the combined use of solar energy, cyanobacteria, EC, and sand filtration. Additionally, sand filtration is typically used as a pretreatment step, however this treatment it was proposed as a post treatment step.

In terms of future experiments, studies could be done on truly contaminated water, such as that from a murky pond in a local city in order to increase the realism. Moreover, the actual solar-EC apparatus could be brought down to an actual third-world country (like mentioned in the beginning of this paper) in order to further apply this to real case studies. This would put to the test not only the technology's ability to filter cyanobacteria/algae, but also other contaminants and particulates. Different metal electrodes could also be used to see the effect that they have on removal as well.

Conclusion

1) Parts of the hypothesis were accepted since part of the lab was hindered by the fact that solar-power was not feasible to power electrocoagulation in a harsh Wisconsin winter. However, it would almost certainly be feasible in other parts of the globe, since, both a 12V battery and a 10W solar panel could produce at least 1.5 watts at their maximum output, after conferring with some researchers and local graduate students.
2) The optimal pH was found to be pH 4, the control (partially due to the odd results of the pH of 2 data). This was determined due to it having a significantly greater impact on turbidity and also a seemingly greater effect on absorbance according to the spectrophotometer data.
3) The sand filter was determined to be effective, and would be a good post-EC treatment step to take. This filtration would best be served as a polishing step to eliminate the residual elements or as a pre-step to purify the water as much as possible, therefore lessening the amount of power needed as a potential decentralized system for developing countries.
4) Errors of the experiment can be found in the pH 2 data, since it resulted in a major increase in turbidity, rather than a decrease. In the future, this

TRIAL 1	
initial	2.55 ntu
final	0.65
difference	1.9

TRIAL 2	
initial	2.95
final	0.46
difference	2.49

TRIAL 3	
initial	2.14 ntu
final	1.05 ntu
difference	1.09

TRIAL 1	
initial	2.12 ntu
final	12.23
difference	-10.11

TRIAL 2	
initial	2.53 ntu
final	11.53
difference	-9

TRIAL 3	
initial	2.43
final	17.72
difference	-15.29

TRIAL 1	
initial	2.45 ntu
final	2.29
difference	0.16

TRIAL 2	
initial	2.52 ntu
final	1.45
difference	1.07

TRIAL 3	
initial	2.73
final	1.69
difference	1.04

TRIAL 1	
initial	2.87
final	1.96
difference	0.91

TRIAL 2	
initial	2.8
final	1.3
difference	1.5

TRIAL 3	
initial	2.72 ntu
final	2.71
difference	0.01

Figure 4.2: Turbidity results for the control (pH of 4), pH of 2, 6, and 8, respectively (all in ntu)

TRIAL 1	
initial	2.98 ntu
final	3.01
difference	0.03

TRIAL 2	
initial	2.54
final	2.84
difference	0.3

TRIAL 3	
initial	2.71
final	2.53
difference	-0.18

Figure 4.6

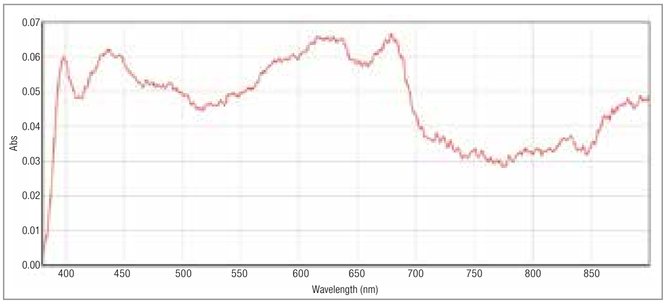

Figure 4.7: Initial for Trial 1

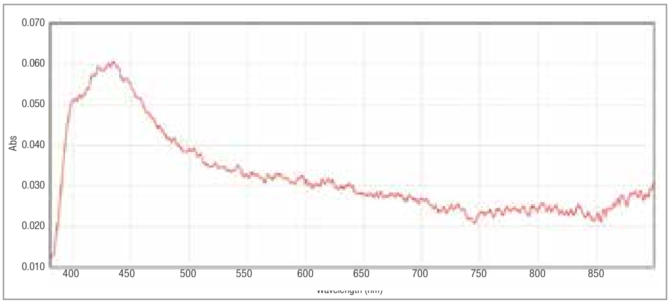

Figure 4.8: Final for Trial 1

phenomenon could be studied more, but is assumed that this result was due to a technological error, though this is not certain.

5) Equipment in general could have produced problems or skewed results (i.e., calibration errors in the scanning spectrophotometer). Overall, a plethora of procedures were taken to reduce data and analytical mishaps.

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