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A Novel Method of Removing Excess Algae in the Chesapeake Bay Region Using Natural Polymers and Ferroferric Oxide

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Cover Page Footnote
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Introduction

Algae are nonflowering plants that grow in the water and have no stems, roots, nor leaves. They contain chlorophyll and other pigments that trap light from the sun allowing them to conduct photosynthesis. They can be either single-celled or multicellular organisms. Some are found on the surfaces of moist soil or rocks, while others are found floating freely in the water column. The many types of algae are determined by their colors—for example, brown algae, blue algae, red algae and more. Algae are important to the ecosystem; in fact, they are primary producers in many food chains. Various species of algae are found naturally in the Chesapeake Bay, helping to support its rich ecosystem.

The Bay acts as a basin for an expanding human population. It is fed by over 500 rivers and streams. Unfortunately, chemical runoff from fertilizers, detergents, and wastewater often pollute the local waterways, which then collect in the Bay. Warm water coupled with high levels of dissolved nutrients create ideal conditions for algae, leading to frequent algal blooms in the warm seasons. Algal blooms are characterized by rapid reproduction of algae, creating dense populations near the surface of the water. These blooms have many negative effects on the health of the Bay. An overabundance of algae takes oxygen from the water during respiration, contributing to the formation of seasonal "dead zones," areas where there is too little dissolved oxygen to sustain life. Constant booming in the Chesapeake Bay can turn large areas into dead zones, pushing many aquatic animals out of their natural habitat, as well as killing any aquatic plants in the zone. Some of the algae that are in the water are toxic to animals and humans. Several toxic Dinoflagellate species, *Prorocentrum minimum* and *Kalrodinium veneficum,* inhabit the

Bay. The toxins produced by these algae are not only dangerous to aquatic animals, but become concentrated in shellfish as they filter feed, posing a serious threat to human health.

The thick layers of densely packed algae created by the blooms rest at the surface of the water and cover the life underneath. This blocks sunlight from the water column below, killing other photosynthesizing plants. When algae die they go through the process of decomposition, which consumes more oxygen, as well as releasing excess nutrients back into the water. This can cause "secondary eutrophication", whereby the nutrients released support a new algal bloom. Consequently, the effect of natural polymer with a magnetite will be tested in order to remove the excess algae from the bay. The solution will be made by combining both, polymer and magnetite and then using magnet with greater strength to extract the remaining aggregation, which is predicted to be on the surface of the water.

Statement of the Problem

Even though there are many locations where algae bloom has caused various problems, the main focus of this study will be on the Chesapeake Bay Region. The Chesapeake Bay Area has been polluted by nitrogen and phosphorus, originating from excessive fertilizer in runoff water, which results in increased algae growth. The algae block the sunlight and create seasonal dead zones. Researchers have tried different methods of removing excess algae from the water. However, the success rate could be improved by the process of using a magnetic polymer. A magnetic polymer will remove the excess algae, which will reduce eutrophication and improve water quality.

Review of the Literature

The algal blooms are the result of excess nitrogen and phosphorous nutrients (Pan, 2006). The introduction of nutrients from excess runoff into water systems causes higher concentrations and increased growth of algae. Because of its inherent genetic superiority, the algae tend to over power plants under these conditions, and cause some plant species to die. In this process, this dead organic matter becomes food for the bacteria that decomposes it. The most effective way to control algal growth is to reduce the nutrient load in the water. To reduce algal cells, an algae removal system needs to be established. Excess nitrogen, phosphorus, and algal toxins stored in the algal cells are released into the water from the excess algae, which accelerates the development of eutrophication. (Li, 2015). A magnetic polymer can be created to remove the algal cells from watersheds, as shown in Lui's (2009) research. This polymer can be composed of a magnetite, ferroferric oxide, and a natural polymer, chitosan. This magnetic polymer will have a higher efficiency rate of algal removal compared to only removing nitrogen

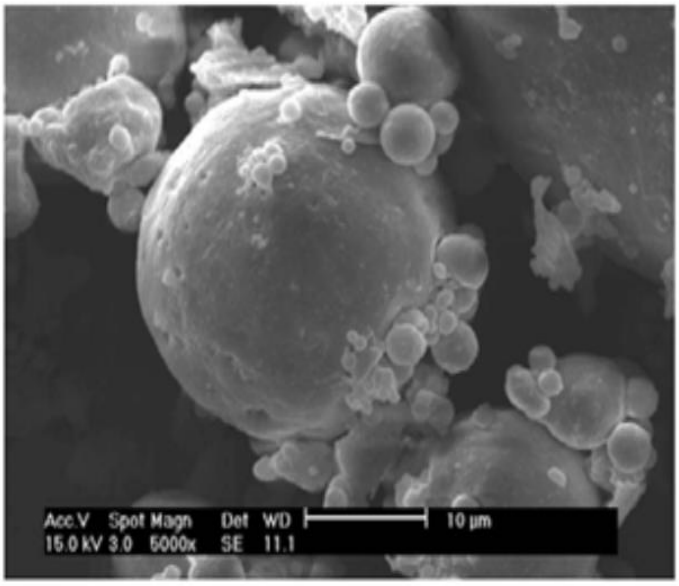

FIGURE 4. Surface Morphology Images of Meso-porous Composite Coagulant.

and phosphorous. The cooperation of chitosan and Fe_3O_4 particles are more effective because chitosan plays an important part in the formation of the algal cells, whereas Fe_3O_4 serves as an effective magnetic indicator in separating the algal cells from the water. The most distinguished advantage of this technique was that the algal cells are kept intact after the removal, which not only avoids secondary pollution but also greatly reduces the waters eutrophication. According to a previous study conducted, the polymer operates ideally when it is composed of 75% of ferroferric oxide, Fe_3O_4, and 25% of a natural polymer (Lui, 2009). Figure 1 and Figure 2 show that a combination of 6 mg/L of Fe_3O_4 and 2 mg/L of a natural polymer will result in an optimum magnetic polymer to remove excess algae in waters.

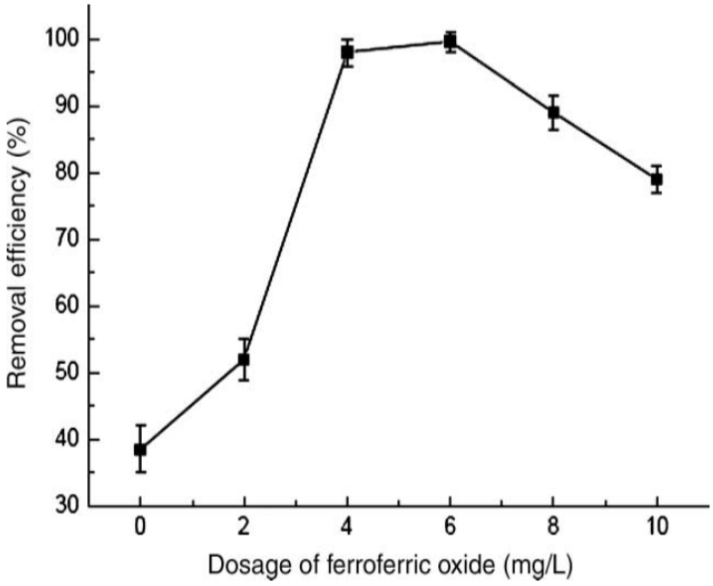

Figure 1 | Effect of different dosage of ferroferric oxide modified with 2 mg/L chitosan on turbidity (mean, SD). $n = 6$.

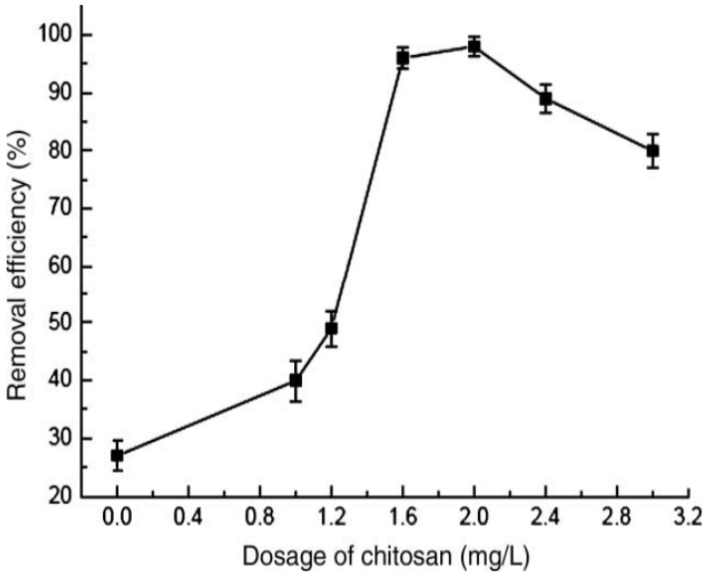

Figure 2 | Effect of 4 mg/L ferroferric oxide modified with different dosage of chitosan on turbidity (mean, SD). $n = 6$.

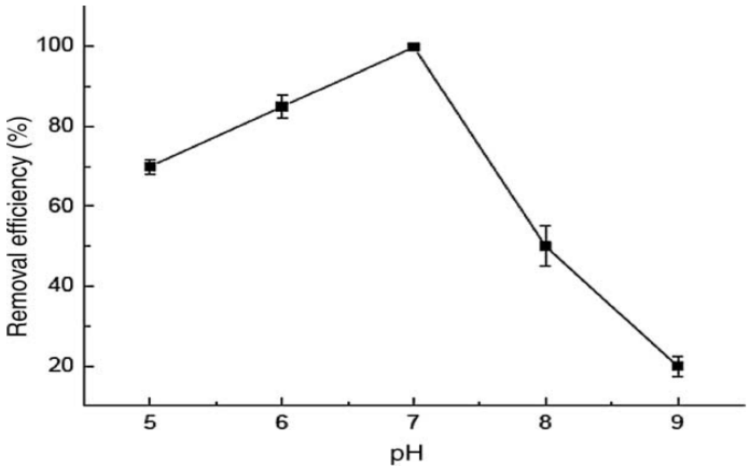

Figure 6 | Effect of pH on turbidity (mean, SD) using 4 mg/L Fe_3O_4 modified with 1.6 mg/L chitosan (0% NaCl). $n = 6$.

The magnetic polymer will also perform at optimum level at a pH of 7, shown in Figure 6.

Purpose of the study

The purpose of the study is to ensure good quality water and to maintain a balanced ecosystem by removing excess algae from the Chesapeake Bay watershed. Considering the results from the previous studies, our novel method of removing excess algae using natural polymers and ferroferric oxide is predicted to be effective. We will use satellite images of the bay with a turbidity detector to locate the specific site of algal bloom. The removal is done by using a solution of chitin, a natural polymer from cellulose of plants and fungi, and ferroferric oxide, which is a magnetite. This solution will aggregate algae on the surface of the water and a magnet with various strengths will be able to extract the algae out due to the help of magnetite. This method will not only remove the algae, but will also be eco-friendly – no bio-hazardous materials or wastes will be produced. The unit of measure will be grams per liter (g/L).

Hypothesis

The process of removing excess algae using a magnetic polymer will be effective because there is a direct relationship between natural polymers and Ferroferric Oxide, Fe_3O_4. The polymers that are being used in the process will result in an efficient removal of excess algae in waters.

The Design

This novel method of removing algae from the Chesapeake Bay region follows similar models from previous studies due to high success rate. Chitin, a polymer that comes directly from fungi and cellulose of plants, will be acquired from Heppe Medical Company. Upon receiving, it will be dissolved with HCl to get a concentration of 1 mg/mL because this helps the chitin to be soluble with ferroferric oxide later in the process. The solution will have a 75% concentration of ferroferric oxide, and 25% concentration of chitin. Then Fe_3O_4, usually red oxide formed by redox reaction of iron and oxygen, is used as a magnetite. To prepare a mixture of chitin and Fe_3O_4, a certain volume of chitin will be added to Fe_3O_4. The mixture will be well stirred, then it will be ready to aggregate the algae cells.

Since this process is more likely to work in freshwater, the experiment will be done where the rivers meet the bay, the estuary. Importantly, this method will be tested on cyanobacteria (*Microcystis aeruginosa*) because they thrive in freshwater. Satellite images will be used to pinpoint the sites of algal blooms. The experiment will be worked on the region that is dark-green in the image, because there are more algae present. After finding a specific region, a 2100Q Portable Turbidimeter (a turbidity monitor) will be used to check for the relative clarity of the water and to see where there is more pollution from biological waste, such as nitrogen and

phosphorus. In the future, the result of turbidity will be used to study about the animals living in that environment. The variables such as the type, and location of algae will be controlled. However, it is statistically impossible to control the variable of physically counting the algae cells.

Method

1. After targeting the area of experimentation, the depth of water, pH, animals, and plants residing in the water will be evaluated. A sample of water and algae will be tested prior to the experiment to record the amount of chemical oxygen demand (COD), nitrogen and phosphorus level. To measure the amount of algae, an Algae Torch will be used. *The Algae torch measures chlorophyll and cyanobacteria content through fluorescence. The probe is submersible in water and has an LCD monitor to view the numbers.*

Fig: Algae torch

2. In order to investigate aquatic life in the water, Wheaton Chromatographic Glass Spray from Fisher Scientific will spray a certain volume mixture of Fe_3O_4 and Chitin, so that if the particles of chitin sink in the bottom, then it is noticeable.

Fig: Glass Spray

3. The concentration that will be sprayed on cyanobacteria will depend on the amount of algae present. If the flocculation of algae exceeds 5 inches, then more concentration will be added. *The concentration in the solution is based by 75% Fe_3O_4 and 25% chitin. The concentration modification of independent variable (solution of mixture) will be 0.0%, 0.01%, 0.05%, 0.1%, 0.5%, and 1.0%, and these will be used depending on the size of algal cells present in the designated area.*

Fig: Aggregation of algae on the surface of water

4. After the solution with certain concentration is sprayed, it will take approximately two hours for algae to aggregate and float on the surface of the water, but again, the time depends on the size of the area of experimentation.
5. Subsequently the algae flocculates, then a magnet with be used to extract the algal cells clustered together by the natural polymer and magnetite. The magnet is predicted to be useful because since the magnetite is present within the algae cells after exposing them to magnetite, the magnet will not let algae sink to the bottom of the estuary and therefore prevents secondary eutrophication. Importantly, neither the magnetite nor the magnet will damage the algae components. (Liu) *The magnetic field ranges from 0.5T, 1.0T, to 1.5T, but the strength used will depend on the size of the area of experimentation, as 0.5T will be used on algae accumulation of below 5 inch in a certain area.*
6. This process will be conducted 3 times in the same region to ensure that the process is removing algae.

Data Analysis

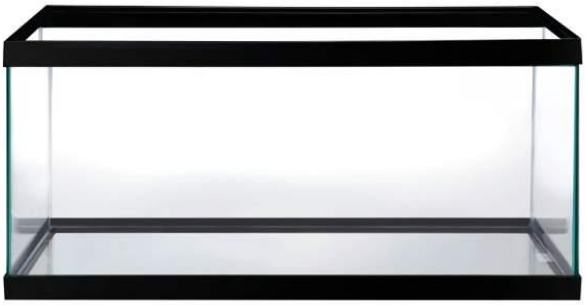

Fig: Tank to hold algae

After using a magnet to gather the algae cells, they will be placed in a glass tank with the capacity of holding 100 gallons of fluid obtained from MarineLand. Since previous studies have shown that glass does not affect algae cells' structure, it is suitable to place the cells in the tank. Then the tank will be taken to the lab for analysis because performing the tests in the bay area is not favorable due to temperature change and environmental hazards.

Left: Fig- Hydra Nitrate Analyzer

Right: Fig- Lachat 8500 Flow Injection Analyzer

The goal is to get the algae to the lab as soon as possible to prevent any damage. Only one area will be focused at a time until the whole process is completed on it. First, the levels of COD, nitrogen, and phosphorus from the certain area will be measured and recorded in the lab. Lachat 8500 Flow Injection Analyzer will be used to measure phosphorus, while HYDRA Nitrate Analyzer System from Electro-Chemical Devices, Inc., will be used to measure nitrogen in the water collected from the estuary.

Then, the same tests will also be performed at the estuary where the experiment was executed after taking excess algae out. These tests are necessary in finding the effectiveness of

removal of algae from the Bay because Nitrogen and Phosphorus are the two key ingredients for algae bloom. The amount of excess algae, nitrogen, and phosphorus are expected to lower at least by 85% because of similar results from previous studies. After performing these tests, the aggregation (algae) from the estuary will be placed in a centrifuge to separate the algae from water. Then, the algae particles will be studied for potential biofuel and fertilizers because algae are full of nutrients that have the ability to play roles of organic fuel and fertilizers.

Potential Error

The first expected error is that the satellite image might not be effective in case of cloudy days, which could impede the experiment to be performed in the impacted area. Also, if the mixture of Fe_3O_4 and chitin do not mix well due to the temperature fluctuation during shipment of the materials, that is a big problem, which is why 5 to 6 trials will be implemented. Importantly, if the magnetic field that is used for specific size does not attract to the magnetite, then it is likely that secondary eutrophication will happen. The work will be done efficiently and effectively to minimize errors.

Limitations/Delimitations

The satellite imaging is only available when the skies are clear, limiting our ability to target blooms under poor weather conditions.

The efficiency of removing algae rapidly decreases as pH increases, with maximum effectiveness at pH of 7. As waters become saltier the pH begins to increase. We reason that the removal efficiency will decrease substantially in salt waters. Furthermore, algae samples were taken from fresh water and suspended in pH 7. Salinity has not been measured as a variable, which

may affect removal efficiency. Because of this study limitation and the pH increase of salt water, we have chosen to target freshwater algal blooms in the Bay. Integrating satellite technology and surface salinity maps of the Bay can pinpoint these freshwater regions.

We have also decided to focus on removal of algal blooms, rather than reduction of dissolved nutrients in the Bay. While the blooms are a product of excess nutrients, we believe that the solution to the excess nutrients is in the hands of lawmakers and the officials that implement these laws. One such solution to excess runoff is set to happen in Washington D.C, whereby the sewage system is being updated to capture runoff in catchments during heavy rainfall. This runoff is then slowly fed through wastewater treatment facilities when the rain subsides. This update will greatly reduce the chemical runoff from the D.C area during storms, helping to combat the high nutrient loads in the Bay. As well as this, large deposits of nutrients have settled at the bottom of the bay over many years of bloom cycles. As the water in the Bay is stirred through ocean tides, these nutrients often find their way into the water column, acting as fuel for the next bloom. It is important to target the blooms so that we can control the health of the bay while the sources of pollution are pinpointed and removed.

Significance of the Study

This study is significant because our use of a natural polymer (chitin) and ferroferric oxide to remove excess algal cells is predicted to be effective. According to the data, this method will not only remove the algae, but will also be eco-friendly; no bio-hazardous materials or wastes will be produced (Liu, 2009). By using self-made magnetic separation polymer, rapid separation of algal cells captured from lake water could be executed. This will prevent the biodegradation of the algal cells in the sediment. With the funds for further research, this technique could be highly effective

and quick for emergency needs to clear up harmful algal blooms in freshwater, which not only causes no second contamination but also greatly reduces the Chesapeake Bay's eutrophication (Beth, 1998).

If this study would be funded, the entire aquatic ecosystem within the Chesapeake Bay could be sustained, and the plants and organisms can thrive more without all the excess algae. Future, more efficient and cost friendly, methods of algal cell removal will also be established, and other watersheds could be aided with this method if needed.

Acknowledgement

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