Principles of Bioremediation: Engineering Wastewater Solutions in Remote Locations

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Research Key

Bioremediation: the use of organisms to fix an environmental problem

Biodiesel: an environmentally friendly biofuel alternative to diesel

FFA: free fatty acid; a fatty acid tail that is not attached to glycerol

Acid esterification: a chemical reaction that utilizes an acid catalyst to produce biodiesel from oil. Acid esterification removes FFAs from vegetable oil, essentially "cleaning" high FFA vegetable oil.

Transesterification: a chemical reaction that utilizes a basic catalyst to produce biodiesel from oil. Transesterification is an efficient process for producing biodiesel from low FFA vegetable oil.

Background

The Bahamas is classified by the United Nations as a Small Island Developing State (SIDS). SIDS have many unique challenges, one being that they are extremely reliant on imported fossil fuels for energy production and automotive fuels. The Island School has been proactive in addressing this challenge by designing and building a Waste Vegetable Oil (WVO) to biodiesel production facility in 2002.

Biodiesel is a great alternative to buying imported diesel because it burns cleaner than conventional diesel. The production facility is capable of producing enough biodiesel to fuel all the vehicles, generators and farm equipment on the Island School campus. However, as of right now, there is not enough biodiesel being produced to run everything solely on this alternative fuel.

Research Objective

In order to produce more biodiesel, the biodiesel facility has introduced a new system called acid esterification. Acid esterification is a way to pretreat high FFA vegetable oil to produce low FFA vegetable oil. This "cleaner" oil can then be used to produce biodiesel through the efficient process of transesterification. Unfortunately, acid esterification creates an effluent that contains water, vegetable oil, biodiesel, methanol, sulfuric acid, glycerol, and soaps.

By taking a whole systems approach to biodiesel production, this research team designed a bioremediation system intended to remove these contaminates from the effluent in order to produce clean, useable water. The overarching goal of the Bioremediation Research team was to create a low tech, gravity fed system that included local, readily available plants so that it could be sustainable at the Island School and act as a model accessible to the larger community of the Bahamas.

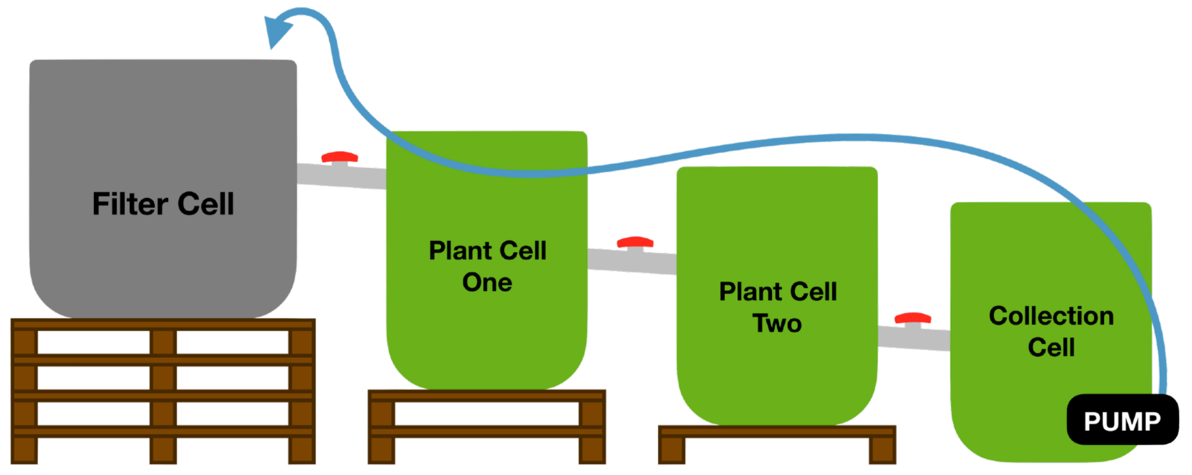


Figure 1: A graphic representation of the initial prototype design, showcasing the four cell system.

Image 1: Current prototype of the treatment systems built and constructed with 85% recycled material found at the Island School.

Image 2: Ezra Smith working hard to cut PVC pipe that eventually connected the separate cells in the treatment system prototype.

Image 3: Nick Healy and Alexis Saunders pumping the biodiesel tanks in preparation for a revamp of the biodiesel facility at the Island School.

Engineering Approach

The initial prototype design consisted of three systems of four cells per system (Figure 1). The first cell is a filter cell, containing filter materials such as seaweed or biochar. The next two cells are the primary bioremediation cells, containing plants such as duckweed, algae, sedge grass, or biomedia, which is a substrate for bacteria. The fourth and final cell is the collection cell, which contains a pump that recirculates the water containing the liquid effluent back into the system via the filter cell.

After some field engineering, a current prototype was constructed. The three treatment systems are all gravity fed, and retain the four cell layout of the initial prototype design. The focus was initially on material choice, overlooking the fact that even the finest grain or sediment has the potential to clog an entire system. The research team adjusted the design in the field in order to reduce this unexpected clogging. Key modifications included adjusting the orientation of the pre filter cell window screens and adding screen filters in front of the output valves of each system.

After fixing the design flaws in the system, most noticeably the clogging, experimental trials to determine what treatments systems most efficiently produced clean useable water were able to be conducted. The first experimental trial was in fact run with clean water to understand the inner workings of the design before bringing in the liquid effluent being treated. After the system was ready to filter the waste liquid effluent from the acid esterification reaction, a second trial began.

Image 4: The Bioremediation team discussing potential solutions to the clogging in the treatment system filtering the liquid effluent.

Image 5: Research advisor Bryan Carroll lecturing the Bioremediation team on problem solving in the field.

Image 3: Clean water flowing through one of the three treatment systems into a jug of sedge grass.

Analysis of Results

The results of the second trial, which used a one to one ratio of effluent to water and had three treatment systems, are displayed as graphs to the right. Treatment one consisted of biochar in the filter cell, sedge grass in cell two, and duckweed in cell three. Treatment two consisted of seaweed in the filter cell, biomedia in cell two, and sedge grass in cell three. The third treatment system consisted of seaweed in the filter cell, duckweed in cell two, and algae in cell three.

The first objective of the systems was to lower the pH of the effluent in order to be close to the pH of clean water, which is pH 7. The second objective was to reduce total dissolved solids as much as possible in order to attempt to achieve distilled water quality, which has zero dissolved solids. The third objective was to have consistent flow rate between each cell of the system.

As hypothesized, treatment system one was the most effective in lowering the pH levels and reducing the total dissolved solids (Figure 2). Furthermore, treatment one also had the most consistent flow rates between each cell (Figure 3). Unfortunately, after conducting the experiment for 48 hours, there was a 100% mortality rate among the bioremediation plants. While this result was not expected, or enthusiastically anticipated, it is a valuable result nonetheless. This result shows that the plants were unable to survive the amount of effluent that was used. Thus, a lower concentration of effluent to water should be used in future trials.

Conclusion and Next Steps

Based on the results from the trials, it can be concluded that a combination of biochar, sedge grass, and duckweed in a bioremediation system is the most effective at removing the contaminants from biodiesel production effluent. However, this combination was not 100% effective at producing clean water from the effluent. To achieve the research goal, which was to produce clean useable water, more trials with different ratios of effluent should be conducted.

If successful, this bioremediation research will allow biodiesel production at the Island School to become more sustainable with less over all environmental costs. The future goal of this project is to create a permanent full scale bioremediation system at the Island School campus. Furthermore, a successful system could act as an accessible model to the rest of the Bahamas, incentivizing biodiesel production in other parts of the country by reducing the final amount of effluent produced. Because the Bahamas is a SIDS, a lot of the waste produced on its islands must be shipped to more developed countries, like the United States, in order to be properly disposed. Low tech and inexpensive bioremediation systems in the Bahamas would make domestic effluent treatment more feasible and also more environmentally friendly, because shipping, which emits CO2 into the atmosphere, would be reduced.

By taking a whole systems approach to biodiesel production, by looking at the interrelated parts of the system, the Island School is looking to divert past, present and future waste streams. More specifically, the Island School can't focus only on the benefits of biodiesel production without looking at the potential negative effects on the natural and built environment. By aspiring to fuel the Island School with what was previously fry oil, the Island School is making a statement to the broader community that many small steps equal a big leap; in other words, progress.

Figure 2: Results of Experimental Trial 2, testing pH and total dissolved solids for the three treatment systems

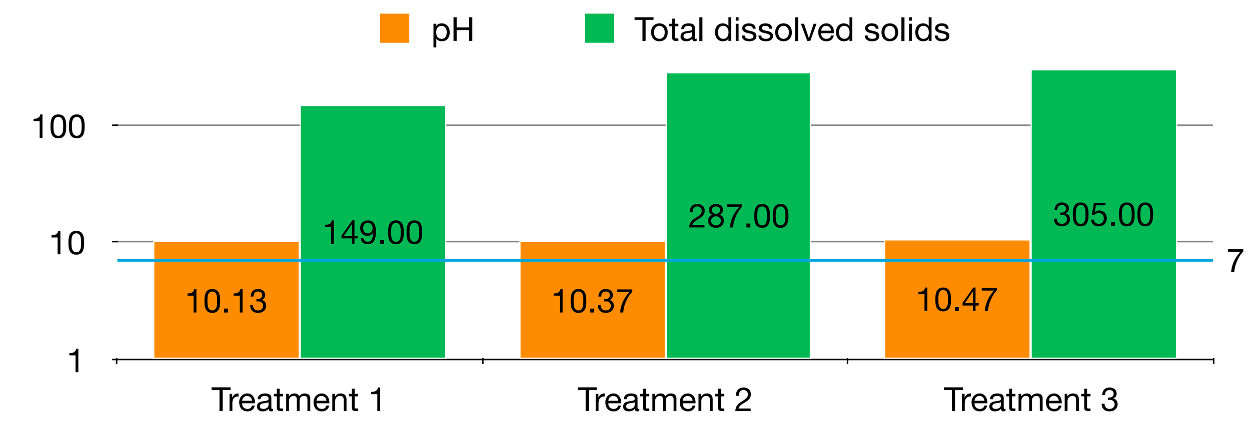
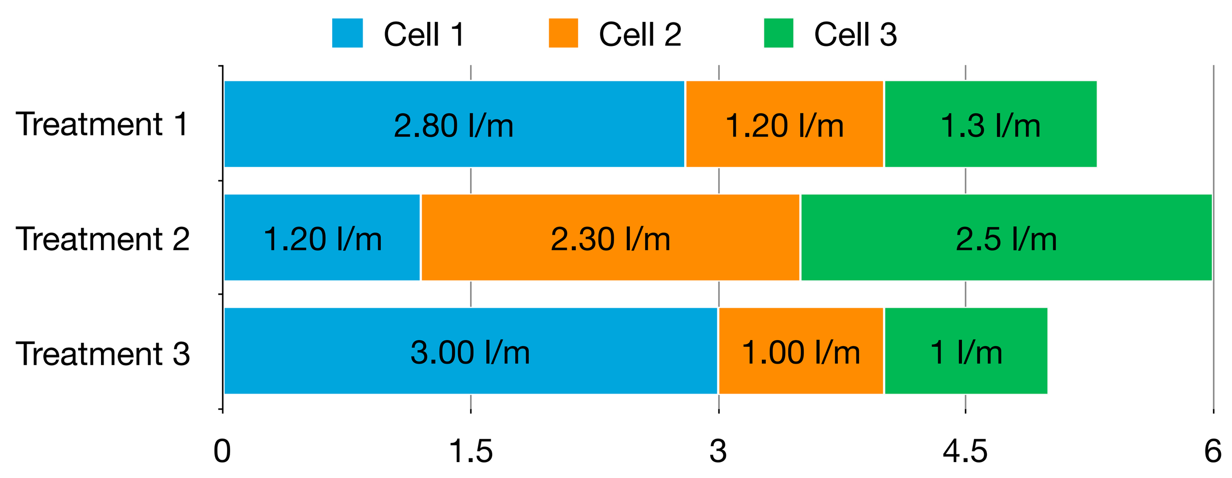


Figure 3: Results of Experimental Trail 1, testing flow rate per cell (l/m)



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