Algae Bioreactor for Biodiesel Production: A Student Capstone Design Project (Paper 218-23-Williams)

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Introduction

- Algae are a diverse group of aquatic organisms.
- Like other plant life, they use photosynthesis to convert sunlight into various carbohydrates, proteins, and oils.
- The proteins produced can be a great source of nutrients for human consumption. There are 3 main inputs vital to algae growth: sunlight, CO_2, and nutrients.

  - The nutrients most vital to algae growth are nitrogen and phosphorus.
  - Most algae are unicellular organisms containing around 50% (by mass) lipids. The oil derived from algae can be used to make biodiesel fuel.
  - Algae can grow in salt water and contaminated areas.
- Algae removes CO_2 from the air and use it for photosynthesis.
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- Biodiesel fuel is produced through transesterification of oils from algae or other fatty materials and can be used in unmodified diesel engines and jet engines.
- Algal biomass can produce up to 10 times more oil per hectare than traditional biofuel crops.
- Algae thrives on excess CO_2. Prime locations: next to existing power plants.
- Algae are responsible for a substantial portion of global oxygen production and CO_2 sequestration.

Production of algae-based biodiesel 6 steps

- Growing the algae
- Harvesting the algae
- Dewatering The algae
- Extraction of the oil from the algae
- Conversion of the oil into biodiesel (transesterification)
- Biodiesel purification process with water (wet washing method)

System Design

- The bioreactor built utilizes a vertical design.
- 3 bins, stacked on a shelving unit serve as the growing area.

  - The top of each bin is open to allow CO_2 capture from the air for use in the photosynthesis process of the algae.
  - A drainage system was made by attaching a ball valve to the bottom of each bin. This allows the algae culture to be partially drained into the lower bins for both diluting and collecting the algae.
  - The algae culture was started by filling the top tub with 34 litres of pond water containing algae.
- At the start of each week, 59 ml of garden liquid fertilizer was added to the culture to replenish lost nutrients in the system.
- Every other day, 5 ml of potassium nutrients were added to the algae culture.
- After 2 weeks of growing, the algae culture was separated equally into the top and middle bin. Each bin was topped off with 15 litres of clean water to dilute the algae culture so that it could continue to grow.
- After another 2 weeks, this process was repeated. The total growing period of the algae culture was 4 weeks, in which the final water volume was 95 litres.

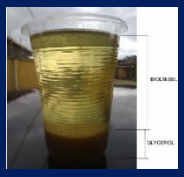
Algae Collection and Oil Separation

To make biodiesel, the oils contained in the algae needed to be separated from the algae membrane. First, the algae were collected by draining the algae water through a cheesecloth filter. This separated the algae from the water so that the oils could be extracted from the algae. This process yielded 1420 ml of algae. Next, the algae were run through a tomato processor to break down the cell walls, then run through a meat grinder to further break down the cell walls of the algae. This process created a paste that was then frozen and thawed multiple times over the course of 5 days. Freezing and thawing the algae breaks down the algae paste enough to allow the oil to escape the algae. The oil was then filtered from the remains of the algae to achieve as close to a pure oil as possible. However, due to filtering limitations, the oil yielded from this process was not free from algae contaminants.

Biodiesel Production

- Algae biodiesel is typically made by mixing the algae oil with methanol and lye (sodium hydroxide); however, we used isopropyl alcohol instead of methanol.
- To convert the algae oil obtained from the system to biodiesel, the oil was mixed with isopropyl alcohol and lye.

  - For 591 ml of algae oil, 5 grams of lye and 296 ml of isopropyl alcohol were used. The mixture was stirred for 10 minutes to allow the fat from the oil to separate from the glycerin which settles at the bottom of the mixture. This forms a thick clump of fat and any leftover algae that remained in the oil.



The Results

- After 4 weeks of growing the algae, a total yield of 1420 ml of algae was obtained.
- The amount of oil extracted out of the collected algae was 591 ml.

  - Typically, algae contain 50% oil by mass. We obtained 42% oil by volume.
  - This can be improved by using more efficient methods for oil extraction. One such method could be to compress the algae oil out of the algae.
  - We yielded 532 ml of biodiesel from the oil, which equates to a 90% biodiesel yield.
  - Losses result from the fat separating out of the oil and accumulating at the bottom of the mixture.

Additionally, the leftover algae membranes that made it through the oil filtering process mixed with the fat, and contributed to the losses as well as the green coloring.

The System Cost

The total budget allocated to this *student capstone design project* was USD 400. The team was able to design a system which used approximately USD 280 of the budget for resources and components such as water bottles, shelving, CO_2 supply, PVC piping, tubing, and an algae culture growth kit for the initial design. Due to design changes and unforeseen complications with the algae culture growth kit, the team effectively retrofitted the initial system and its components for a final system that cost approximately USD 140 to produce. Components used for the final design incorporated shelving, totes, PVC piping, ratchet straps, and lye water. Areas of improvement for the system include keeping large particulates out of the system with covers or screens for the totes. Another design improvement that could be made to the system would be to devise a way to integrate the biodiesel production process into the algae growth system.

Safety Considerations

The process of transesterification should only be carried out with extreme caution while wearing an approved lab coat, goggles and gloves.

Summary

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  - We yielded 532 ml of biodiesel from the oil, which equates to a 90% biodiesel yield.
- Total cost of this 11-week student project was about 262 €.
- The current cost of biodiesel derived from algae is much higher than traditional petro-diesel derived from petroleum.
- A study conducted by Auburn University found the average cost of biodiesel to be 7.67 €/litre in California, far above the current cost of traditional petro-diesel.
- This student design project was carried out during summer in Flint, Michigan.
- Implementing a similar project outdoors is not recommended during cold and cloudy seasons.

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