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ARTICLE

Algae-Based Carbon Capture System (ABaCaS): A Sustainable Solution for CO_2 Emissions

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According to the US Environmental Protection Agency (USEPA), the burning of fossil fuels for electricity and heat accounts for 25% of global greenhouse gas emissions, which in turn contribute to climate change (USEPA, 2017). Despite the impressive growth in renewable energy, the International Energy Agency (IEA) and the US Energy Information Administration (USEIA) have estimated that fossil fuels will still account for 77% of all energy produced in 2040 (IEA, 2017; USEIA, 2017). Therefore, it is crucial to develop a sustainable solution that can effectively reduce the release of CO_2 into the atmosphere without causing additional financial losses to fossil fuel-based power industries.

INTRODUCTION

Research shows that algae have a very high photosynthetic efficiency in capturing CO_2 from the environment and also they are abundantly available in nature (ABO, 2017). Microalgae are the microscopic unicellular species which exist individually or in chains or groups. They are typically found in freshwater and marine systems, living in both the water column and sediment. Usually, the photosynthetic efficiency of algae is higher than land plants because it has superior abilities to capture light and convert it to functioning chemical energy. When growth conditions are ideal, most of the algae's energy is directed into cell division, yielding rapid biomass accumulation. Since, microalgae do not need energy-intensive supportive structures such as stems and roots (unlike land plants), large quantities of biomass are saved. Thus, algae-based biomass is more feasible for biofuel production (Andersen & Lewin, 2018).

However, the question is whether an algae-based bioreactor can reduce the release of CO_2 into the atmosphere after the burning of fossil fuels. It was hypothesized that an Algae-Based Carbon Capture System (or ABaCaS) can be an effective, efficient and sustainable technological solution to reduce the release of CO_2 into the atmosphere after the burning of fossil fuels. The following experiment has developed ABaCaS and it has two phases with the following objectives:

Phase 1: to explore natural algae's natural capacity for capturing CO2 produced by the burning of kerosene (a fossil fuel like gasoline).

Phase 2: To explore the roles of various essential inputs (heat and light) in capturing CO_2 using microalgae (Nannochloropsis).

The variables for the projects are a) Independent - CO_2 utilization by algae; b) Dependent - Algal growth, pH; c) Controlled - Algae, CO_2, exposure to sunlight and Ultra Violet (UV) light.

MATERIALS AND METHODS

Phase 1

Materials: 7 transparent plastic bottles (500mL), an oil lamp, refined kerosene (10 mL or 8g) (Wikipedia, 2018), an airtight storage box, an electrical air pump, freshwater algae gathered from Waterford Bridge River at Bowring Park, St. John's (Newfoundland), lab filter papers, 48 syringes (10 ml each), tubes (glass and rubber), a heat mat, a UV lamp (plant-specific LED), and a thermostat.

Developing the ABaCaS: The CO_2 Production Unit (CPU) (figure 1) was built using a kerosene lamp, the glass chimney of which was fitted with a tube connected to the CO_2 Holding Chamber (CHC) (Figure 2). The CHC was an airtight box fitted with syringes, an air pump, and a tube (blue) connected to the Algae Chambers (AC) (Figure 3 and 4). The AC consisted of seven interconnected plastic bottles (experimental bioreactors), each filled with water and a tiny amount of algae that was collected by scraping it off rocks in a local brook. The AC was placed on a heat mat

Figure 1. The CO_2 production unit.

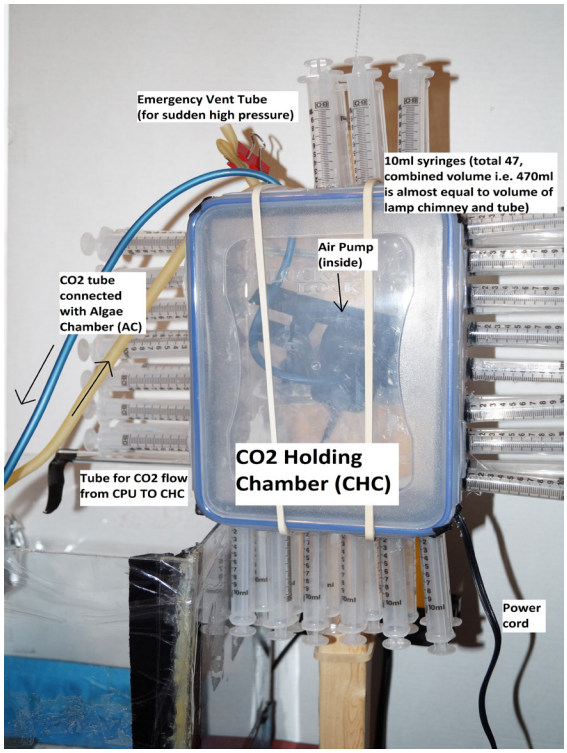

Figure 2. CO_2 Holding Chamber (CHC).

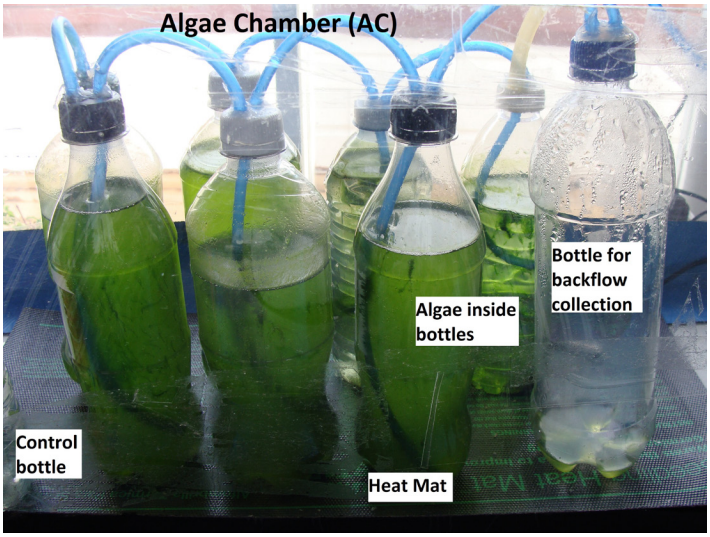

Figure 3. Algae chambers (AC).

and joined by tubes (yellow) with the CHC.

Daily activities and collection of algae: The lamp was lit for 5-10 seconds to produce CO_2 which was trapped in the CHC by pulling the plungers of the syringes and creating negative pressure. The air pump was then run (average 3.4h/day) to pass the trapped CO_2 into the AC. At night, the UV lamp was turned on for photosynthesis to continue. The temperature was recorded twice daily and the running time of the pump was recorded once daily.

The algae grew rapidly and spread across the experimental bioreactors. After burning of 8g of kerosene (in 40 days), the algae

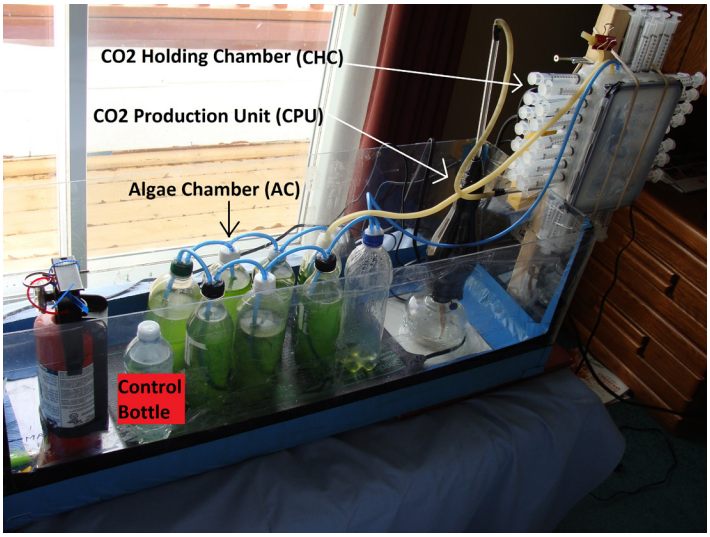

Figure 4. Assembled Algae-Based Carbon Capture System (ABaCaS).

were collected by scraping the sides of the bottles using filter papers and also using a Büchner flask to filter the algae in the water from 7 bioreactors using filter papers (75 total for scraping and flask). The filter papers were then dried and kept at room temperature for 3 days.

RESULTS

Calculation of Carbon (C) from CO_2 produced by kerosene ($C_{12}H_{26}$) burning: Two types of reactions occurred: a) $C_{12}H_{26}+8\ O_2 \rightarrow CO_2+10\ C+13\ H_2O+CO$ (incomplete combustion, producing carbon black); b) $2\ C_{12}H_{26}+37\ O_2 \rightarrow 24\ CO_2+26\ H_2O$ (complete combustion) (Wikipedia, 2018). Although in ideal conditions 10% of the C12H26 was converted to carbon black (Lam et al., 2012), in my experiment I assumed the conversion rate was 20%. Therefore, 80% of the burned C12H26 contributed CO2 to the algae. The weight of C of 80% of 8g of $C_{12}H_{26}$ = {8x ((12x12)/171)}x0.8 = 5.4g

C captured by algae: The weight of 75 dry filter papers with algae = 21.1g; the weight of 75 unused filter papers = 15.05g. So, the weight of dry algae = 21.1-15.05 = 6.15g

Estimated C in dry algae (40% of total dry weight) (Sayre, 2010) = 2.5g

Conclusion of Phase 1: Percentage of C captured by algae was 46% ((2.5g/5.4g)x100). Therefore, algae has a high potential to capture CO_2 from the burning of fossil fuel.

Phase 2

In order to explore the roles of various essential inputs, such as heat and light in capturing CO_2 by microalgae (Nannochloropsis), the phase 2 experiment was conducted.

PROCEDURE

The Freshwater algae were replaced with microalgae Nannochloropsis, provided by the Ocean Sciences Centre (OSC, Memorial University). A new CPU was built using vinegar and baking soda for the more accurate measurable production of CO_2 and pH strips

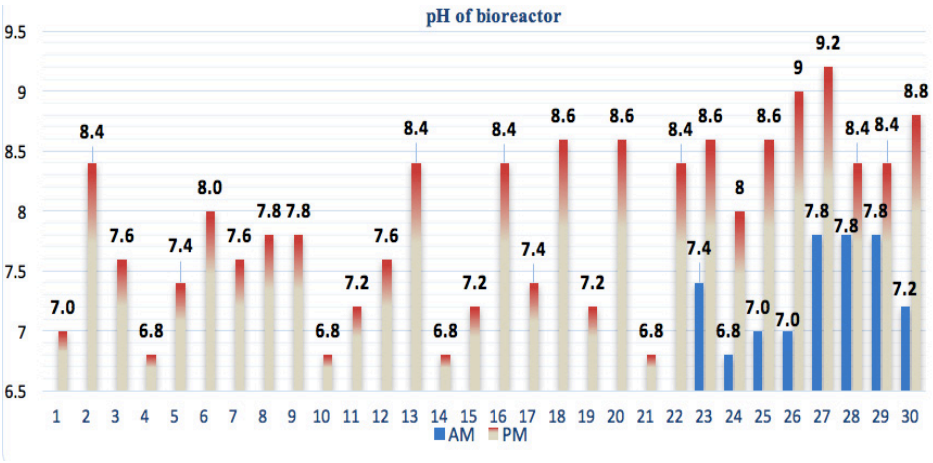

Figure 5. Optimization of daily CO2. Day 1-22 with daily testing dose (3.5g), day 23-30 with optimized dose (1.7g)

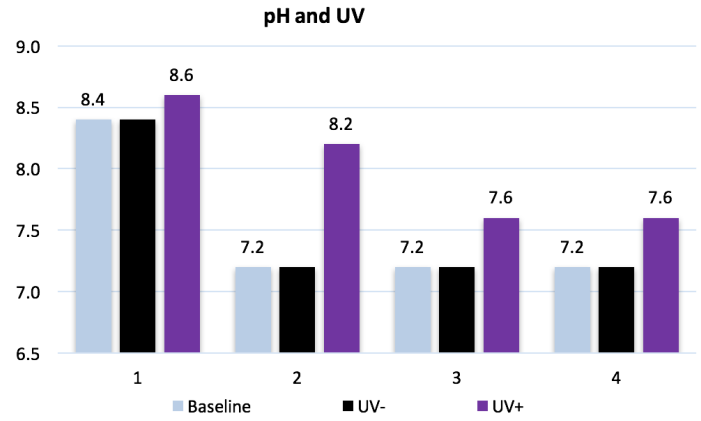

Figure 6. Impacts of UV on pH of bioreactors.

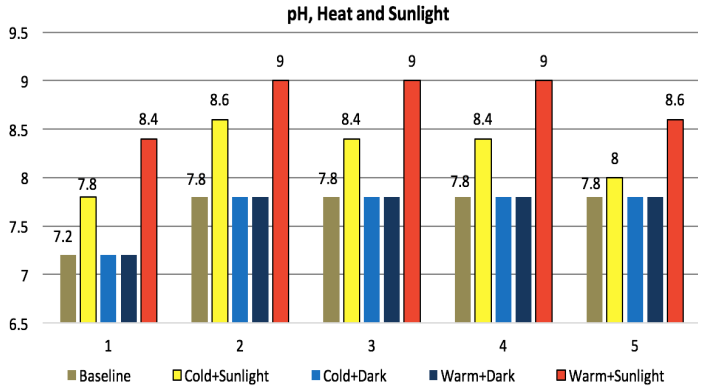

Figure 7. Impacts of heat and sunlight on pH of bioreactors.

were used to measure the relative presence of dissolved CO_2 in experimental bioreactors containing microalgae. Other materials used were the same as indicated in Phase 1.

Daily activities: CO_2 (produced by reacting vinegar and baking soda) was trapped inside the same CHC and passed through the ACs by running the air pump.

A. Optimization of daily CO_2 dose - Testing dose (two-quarter spoon i.e. 3.4g) of $NaHCO_3$ was added to CPU (at 7 pm) for maintaining daily optimum pH (range 7.5-8.5) of bioreactors for best algal growth (as suggested by the OSC) for 22 days (fig 5). Some days pH recorded very low (even before CO_2 infusion) of bioreactors resulting in interruption of daily CO_2 infusion. From 23rd to 30th day, the daily dose optimized to one-quarter spoon (1.7g) for the maximum photosynthetic efficiency of the bioreactors. Checking pH twice a day (7 am and 7 pm) showed nearly optimum pH range. The average pH of 7am and 7pm were 7.4 (95% Confidence Interval = 7.1 - 7.7) and 8.6 (95% Confidence Interval = 8.3 - 8.9) respectively. The dose (1.7g) was accepted for subsequent input analysis. A control bioreactor was made and supplied with atmospheric air by a separate air pump.

B. Testing impacts of daily inputs i.e. sunlight, UV, and heat – Microalgae from 6 bioreactors (1L each) were mixed in a large container and their pH was measured as the 'baseline' and all the bioreactors were refilled. The bioreactors were separately exposed to the inputs for 12 hours and the carbon capture efficiency was checked by the differences in pH. 1) For testing the impacts of UV (7pm-7am), 5 bioreactors were kept under UV lamp and 1 was covered with aluminum foil to prevent the entry of UV rays. All the bioreactors were kept on the heat mat (average temperature of 28.8°C (95% confidence interval = 28 - 29.6°C)). The pH of 'exposed' (UV+) and 'non-exposed' (UV-) bioreactors were checked at 7 am every day. The test continued for 4 days. 2) For testing the impacts of sunlight and heat (7 am-7 pm), 2 bioreactors (one wrapped with aluminum foil) were kept outside in an open space (~0°C). The site received direct sunlight for 6 hours a day. Another 2 bioreactors (one wrapped with aluminum foil) were kept on a heat mat. The room also received direct sunlight for 6 hours. Every day at 7 pm, the pH of 4 bioreactors were measured separately. The test continued for 5 days. Every day, the optimum dose of CO_2 was produced and infused into the 6 bioreactors for 12 hours (7am-7pm while testing the impacts of UV and 7 pm–7 am while testing the impacts of sunlight and heat).

RESULTS

Except in the controlled bioreactor, the microalgae became denser in the experimental bioreactors. For the complete capture of CO_2 by 6 liters of microalgae, 1.7g of $NaHCO_3$ was determined as the optimum dose.

The pH of the bioreactors exposed to UV had increased (average increase of pH – 0.5). There was no change of pH of the unexposed bioreactor (Fig 6). Sunlight exposed indoor bioreactor had higher rise of pH (average increase – 1.12) than the sunlight exposed outdoor bioreactor (average increase – 0.56) (Fig 7). The rise of pH in the bioreactors, exposed to UV, sunlight, and heat indicate their essential roles in photosynthesis and in turn the capture of CO_2. However, the changes in pH indicate that sunlight and heat

are stronger factors than UV.

DISCUSSION

The experiment shows that microalgae such as Nannochloropsis has high capacity to capture CO_2 from the burning of fossil fuel. For maintenance of algal growth, light and heat are the essential inputs for maximizing the CO_2 capture capacity of ABaCaS. However, further research is needed to develop more robust technology. Measuring pH of water can be an important monitoring tool for CO_2 infusion and capture by microalgae.

There are several limitations of the experiment, such as; a) the proportion of the CO_2 captured by Nannochloropsis could not be measured, b) pH strips was not a reliable technique to measure exact pH (like any pH meter), c) since the experiment was done at home without a laboratory set up, several parameters could not be measured, such as power utilization (in watts) and growth of microalgae (by counting the number of cells per cm2 by using hemocytometer). My research also didn't have scope to explain the alkalinity of the water (pH above 7). When CO_2 was infused with the algae, water pH dropped due to formation of carbonic acid. Ideally, after full utilization of CO_2 by photosynthesis the water should have gone back to the pH of normal water. Instead, the pH increased above 8 on certain days. To explain this phenomenon more research is required.

Despite several limitations, the ABaCaS has great potential to reduce greenhouse gas emission from burning of fossil fuel in power sector. In fact, Nannochloropsis cultivation represents a low risk for fossil fuel-based industries (Mondal et al., 2017). Free heat from power plant costs nothing for heating bioreactors. Recovered Nannochloropsis can bring additional revenue for the industry by using them to create biodiesel, using them in aquaculture, pharmaceuticals, cosmetics, and purchasing carbon credits from investment firms (as a carbon offsetter) (Selin, 2011). Recently there has been a lot of interest and investment in the development of microalgae to produce biofuels. There are several advantages of microalgae-based biofuels, for example, high yields and lesser requirement of land (as compared to terrestrial crops) due to higher ability to capture CO_2. With microalgae, all the biomass can be harvested at any time of the year, rather than seasonally.

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Aaron Sarkar is a grade 11 student at Holy Heart of Mary High School (St. John's) and pursuing full IB diploma program. Aaron is very passionate about science, especially in new and innovative discoveries. In free times he enjoys going to gym, play basketball, and playing flute, reading books. His future plan for the project is to advance his research in the field of algae-based carbon capture system.