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Technical Note: DEVELOPMENT OF A PHOTOBIOREACTOR FOR MICROALGAE CULTURE

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Abstract

In view of the technical and biological limitations of open pond systems, a study was conducted to develop a cost-effective experimental photobioreactor that would permit efficient cultivation of microalgae for biodiesel production. The photobioreactor was developed using low cost materials, cylindrical translucent tubes and plexiglass. The photobioreactor prototype was equipped with alternative arrangement for light source: solar and fluorescent bulb light. It provides uniform illumination by sunlight and a centrally located fluorescent light powered by electricity and rechargeable dry cells. The 12-chamber photobioreactor each measuring 122cm tall and 36cm in diameter approximately 12 liters; in all, occupies a minimal demand on land area. The 12-chamber photobioreactor produced approximately 430gram/day with the application of 2.4 litres of liquid poultry droppings.

Keywords: photobioreactor, microalgae, culture, translucent tubes, plexiglass

1. Introduction

An increasing number of developed and rapidly developing nations see biofuels as a key to reducing reliance on fossil fuel, lowering emissions of greenhouse gases (GHG) and meeting rural development goals [1]. Commercial biofuel however is currently produced from food crops such as maize, soybean and vegetable oils whose competition with edible vegetable oil for agricultural land is still a controversial issue [2]. These feedstocks could instead enter the animal or human food chain, so that as global population continues to rise, their use in the production of biofuels does not lead to food shortage and price increase [3]. To avert the looming crises situation, non-edible source of oil are being investigated for biodiesel production. One of these is microalgae. Microalgae have thus been widely recognized as a good feedstock for third-generation of biofuels [4]. However, mass production of microalgal oil faces a number of technical hurdles that render the current development of the algal industry economically unattractive [5] such as low temperature and pH ranges, insufficient nutrient concentration and low carbon dioxide, etc.

There are two main microalgal cultivation systems, i.e., open pond and closed photobioreactor (PBR). Open pond system entails comparatively low capital investment and operational costs. However, it is characterized by low productivity which is its main drawback. Cell mortality and contamination are often common and are caused by high light intensity, difficulty in the control of temperatures and system circulation [6] [7]. In a PBR system, algae are cultivated in suspension, but the system is closed and illuminated by artificial light. Nutrient and gas levels are closely monitored and adjusted continuously. The PBRs have the advantages of high productivity, low contamination, efficient CO_2 capture, continuous operation, and controlled growth conditions [8]. However, their major drawbacks in contrast to the open system are the high capital and operating costs. This is especially more worrisome when PBRs are needed for experimental purposes. There are many design and operational challenges which need to be resolved before commercial production of microalgae using PBR can be considered as recommended in literatures. Intermediate systems have also been designed, such as open ponds under greenhouses which allow a more controlled environment. Most of the existing closed systems are either very costly or suffer from significant operating limitations, or both [9]. Therefore, there is need to develop a low cost photobioreactor for culturing microalgae. The objective of this study is to develop a cost-effective experimental photobioreactor that would permit efficient microalgae production for biodiesel production.

2. Conditions for Growing Microalgae

Microalgae require an energy source, either light energy for autotrophic growth or an organic compound for heterotrophic growth [10]. Recommended range of light intensity for growing micro-algae is 2500 – 5000 lux [11] which depends on a number of factors. In the use of artificial source of light, fluorescent tubes emitting either the blue or the red light spectrum are preferred as being the active portions for photosynthesis. The best choice for an artificial light source during the night is the fluorescent cool daylight lamps (colour: 6500 K; efficacy: 89–104 lm W^{-1}) as they resulted in the most stable production [12]. Growth in a photobioreactor implies autotrophic growth and for this they require mainly plant growth nutrients, especially the macro and micronutrients. Microalgae also require a carbon source and, for autotrophic growth, this is either dissolved CO_2 or HCO_3.

The temperature should be in the toleration range of the cultured microalgae. Most commonly cultured species of micro-algae tolerate temperature range between 16 and 27°C [11]. Temperatures lower than 16°C will slow down growth, whereas those higher than 35°C are lethal for a number of species [11]. Most species grow best at salinities of 20–24% slightly lower than that of their native habitat [11]. For some microalgae, various salinities have been proposed ranging from 0–40% [13, 14]. For most cultured algal species the pH range is 7–9, with the optimum range being 8.2–8.7 [11]. The supply of CO_2 has been shown to affect the density of microalge biomass. Elevating CO_2 level from 350 to 2800μl l^{-1} raises biomass yield by 39% in photoautotrophic culture and 21% in a mixotrophic culture [15].

Furthermore, a habitat is needed being moist soil, a moist surface or an aquatic environment. If these basic requirements are present, then microalgae will grow. Mixing is necessary in photobioreactors to prevent sedimentation of the algae, ensure that all cells are equally exposed to light and nutrients, avoid thermal stratification and improve gas exchange between the culture medium and the air [12]. Pure CO_2 may also be supplemented to air supply [11] but the cost of supplementing pure CO_2 could make the system uneconomical.

3. Development of the Photobioreactor

The single most important factor limiting microalgae production is light, hence the need for uniformity

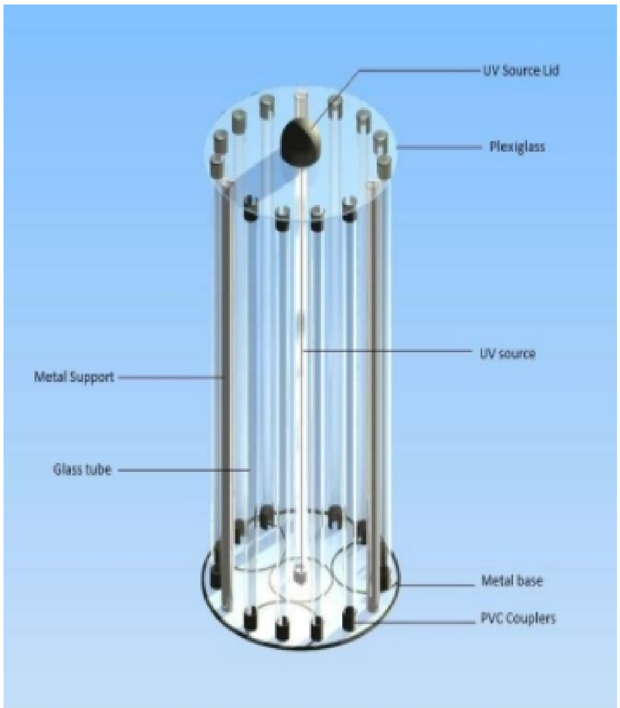

Figure 1: General arrangement of the photobioreactor.

of illumination inside the reactor. The sources of light considered were solar radiation, a 36 Watts fluorescent tube powered by electricity and a rechargeable dry cell battery. Continuous bioreactors primarily consist of transparent vessels, columns or tubes, made of specialty plastics or glass. Algae bearing fluid is slowly pumped into the system, presenting all the algae to the sun absorption zone. The algae grow inside the closed system reducing the possibility of contamination. A controlled amount of CO_2 is injected into the photo-bioreactor to maximize photosynthesis. The following criteria were taken into consideration while developing the photobioreactor: (a) large surface area exposed to sunlight and (b) readily available and low cost construction materials.

The general arrangement of the photo-bioreactor is shown in Fig. 1 and algae culture in the photobioreactor is shown in Fig. 2. The materials used for the construction of the bioreactor include cylindrical glass tubes (12), PVC couplers (24), 36cm diameter plexiglass (2), steel bracket (1), rod support (3), aquarium silicone, fluorescent tube (1), rechargeable dry cell (1), glass screws and washers, wires and connectors. The culture medium used was poultry dung. A 12-chamber algal photo-bioreactor was developed. It consists of 12 separate algal Column (1 liter each) made of translucent cylindrical glass tubes of 20mm diameter with a centrally located 36 Watts fluorescent tube for uniform illumination to all the columns. The fluorescent tube is powered by electricity and a rechargeable dry cell in absence of sunlight. This permits operation

Figure 2: Algae culture in the photobioreactor.

under full daylight conditions without providing any dark phase in the pathway of the media as well as a complimentary artificial light system during nighttime and overcast periods without any time interval of dark phase throughout the production period.

The photo-bioreactor set up is approximately 122cm in length and 36cm in diameter. The plexiglasses serve as the top and base of the bioreactor. The photobioreactor is equipped with metal supports for lifting purposes. The cylindrical tubes are so fitted to the top plexiglass such that it prevents excessive evaporation of the fluid and at the same time can be easily removed. The culture medium was prepared using poultry dung, which served as the source of nutrient for algae growth, thus enhancing its growth. The 12-chamber photobioreactor produced approximately 430gram/day with the application of 2.4 litres of liquid poultry droppings after 14 days of culture. The total cost of constructing the photo-bioreactor was ₦45, 600 (US$285).

4. Conclusion

The photobioreactor developed is inexpensive, made of readily available materials and easy to construct. The photobioreactor is expected to addresses some of the specific problems encountered in photobioreactor design which include cost effectiveness, universality of the photobioreactor in permitting the cultivation of various unicellular photosynthetic organisms and uniformity of illumination. The photobioreactor with few modifications can be effective for commercial algal biomass multiplication, as well as having implied economic aspects.

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