FEASIBILITY OF CULTIVATING HARTBEESPOORT DAM MICROALGAE

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ABRSTRACTS: Three cultivation experiments were conducted to grow microalgae in three consecutively scaled-up laboratory systems, which consisted of one, five and 135-litre bioreactors. The highest productivity achieved under optimum growth conditions was in the 5-litre Erlenmeyer bioreactors with 0.0862 g/L/d at an average bioreactor day-time temperature of 26.0°C and an aeration rate of 1.5 L/min. The three cultivation experiments revealed that closed-cultivation systems would not be feasible for the economic cultivation of micro-algal biomass from the Hartbeespoort Dam, as the highest biomass concentrations achieved under optimum laboratory conditions were too low. Open-cultivation systems are only feasible if the infrastructure already exists, like in the case of the Hartbeespoort Dam. It is recommended that designers of new micro-algal biomass-to-liquids (BtL) biodiesel processes first try to capitalize on existing cultivation infrastructure, like dams, by connecting their processes to them. This will reduce the capital and operating costs of a BtL process significantly.
Keywords: biodiesel, biomass to liquid (BtL), cultivation, microalgae

1 INTRODUCTION

The cultivation of micro-algal biomass is one of the most inefficient and costly steps in the whole biomass-to-liquids (BtL) value chain. Cultivation costs may contribute between 20–40% of the total cost of micro-algal BtL oil production [1]. The Hartbeespoort Dam, 37 west of South Africa's capital city Pretoria, has one of the world's dense populations of microalgae and has great potential for micro-algal biomass production and beneficiation due to its high nutrient loading, stable climatic conditions, large service area, and close proximity to major urban and industrial centres.

2 METHODS & MATERIALS

2.1 Cultivation in 1-litre bioreactors

Erlenmeyer flasks were used to cultivate Hartbeespoort Dam algae. The flasks were filled to 1000 mL with growth medium prepared according to the recipe given by Krüger and Eloff [2]. A pipette was used to inoculate each 1-litre growth medium with 10 mL of Hartbeespoort Dam-sourced micro-algal biomass of 0.97 g/L concentration (Fig. 1 and 2). Continuous aeration was provided with air pumps at different flow rates for each bioreactor. The cultures were kept indoors, but exposed to a 12 hour day/night cycle. The temperature of each bioreactor was measured with a thermometer (±1°C experimental error), every hour on the hour from 09:00 to 18:00. After three weeks of cultivation, the contents of the flasks were filtered through 0.7 µm glass microfibre filter paper (Whatman cat. no. 1001090), which was weighed prior to filtration, and then placed in an oven to dry for an hour at 110°C. The dried filter paper was then weighed again in order to determine the dry weight accrual of biomass. The weight of microalgae was measured to the nearest 0.1 mg with a Sartorius 1602 MP8-1 balance.

2.2 Cultivation in 5-litre bioreactors

Erlenmeyer flasks were used to cultivate Hartbeespoort Dam algae. The flasks were filled to 4000 mL with growth medium prepared according to the recipe given by Krüger and Eloff [2]. A pipette was used to inoculate each 4-litre growth medium with 100 mL of Hartbeespoort Dam-sourced micro-algal biomass of 0.0114 g/L concentration (Fig. 3, 4 and 5). Continuous aeration was provided with air pumps at different flow rates for each bioreactor. The cultures were kept indoors, but exposed to a 12 hour day/night cycle. The temperature of each bioreactor was measured with a thermometer (±1°C experimental error), every hour on the hour from 08:00 to 18:00. After every two weeks of cultivation, the contents of the Erlenmeyer flasks were filtered through 0.7 µm glass microfibre filter paper (Whatman cat. no. 1001090), which was weighed prior to filtration, and then placed in an oven to dry for an hour at 110°C. The dried filter paper was then weighed again in order to determine the dry weight accrual of biomass.

After six weeks of cultivation, the entire content of each Erlenmeyer flask was also filtered through 0.7 µm glass microfibre filter paper and the whole drying and measuring procedure repeated as described above. The weight of microalgae was measured to the nearest 0.1 mg with a Sartorius 1602 MP8-1 balance.

2.3 Cultivation in 135-litre bioreactor

Hartbeespoort Dam-sourced micro-algal biomass was grown in a 180 litre (400 x 500 x 900 mm^3) tank made from 5 mm thick glass panes (Fig. 6, 7 and 8). Six perspex plates of 3 mm thickness were inserted to act as growth substrates for support of micro-algal biomass growth. Samples of micro-algal biomass were collected from the Hartbeespoort Dam and used to inoculate the glass tank bioreactor, filled with a growth medium prepared according to the modified recipe set out by Krüger and Eloff [2]. One litre of Hartbeespoort Dam water, containing 0.0114 g/L of dry weight micro-algal biomass, was also poured into the tank, filling it to a height of 300 mm or 135 litres. Continuous aeration at a flow rate of 5.4 L/min was provided with six air pumps.

The tank was kept indoors, but exposed to a 12 hour day/night cycle. The temperature of the bioreactor was measured with a thermometer, every hour on the hour from 08:00 to 18:00. After every two weeks, one plate was removed from the tank and the micro-algal biomass scraped off manually with a scraper. The biomass was placed on glass microfibre filter paper (Whatman cat. no. 40) and placed in a desiccator with silica gel to dry for seven days. The dried biomass and filter paper was weighed and the combined weight subtracted from the original filter paper weight to determine the dry weight yield of the biomass. The weight of microalgae was

measured to the nearest 0.1 mg with a Sartorius 1602 MP8-1 balance.

3 RESULTS & DISCUSSION

3.1 Cultivation in 1-litre bioreactors

A maximum average growth yield of 0.909 g/L, specific growth rate of 0.217 day^{-1} and productivity of 0.043 g/L/day, were obtained in the 1-litre Erlenmeyer bioreactors after three weeks of cultivation, at an average day-time temperature of 24.1°C and an aeration rate of 72.0 L/h.

Figure 1: Hartbeespoort Dam microalgae inoculated into 1-L Erlenmeyer flasks on day one

Figure 2: Hartbeespoort Dam microalgae growth in 1-litre Erlenmeyer bioreactors after three weeks of cultivation

3.2 Cultivation in 5-litre bioreactors

In this experiment, micro-algal biomass, sourced from the Hartbeespoort Dam, was cultivated successfully in 5-litre Erlenmeyer flask bioreactors, using a modified batch growth medium with a high concentration of nitrates and phosphates, which exceeds that found in the Hartbeespoort Dam. Growth followed an exponential S-curve, typical of micro-algal growth, reaching its stationary phase after four weeks. Only a small increase in growth occurred after six weeks. A maximum growth yield of 2.06 g/L and productivity of 0.0862 g/L/d of dry weight micro-algal biomass were achieved after six weeks of cultivation respectively, at an average day-time bioreactor temperature of 26.0°C and an aeration rate of 1.5 L/min.

Figure 3: Hartbeespoort Dam microalgae inoculated in 4-L Erlenmeyer bioreactor flasks

Figure 4: Hartbeespoort Dam microalgae growth in 5-litre Erlenmeyer bioreactors after 3 weeks of cultivation

Figure 5: Hartbeespoort Dam microalgae growth in 5-litre Erlenmeyer bioreactors after six weeks of cultivation

3.3 Cultivation in 135-litre bioreactor

Micro-algal biomass from the Hartbeespoort Dam was cultivated successfully in a 135-litre glass tank bioreactor, using a modified growth medium with high concentrations of nitrates and phosphates, natural solar lighting, and externally supplied aeration. Average temperatures between 24-26°C, and aeration rates which are sufficiently strong to keep the biomass in suspension, delivered the best production rates, after the optimum growth period of 4 weeks. A maximum yield of 2.9557 g/m^2 of dry weight biomass per growth plate (0.3 m^2) were achieved after 4 weeks of cultivation. Cultivation of

micro-algal biomass was improved through the addition of growth plates in the bioreactors. These growth plates mimic sheltered rock surfaces in the Hartbeespoort Dam, which create favourable conditions for algal blooming, by providing inoculums of cyanobacterial species. These growth plates also act as substrate on which the micro-algal biomass could grow and allow for easy manual harvesting.

Figure 6: Cultivation of Hartbeespoort Dam microalgae in glass tank bioreactor with growth plates

Figure 7: Hartbeespoort Dam microalgae growth in 135-litre glass tank bioreactor after two weeks of cultivation

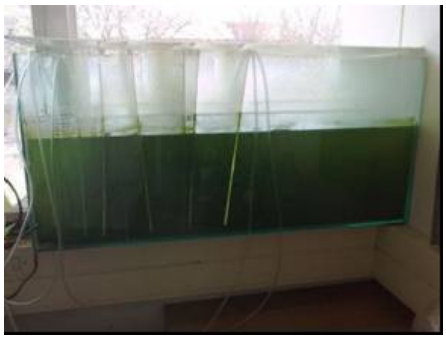

Figure 8: Hartbeespoort Dam microalgae growth in 135-litre glass tank bioreactor after six weeks of cultivation

3.4 Cost estimate of cultivation system

A cultivation system, operating at 183 days per year, and a maximum productivity of 0.0862 g/L/d requires a pond capacity of 473,415 m^3 to cultivate 14,283 tons of dry weight micro-algal biomass per year. Using an optimum pond depth of 30 cm requires a surface area of 158 hectares for a cultivation system. At an average capital cost of $150,000 and $200,000 per hectare for an open and a closed-cultivation system [1], respectively, the capital cost of an open-cultivation system near the Hartbeespoort Dam is estimated at $23.7 million, and a closed-cultivation system is estimated at $31.6 million. At an average operating cost of $35,000 and $45,000 per hectare per year for an open and a closed-cultivation system [1], respectively, the operating cost of an open-cultivation system near the Hartbeespoort Dam is estimated at $5.5 million per year, and a closed-cultivation system is estimated at $7.1 million per year.

4 CONCLUSIONS

The cultivation of micro-algal biomass from the Hartbeespoort Dam is only economical if the growth is allowed to occur naturally in the Dam without any additional cultivation equipment. The cultivation of micro-algal biomass in either an open or a closed-cultivation system will not be feasible, as the high cost of cultivation, which is double the present cost of diesel in South Africa, will negate the value of the biodiesel derived from the cultivated biomass.

The Hartbeespoort Dam currently acts as a natural open-cultivation system, producing 160 g/m^2 of micro-algal biomass for six to ten months of the year [3]. This is sufficient to produce between 14 and 24 kilotons of dry micro-algal biomass, and 2.6 and 4.3 megalitres of biodiesel per year, without spending additional capital and operating costs to cultivate the micro-algal biomass feedstock. It is recommended that designers of new micro-algal BtL biodiesel processes first try to capitalize on existing cultivation infrastructure, like dams, by connecting their processes to them. This will reduce the cost of a BtL process significantly.

5 REFERENCES

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6 ACKNOWLEDGEMENTS

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