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Abstract

This report highlights significant achievements in the Enhanced Practical Photosynthetic CO₂ Mitigation Project during the ending 12/31/2004. Specific results and accomplishments for the program include review of pilot scale testing and design of a new bioreactor. Testing confirmed that algae can be grown in a sustainable fashion in the pilot bioreactor, even with intermittent availability of sunlight. The pilot-scale tests indicated that algal growth rate followed photon delivery during productivity testing.

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Executive Summary

This report highlights significant achievements in the Enhanced Practical Photosynthetic CO₂ Mitigation Project during the ending 12/31/2004. Specific results and accomplishments for the program include review of pilot scale testing and design of a new bioreactor. Testing confirmed that algae can be grown in a sustainable fashion in the pilot bioreactor, even with intermittent availability of sunlight. The pilot-scale tests indicated that algal growth rate followed photon delivery during productivity testing.

Results and Discussion

Experimental Apparatus

The experimental apparatus used include photosynthetic incubators, bench-scale bioreactors, and a pilot-scale bioreactor that have been previously characterized. Other equipment used includes pipettes, electric balances (mass scales), natural gas burners, CO/O₂/CO₂ gas analyzers, and DNA sequencing equipment. Details of the specific applications of the experimental equipment are included in the discussion of the actual data collection and reduction.

Data Collection and Reduction

Task 3.0. Implement the optimum system in scaled model

3.1 Final System Design

A final bioreactor design, shown in Figure 1, was completed and built at 1005 E. State St. in Athens Ohio, where it was tested. The results of productivity testing, shown in Figures 2 and 3, indicate the viability of the process.

Fig. 1. Bioreactor facility (final design)

The test facility was designed to simulate the flue gas emission from fossil-fired power plants and to study the effects of change in temperature, gas flow rate, pH value, nutrition concentration and CO₂ concentration in simulated flue gas on the growth ability of microalgae species. This assembly assists in reducing the pressure drop of flue gas and increases the effective area for efficient trapping and bioconversion of CO₂ in the flue gas. Eight light panels were used to illuminate over 200 ft² of algal growth substrates.

3.2 Algal productivity

Sustainability tests with approximately 30 gallons of a specially isolated strain of *Chlorogloeopsis* and two Omnisil membranes were performed to quantify the growth of cyanobacteria in the bioreactor. After completing the initial mass determination, which enabled us to quantify the cyanobacterial growth over the course of the experiment, the system was allowed to reach steady conditions (five days) before experimentation.

The daily yield of cyanobacteria was determined by harvesting each night. The harvested cyanobacteria were pumped through a 5-micron filter, which was dried for 7 days in a convective oven at 90°C. The mass results of the daily harvesting are shown in Figure 2. Also shown in Figure 2 is the average (daily) solar flux for Athens, Ohio, during the experiment as measured at Scalia Laboratory, Ohio University's weather station.

We noted that the productivity for the following day tracked the average solar flux for the previous day's growth very well (correlating to over 98%). While not confirmed in this work, it seemed intuitive that if the solar collector/distributor system is tuned to produce an optimal photon flux ($\approx 100 \mu\text{mol m}^{-2} \text{s}^{-1}$), then reducing the daily photon exposure would correspondingly reduce biomass productivity.

The tests were repeated for cyanobacterial growth over a period of ten days following an acclimation period of seven days. The results, shown in Figure 3, were slightly lower than the results presented in Figure 2, especially when normalized to the average solar flux from the day before. This is likely because the solar collector experienced significant loss of reflective coating between May and July. However, these results are significant because they show the cyanobacteria have a considerable ability to grow once acclimated to the membrane substrate.

Fig. 2. Preliminary productivity data.

Fig. 3. Repeated productivity results.

Conclusions

The subsystem research has progressed to the point that a viable pilot-scale bioreactor is being constructed to test long-term, sustainable and continuous conversion of CO₂ to biomass using collected solar photons. Further, this photobioreactor offers numerous possibilities for not only greenhouse gas mitigation, but for control of a wide variety of pollutants, notably NO_x and ammonia slip, while yielding a product that could have sustainable economic value. That product could be extremely useful in the production of domestic transportation fuel.

The productivity data strongly indicate that the harvesting method of higher water flow does not physically stress the cyanobacterial mass that remains on the substrate. This finding is critical for long-term sustainability. Further, the data reflect that productivity, at least in the current implementation, is a function of photon availability. Thus, it seems logical that deployment should be favored in locations with higher average incident solar flux.

References

- Benemann, J. (1997) *Energy Conversion and Management*, 38(Supplemental Issue), 475-479.
- Brock, T.D. (1978) *Thermophilic Microorganisms and Life at High Temperatures*, Springer-Verlag, New York, USA.
- Cooksey, K.E., and Wigglesworth-Cooksey, B. (1995) *Aquatic Microbial Ecol.*, 9, 87-96.
- Fisher, A., (1961) *Solar Energy Research*, University of Wisconsin Press, Madison, WI, USA, 185-189.
- Hanagata, N., Takeuchi, T., Fukuju, Y., Barnes, D., Karube, I. (1992) *Phytochemistry*, 31(10), 3345-3348.
- Kajiwarra, S., Yamada, H., Ohkuni, N., and Ohtaguchi, K. (1997) *Energy Conversion and Management* 38(Supplemental Issue), 529-532.
- Kaplan, A., Schwarz, R., Lieman-Hurwitz, J., and Reinhold, L. (1997) *Plant Physiology*. 97, 851-855.
- Maeda, K., Owada, M., Kimura, N., Omata, K., Karube, I. (1995) *Energy Conversion and Management* 36(6-9), 717-720.
- Nagase, H., Eguchi, K., Yoshihara, K., Hirata, K., Miyamoto, K., (1998) *Journal of Fermentation and Bioengineering*, 86(4): 421-423.
- Nubel, U., Garcia-Pichel, F., Muyzer, G. (1997) *Applied Environmental Microbiology* 63(8):3327-3332.
- Ohtaguchi, K., Kajiwarra, S., Mustaqim, D., Takahashi, N., (1997) *Energy Conversion and Management* 38(Supplemental Issue), 523-528.
- Ramsing, N.B., Ferris, M.J., and Ward, D.M. (1997) *Applied Environmental Microbiology* 63(6): 2347-2354.