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Carbon Dioxide Sequestration

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Principal Author: V. J. Fabry, Ph.D.

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Name and Address of Submitting Organization:

Dr. V. J. Fabry
Department of Biological Sciences
California State University San Marcos
San Marcos, CA 92096-0001

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Abstract

Predictions of increasing levels of anthropogenic carbon dioxide (CO₂) and the specter of global warming have intensified research efforts to identify ways to sequester carbon. A number of novel avenues of research are being considered, including bioprocessing methods to promote and accelerate biosequestration of CO₂ from the environment through the growth of organisms such as coccolithophorids, which are capable of sequestering CO₂ relatively permanently.

Calcium and magnesium carbonates are currently the only proven, long-term storage reservoirs for carbon. Whereas organic carbon is readily oxidized and releases CO₂ through microbial decomposition on land and in the sea, carbonates can sequester carbon over geologic time scales. This proposal investigates the use of coccolithophorids ? single-celled, marine algae that are the major global producers of calcium carbonate ? to sequester CO₂ emissions from power plants. Cultivation of coccolithophorids for calcium carbonate (CaCO₃) precipitation is environmentally benign and results in a stable product with potential commercial value. Because this method of carbon sequestration does not impact natural ecosystem dynamics, it avoids controversial issues of public acceptability and legality associated with other options such as direct injection of CO₂ into the sea and ocean fertilization. Consequently, cultivation of coccolithophorids could be carried out immediately and the amount of carbon sequestered as CaCO₃ could be readily quantified. The significant advantages of this approach warrant its serious investigation. The major goals of the proposed research are to identify the growth conditions that will result in the maximum amount of CO₂ sequestration through coccolithophorid calcite production and to evaluate the costs/benefits of using coccolithophorid cultivation ponds to abate CO₂ emissions from power plants.

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Introduction

The objective of this project is to determine the efficacy of using coccolithophorid CaCO_3 production in CO_2 removal technology. This project will determine the methods and biological and chemical conditions needed to optimize the native ability of coccolithophorid algae to sequester CO_2 in the form of CaCO_3 . This project will identify the parameters necessary to produce coccolithophorid blooms and the factors required to obtain maximum calcification rates. The information gained in this study can be incorporated into the design and construction of future algal ponds or bioreactors in follow-up research (not a part of this project) on CO_2 sequestration by coccolithophorids. The initial task of the research is to identify the species, cell strain and the specific growth conditions (e.g., temperature, light intensity, nutrient concentrations) that maximize population growth rates and rates of calcification. The second task of the project is to quantify the amount of CO_2 sequestration by coccolithophorids when cells are grown under high-calcifying conditions in a custom-manufactured experimental vessel.

In the last quarterly review period, we reported that there was no significant differences in growth rates or maximum yield of coccolithophorids when cells were grown in F/ 50 Guillard, 1975) versus K media (Keller et al., 1987). Therefore, we concluded that F/50 media, which is less costly to produce than K media, would be a better choice for use in coccolithophorid CO_2 sequestration. During this quarterly review period, we completed nutrient analyses of samples from the closed vessel experiment and began work on 3rd Quarter Milestone activities investigating coccolithophorid growth at different levels of dissolved CO_2 .

Experimental

We conducted closed vessel experiments in which 7 liters of F/50 media was inoculated with a very small volume of *Emiliania huxleyi* cell strain CCMP 371 to give an initial cell density of 4×10^2 cells ml^{-1} . The culture was stirred continuously to keep cells uniformly suspended. This vessel was placed in a temperature and light-controlled environmental chamber. The temperature during the experiment was 18.5°C and the light/dark cycle was 16 hours light/8hours dark. Subsamples were taken for cell densities and measurement of total alkalinity (TA) and dissolved inorganic carbon (DIC). Total alkalinity (TA) was determined using our own software. Total dissolved inorganic carbon in duplicate samples was measured using coulometry (Dickson and Goyet, 1994). Cell densities were determined daily by direct count. Additional samples were taken for nitrate analyses measured on a Lachat Quik Chem 8000 flow injection ion analyzer.

In another experiment, we made F/50 media using laboratory-made seawater and filled each closed vessel with 7 L. In one closed vessel, we added additional CaCO_3 to increase the initial pH to 8.18; we refer to this experimental chamber as the “high CO_3 vessel or high pH vessel.” In the second closed vessel, we injected CO_2 gas into the media which lowered the initial pH to 7.58; we refer to this experimental chamber as the “high CO_2 vessel.” We inoculated each vessel with a small volume of *Emiliania huxleyi* cell strain

CCMP 371 to give an initial cell density of 2.5×10^4 cells ml^{-1} in the high CO_3 vessel and 5.6×10^3 cells ml^{-2} in the high CO_2 vessel. Subsamples were taken for cell counts, and measurements of DIC, TA, total particulate calcium, organic carbon, and nitrate.

Results and Discussion

F/50 media and nitrate utilization

Results of the 12-day experiment are graphically illustrated in Figure 1. Population cell growth showed the expected exponential growth curve. Maximum cell density of $> 10^7$ cells ml^{-1} was reached in 11 days. The decrease in DIC from day 7 to day 12 is marked and indicates that cells were probably carbon-limited by day 12. The changes in nitrate concentration and cell density are shown in Figure 1B. At day 12, the nitrate concentration was still high, having declined by only about 100 μM or 10% of the initial concentration. These results indicate that cell growth was not limited by nitrate, and thus enhanced nitrate concentrations would not increase cell growth. These data suggest that cell growth was limited by DIC levels and support our previous hypothesis that introducing additional dissolved CO_2 at day 12 could possibly lead to greater cell growth and CO_2 sequestration.

Cell growth in F/50 at high pH and low pH

In the high CO_3 /high pH closed vessel experiment, cell densities reached stationary phase by day 4 and the experiment was terminated at day 8. Figure 2A illustrates the steady decrease of DIC as cell density increased. By day 8, the DIC concentration approached zero and limited further population growth of the coccolithophorids. In contrast, the high CO_2 /low pH closed vessel experiment was conducted over 26 days (Fig. 2B.). In response to the initial low pH of 7.58, the cell density decreased for the first four days, after which cell numbers steadily increased and reached approximately the same maximum cell density as the high pH vessel by day 20. These results demonstrate that coccolithophorid cell strain CCMP 371 shows a marked delay in population growth in response to low pH. Interestingly, however, enough cells survived the low pH conditions to grow and eventually reach a population density similar to the high pH vessel. By the end of the experiment at day 26, the DIC concentration approached zero, again indicating that DIC was limiting further population cell growth.

Changes in particulate calcium in the two closed vessel chambers are graphed in Figure 3. The high CO_3 /high pH experimental vessel showed consistently greater particulate calcium levels as cell population increased over 8 days. In the high CO_2 /low pH closed vessel, however, the particulate calcium concentration was low through day 10. By day 20, the particulate calcium increased by 100 times the particulate calcium on day 1. However, at day 26 the particulate calcium was only 50% that of the high CO_3 /high pH closed vessel on day 8.

Conclusion

The results of these experiments suggest that when the coccolithophorid *Emiliani huxleyi* cell strain CCMP 371 is grown in F/50 media nitrate is still in excess when stationary

growth phase is reached. We conclude that cell growth in our experiment was limited by insufficient dissolved inorganic carbon, not nitrate. Experiments comparing cell growth and calcification in F/50 media made with high CO₃/high pH seawater versus high CO₂/low pH seawater substantially delayed the population growth in the low pH vessel relative to the high pH vessel. Although similar maximum cell densities were achieved over very different timeframes, the particulate calcium content of the low pH vessel was only half that of the high pH vessel. We plan to repeat this experiment in the subsequent quarter.

References

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Fig. 1. Closed vessel experiment with *Emiliana huxleyi* cell strain CCMP 371 grown in F/50 media. (A) Changes in cell density (blue diamonds), total alkalinity (pink squares), and total dissolved inorganic carbon (DIC; red triangles). (B) Changes in cell density (blue diamonds) and nitrate concentration (pink squares).

Fig. 2. Changes in cell density (black triangles), total dissolved inorganic carbon (DIC; blue diamonds), and total alkalinity (pink squares) in closed vessel experiments with *Emiliania huxleyi* cell strain CCMP 371 grown in F/50 media. (A) Initial seawater conditions of high carbonate and high pH. (B) Initial seawater conditions of high carbon dioxide and low pH.

Fig. 3. Changes in particulate calcium in closed vessel experiments with *Emiliana huxleyi* cell strain CCMP 371 grown in F/50 media. (A) Initial seawater conditions of high carbonate and high pH. (B) Initial seawater conditions of high carbon dioxide and low pH.