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Abstract

This quarterly report documents significant achievements in the Enhanced Practical Photosynthetic CO₂ Mitigation project during the period from 10/2/2003 through 1/1/2004. As indicated in the list of accomplishments below we have seen very encouraging results from the model scale tests in terms of organism growth rates and we have begun the final tests necessary to meet our project goals.

Specific results and accomplishments for the fourth quarter of 2003 include:

Bioreactor support systems and test facilities:

- The solar collector is working well and has survived the winter weather.
- The improved high-flow CRF-2 test system has been used successfully to run several long-term growth tests with periodic harvesting events. The high flow harvesting system performed well. The mass measurement results after a 4-week test show 275% growth over the initial mass loading. This figure would have been higher had there been no leakage and handling losses. Carbon dating of biomass from this test is planned for carbon uptake estimation. The next test will include direct measurement of carbon uptake in addition to organism mass measurements.
- Qualitative organism growth testing has begun in the pilot scale bioreactor. Some issues with uniformity of organism loading, fluid leakage and evaporation have surfaced and are currently being addressed, and quantitative testing will begin as soon as these problems are resolved.

Organisms and Growth Surfaces:

- Montana State University (Subcontracted to do organism studies) submitted their final (3-year) project report. An abstract of the report is included in this quarterly report.

Table of Contents

	Page
Executive Summary	1
Results and Discussion.....	2
Task 1.0 Evaluate and rank component and subsystem level alternative design concepts ..	2
Subtask 1.1 – Investigate critical properties of alternative photosynthetic agents	2
Subtask 1.2 – Design deep-penetration light delivery subsystem	6
Subtask 1.3 – Investigate growth surface subsystem design	6
Subtask 1.4 – Investigate the use of a hydraulic jumps to improve the system’s overall CO ₂ conversion efficiency	6
Subtask 1.5 – Design harvesting subsystem.....	6
Subtask 1.6 – Quantify properties of dried biomass for potential end-uses	6
Task 2.0. Evaluate subsystem combinations and select an “optimum” system design	6
Task 3.0. Implement the optimum system in scaled model	7
Webpage	9
Conclusion	9

Figures

Figure 1 – Pictures from CRF-II organism growth mass measurement test.....	5
Figure 2 – Early problems with non-uniform coverage.....	8
Figure 3a – Organism coverage in second run.....	8
Figure 3b – Organism coverage in second run – detailed views	9

Executive Summary

This quarterly report documents significant achievements in the Enhanced Practical Photosynthetic CO₂ Mitigation project during the period from 10/2/2003 through 1/01/2004. As indicated in the list of accomplishments below we are preparing for the final tests necessary to meet our project goals. As indicated in the list of accomplishments below we have seen very encouraging results from the model scale tests in terms of organism growth rates and we have begun the final tests necessary to meet our project goals.

The solar collector is working well and has survived the winter weather. This is extremely important to overall system viability – as the harsh winter was expected to have some impact on the drive and mirror systems, but did not!

The improved high-flow CRF-2 test system has been used successfully to run several long-term growth tests with periodic harvesting events. The high flow harvesting system performed well. The mass measurement results after a 4-week test show 275% growth over the initial mass loading. This figure would have been higher had there been no leakage and handling losses. Carbon dating of biomass from this test is planned for carbon uptake estimation. The next test will include direct measurement of carbon uptake in addition to organism mass measurements.

Qualitative organism growth testing has begun in the pilot scale bioreactor. Some issues with uniformity of organism loading, fluid leakage and evaporation have surfaced and are currently being addressed, and quantitative testing will begin as soon as these problems are resolved.

Montana State University (Subcontracted to do organism studies) submitted their final (3-year) project report. An abstract of the report is included in this quarterly report.

Results and Discussion

Task 1.0. Evaluate and rank component and subsystem level alternative design concepts

Subtask 1.1 Investigate critical properties of alternative photosynthetic agents (cyanobacteria)

Report from the researchers at Montana State:

Copied below is the abstract from the final project report submitted by Montana State 12/31/03.

The goal of our part of the project “Enhanced Practical Photosynthetic CO₂ Mitigation” was to supply Ohio University team with thermophilic cyanobacteria and to find optimal conditions for the growth of thermophilic cyanobacteria on artificial substrata. During the period from December 2000 to September 2003 we isolated 36 primary samples from different thermal springs inside and outside of Yellowstone National Park (Wyoming and Montana, USA). Coupons of different polymers were used to enhance the efficacy of the sampling of cyanobacteria from the environment. These samples were the subjects of further purification. By the end of the project we had 24 frozen unialgal cultures. Six of them have been genotyped. It was found that one isolate belongs to an undescribed cyanobacterial genus.

Tap water was found to inhibit partially the growth of thermophilic cyanobacteria. Because of this all experiments were carried out in distilled water. Cyanobacterial isolates grew well in standard growth media. However, the cultivation of these organisms with CO₂ aeration required buffering of growth media.

Calcium was found to stimulate the generation of cyanobacterial biofilm on artificial substrata. Special calcium-based medium to cultivate cyanobacterial isolates was developed to increase CO₂ trapping and to decrease the contamination of environment with sodium.

The environmental alkalinity was found to be a signal for the morphological changes of highly thermophilic strain *Chlorogloeopsis* sp. A method for the selection of acid resistant strains of cyanobacteria was also elaborated. Recommendations for further sampling of cyanobacteria in YNP were made.

Prof. K.E. Cooksey and Dr. I. Brown visited Ohio University with the aim of information exchange and advising. Project results have been presented at: The 1st Congress of the International Society for Applied Phycology. May 26-30, 2002. Almeria, Spain; Conference of Yellowstone Association. October, 2002; 103rd General Meeting of ASM. May 18-22, 2003. Two papers based on the results obtained during this project are in preparation.

Report from Ohio University

The following list of activities was completed during the last quarter of 2003:

1. New header insert was designed.
2. Fabric stitching was modified to reduce flow irregularities.
3. Testing new header design was done.
4. Header was modified with addition inlets for harvesting flows.

5. Harvesting setup was commissioned; the setup consisted of a high pressure and flowrate screw pump, piping, 50gal harvesting tank & filtration setup.
6. Resealing of CRF-II setup and hydraulic testing of the complete test rig.
7. Complete refit of all piping and allied accessories.
8. New growth flow pump assembly consisting of two pumps, one for regular growth flow and the other as a standby.
9. Test-2 for “CRF-II organism growth mass measurement” was started on December 2nd, 2003.
10. The testing was stopped in the first week of January 2004, after four weeks of testing.
11. We faced some serious leakage problems leading to stopping of the test run.

Results:

1. We have had excellent organism growth during the Test-2 test run.
2. There needs to be some fine tuning done to the header setup to even out flow irregularities.
3. The results of mass measurement are summarized in the enclosed datasheet. We achieved a 275% growth over the initial mass loading. These figure would have been higher had there been no leakages and handling losses.

Future activities:

1. The new header design will be tested in CRF-II using live organism for flow and growth analysis.
2. New CRF-II setup assembly to eliminate all leakages
3. Carbon dating of biomass from test-2 for carbon uptake analysis.
4. Hydraulic and pneumatic testing of CFR-II for leakages.
5. Preparation for Test-3.

CRF-II Mass Quantification (Final)

Sr.No	Description	Initial weight (gms)	Final Weight (gms)	Net Weight (gms)
Initial Loading Calculations				
1	Pre-Filter # 1	225.01	229.37	4.36
2	Final-Filter # 1	317.45	319.25	1.8
Total Initial Mass Loading in 20 liters of solution				6.16
Total Initial Mass Loading in 50 liters of solution				15.4
Final Growth Calculations				
Omnisil Membrane weight				
1	Screen # 1	252.25	260.42	8.17
2	Screen # 2	237.72	245.73	8.01
3	Screen # 3	234.64	241.23	6.59
4	Screen # 4	256.19	260.46	4.27
Filter Weights (in grams)				
1	Pre-Filter # 2	221.52	228.06	6.54
2	Final-Filter # 2	316.75	318.56	1.81
3	Pre-Filter # 3	235.47	239.53	4.06
4	Final-Filter # 3	307.02	308.25	1.23
5	Pre-Filter # 4	233.83	240.18	6.35
6	Final-Filter # 4	313.39	316.99	3.6
7	Pre-Filter # 5	232.47	238	5.53
8	Final-Filter # 5	323.16	324.81	1.65
Total Final Mass				57.81 grams
Total Mass Growth				42.41 grams

Figure 1: Pictures from CRF-II organism growth mass measurement test

Subtask 1.2 Design deep-penetration light delivery subsystem)

No report - the new solar collector is operating well and has survived the winter weather.

Subtask 1.3 Investigate growth surface subsystem design

No new material tests have been run. We are focusing our efforts on Omnisil fabric since it has excellent wetting and rewetting properties, organisms adhere well to it, and it has properties that are appropriate for the bioreactor environment.

Subtask 1.4 Investigate the use of a hydraulic jump to improve the system's overall CO₂ conversion efficiency

Based on the results collected and reported in previous reports, the experiments in this area have been discontinued. The Phase I experimental evaluation of the hydraulic jump is complete.

Subtask 1.5 Design harvesting subsystem

Tests have shown that the new high flow rate pump works well and it has been used for harvesting in the long-term CRFII tests. Some detail work continues on the headers and stitching of the membranes, but the basic harvesting system design is functioning well and is adequate for the planned tests.

Subtask 1.6 Quantify properties (higher heating value, elemental composition, volatile content) of dried biomass for potential end-uses.

We continue to search the literature and search for potential end uses for the biomass, but experiments in this area are on hold until we get closer to making a final decision for the organism.

Task 2.0. Evaluate subsystem combinations and select an “optimum” system design

The CRF-2 is the primary test facility for evaluating the subsystem combinations. Long-term quantitative tests began in the CRF-2 bioreactor last quarter. System improvements to allow harvesting and regrowth phases of the long term testing were completed and several successful tests were run. The results of the CRFII tests are being used to set up the upcoming pilot scale tests.

Task 3.0. Implement the optimum system in scaled model

The pilot scale bioreactor is in the final stages of preparation for quantitative tests. A discussion of accomplishments and actions items from the pilot scale bioreactor team is copied below.

Pilot-scale Bioreactor Accomplishments:

During the last quarter the main focus of all our experiments was to get a uniform flow of algae over the entire surface of the membrane and ensure survivability. Several tests were conducted and many modifications made to the existing design for achieving the desired flow pattern.

Our first test run with algae introduced in the system gave us valuable information about the modifications that were needed to be made in the system. In addition to fixing leaks and modifying the plumbing system, we had to refine our header pipe design and our method for stitching the Omnisil membrane. This was mainly due to the non-uniform distribution of the algae over the entire surface of the membrane. As seen in Figure 2 only about 20% of the screen was covered on either side.

The reason for the uneven flow over the membrane was found to be the method employed to stitch the membrane and insert it into the header pipe. It was decided to refine the stitching process and conduct another test run with fresh membranes and algae.

Our next test run gave us a better flow pattern as a result of modifications. However, the flow was still not as desired and there was also the appearance of a brown discoloration. It was observed that the method employed for stitching and inserting the membrane into the header pipe was causing the membrane to block parts of the slot in the header pipe. It is seen in Figure 3 that these parts of the header pipe (marked in blue) are consistent with the parts of the membrane over which there is no flow of algae.

A new method for stitching the membrane and inserting it into the header pipe was employed for the next test run, which despite further improving the flow pattern over the membrane, did not produce 100% coverage.

Action Items:

- We are trying to come up with a new shim design for the header pipe which will yield a much improved method of stitching the membrane, which seems to be the primary factor in achieving a uniform flow of algae over the surface of the membrane.
- Maintain the entire bioreactor including all subsystems to ensure proper functioning.
- We plan to conduct several tests in the future to determine sustainability of the system, survivability of the algae in the bioreactor, and the efficiency of the entire system in removal of carbon dioxide.

Figure 2: Early problems with non-uniform coverage

Figure 3a: Organism coverage in second run

Figure 3b: Organism coverage in second run - detail views

Webpage

The web page is running at <http://132.235.19.45/DOE>.

Conclusions

As we begin the fourth year of this project we can report that we have made significant progress towards achieving our overall project goals and are working hard to complete all of our deliverables. All of our test facilities are developed and our test plans and procedures are in place and the CRF-2 tests that will provide the results needed to proceed with the pilot scale bioreactor testing are in process. We will proceed with the tests needed to meet our project goals and will report the results as soon as possible.