Growth and optimization of algal biofilms on the rotating algal biofilm reactor for nutrient removal

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Abstract

One promising method for the removal of excess nutrients from the effluent of wastewater treatment facilities involves enhancing, then harvesting, the growth of naturally occurring algal species. The accumulated algal biomass, in addition to its role in water treatment, can then be used as a feedstock for products such as biogas, biodiesel, bioplastics, and industrial solvents. However, growing and harvesting sufficient quantities of algae in a cost effective manner has proved challenging. One inventive system that has been demonstrated to overcome this difficulty is the Rotating Algal Biofilm Reactor (RABR), which was invented at USU.

The RABR system was built and tested at both the bench and pilot scale at the regional wastewater treatment facility in Logan, UT, in collaboration between Utah State University and the Logan City Environmental Department. The Logan City facility treats approximately 15 million gallons a day of weak domestic wastewater via a series of facultative lagoons, and is currently releasing an average of approximately 4.5 mg/L of phosphorus in its effluent. Application of the RABR system to the effluent of the facility resulted in a reduction of both nitrogen and phosphorus concentrations to below 1 mg/L, as well as production of dried algal biomass exceeding 30 g/m²/day.

Methods

Bench/Pilot scale operation at Logan City Wastewater Treatment Facility

- Average wastewater characteristics - 4.5 mg/L Total Phosphorus, 7.8 mg/L Ammonia
- Influent drawn from final processing pond or facility effluent
- Operates during the four seasons (Pilot)

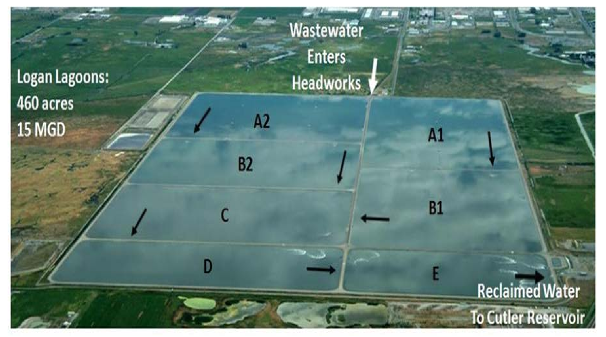

Figure 1: Logan Utah Wastewater Treatment Plant

Source: Woolsey, Paul. "Rotating Algal Biofilm Reactors: Mathematical Modeling and Lipid Production." MS thesis. Utah State University, 2011. Print. Figure 1.

RABR construction

- Aluminum irrigation wheels, 76" in diameter, 60" width
- ~4000 ft. of ¼" cotton rope per RABR
- ~10,700 liters wastewater per tank.
- Rotates at 1.33 rpm
- Variable retention times, loading rates

Figure 2: Pilot Scale RABR Units

Results

Initial research (Bench Scale)

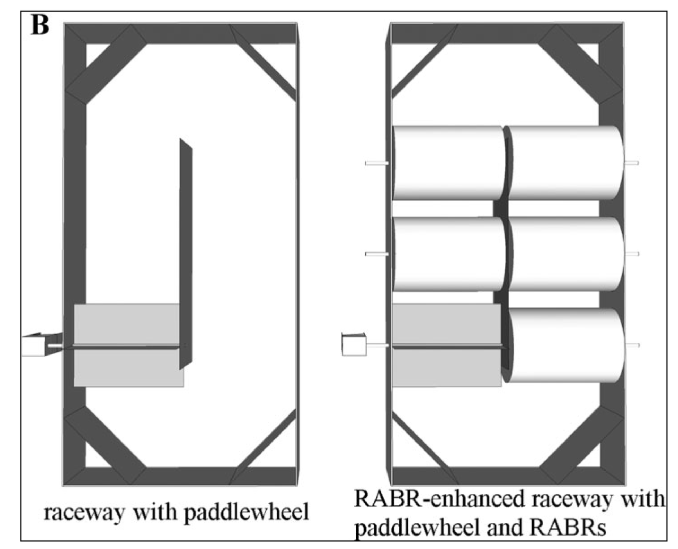

Figure 3: Bench Scale RABR and suspended growth reactors

Source: Christenson, L. and Sims, R. "Rotating Algal Biofilm Reactor and Spool Harvester for Wastewater Treatment with Biofuels By-Products" Biotechnology and Bioengineering, Vol 109 (2012): 1674-1684. Print.

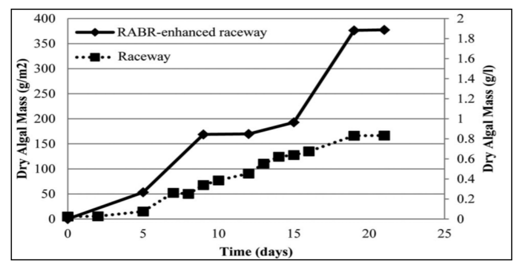

Figure 4: Biomass growth: RABR vs. Suspended

Source: Christenson, L. and Sims, R. "Rotating Algal Biofilm Reactor and Spool Harvester for Wastewater Treatment with Biofuels By-Products" Biotechnology and Bioengineering, Vol 109 (2012): 1674-1684. Print.

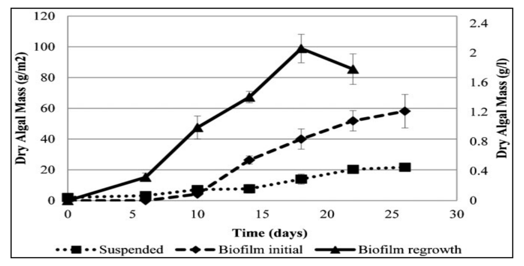

Figure 5: Biomass growth: Regrowth vs. Initial Growth.

Source: Christenson, L. and Sims, R. "Rotating Algal Biofilm Reactor and Spool Harvester for Wastewater Treatment with Biofuels By-Products" Biotechnology and Bioengineering, Vol 109 (2012): 1674-1684. Print.

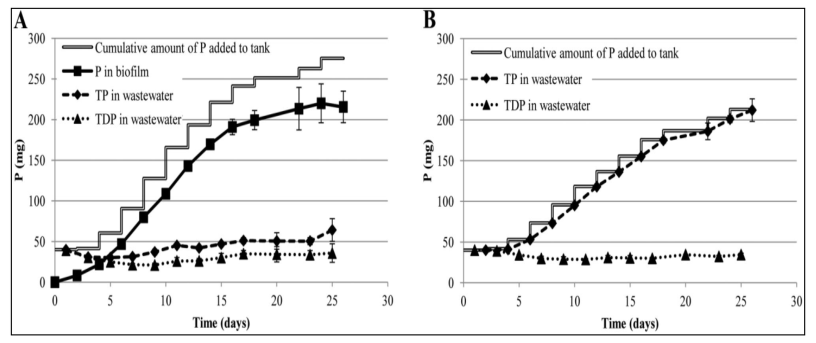

Figure 6: Phosphorus Removal: RABR vs. Suspended

Source: Christenson, L. and Sims, R. "Rotating Algal Biofilm Reactor and Spool Harvester for Wastewater Treatment with Biofuels By-Products" Biotechnology and Bioengineering, Vol 109 (2012): 1674-1684. Print.

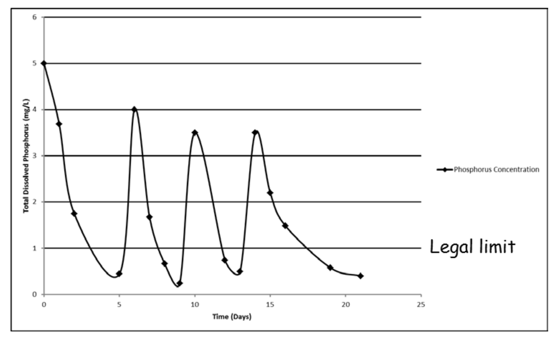

Figure 7: Phosphorus Removal: RABR
Data collected by Logan Christenson.

Source: Christenson, L. and Sims, R. "Rotating Algal Biofilm Reactor and Spool Harvester for Wastewater Treatment with Biofuels By-Products" Biotechnology and Bioengineering, Vol 109 (2012): 1674-1684. Print. (Data)

Current Testing (Pilot Scale)

Figure 8: Pilot scale RABR

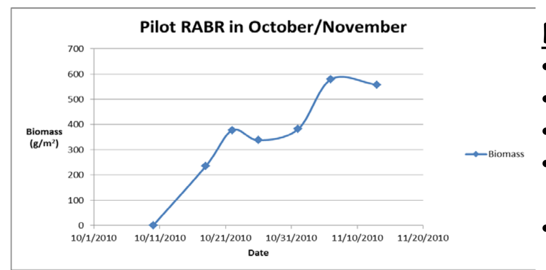

Figure 9: Biofilm biomass growth rate in Oct./Nov. 2010 Data collected by Logan Christenson.

Source: Christenson, L. and Sims, R. "Rotating Algal Biofilm Reactor and Spool Harvester for Wastewater Treatment with Biofuels By-Products" Biotechnology and Bioengineering, Vol 109 (2012): 1674-1684. Print. (Data)

Details
- Initial experiment
- 11 hour retention time
- No limiting nutrients
- Lower (seasonal) temperatures
- Triplicate sampling

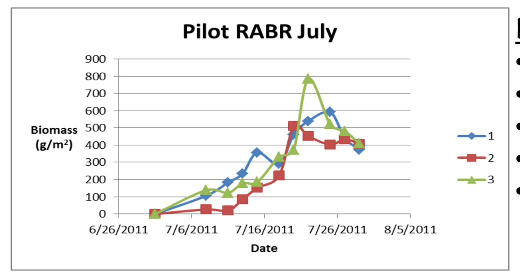

Figure 10: Biofilm biomass growth rate. In July 2011. Data collected by Paul Woolsey.

Source: Woolsey, Paul. "Rotating Algal Biofilm Reactors: Mathematical Modeling and Lipid Production." MS thesis. Utah State University, 2011. Print

Details
- Second experiment
- 24 hour retention time
- No limiting nutrients
- Photoinhibitionm
- Triplicate RABRs

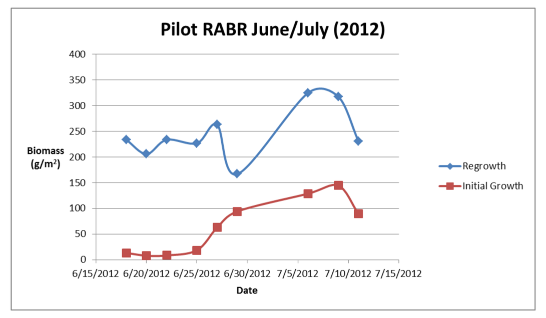

Figure 11: Biofilm biomass growth August/September 2012.

Details
- Summer experiment
- 6 day retention time
- Nitrogen limited
- Photoinhibition
- Triplicate sampling
- TDP below 1 mg/L

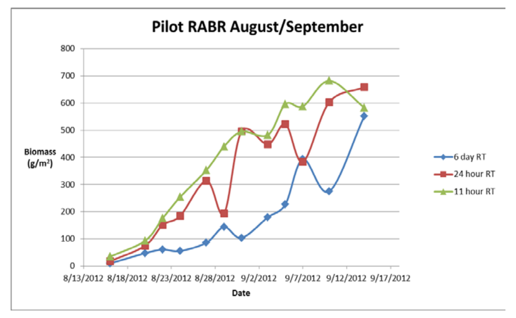

Figure 12: Biofilm biomass growth August/September 2012.

Details
- Retention time experiment
- 6 Day retention time
- Nitrogen limitation (6 Day RT RABR)
- Photoinhibition
- Triplicate sampling

Conclusions

- The RABR system is capable of meeting domestic wastewater nutrient removal requirements
- The RABR system represents a substantial improvement in the growth and harvesting of algal biomass
- The important variables to consider for management of the RABR system include temperature, light, and nitrogen concentrations

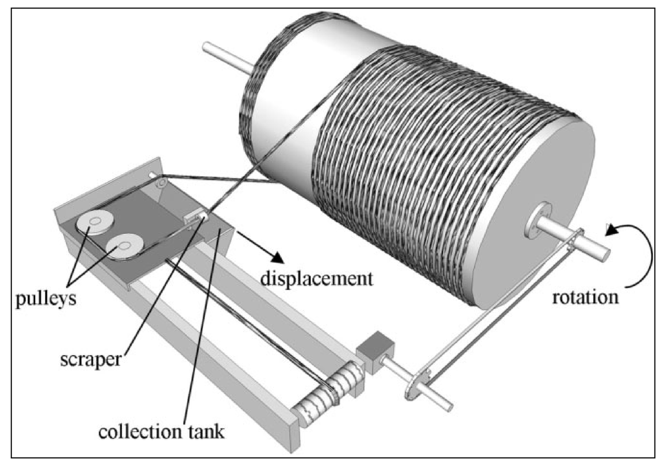

Figure 12: Spool harvesting operation

Source: Christenson, L. and Sims, R. "Rotating Algal Biofilm Reactor and Spool Harvester for Wastewater Treatment with Biofuels By-Products" Biotechnology and Bioengineering, Vol 109 (2012): 1674-1684. Print.

Future work

Test RABR under winter conditions
- Greenhouse
- Batch Mode (7 Day RT)
- Nitrogen addition

Test new RABR design
- Increased surface area to volume ratio
- Increase value of downstream bioproducts
- Minimize photoinhibition

Predictive Model
- Critical variables
  - Nutrients
  - Light
  - Temperature
  - pH

Figure 13: Greenhouse during construction

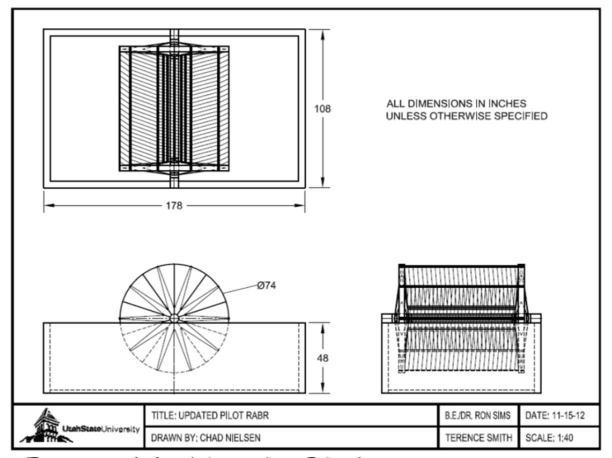

Figure 14: New RABR Design

Acknowledgements

1) Utah Science, Technology, and Research (USTAR)
2) *Biomass Production Using a Rotating Bioreactor and Spool Harvester* Christenson, L.B., & Sims, R.C. 2010. USA. Provisional Patent Application Number 61/310,360
1) Dr. Ronald Sims, Dr. James Powell, Dr. Charles Miller, Reece Thompson, Chad Nielson, Madeleine Smith
2) City of Logan Environmental Dept.
3) Christenson, L. and Sims, R. "Rotating Algal Biofilm Reactor and Spool Harvester for Wastewater Treatment with Biofuels By-Products" Biotechnology and Bioengineering, Vol 109 (2012): 1674-1684. Print.
4) Woolsey, Paul. "Rotating Algal Biofilm Reactors: Mathematical Modeling and Lipid Production." MS thesis. Utah State University, 2011. Print.