Modeling of Photosynthetic Aeration for Energy Efficient Wastewater Treatment

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Wastewater treatment is an energy-demanding process with one of the main contributors to energy usage being the intensive aeration that aerobic bacteria require in order to break down organic waste materials[1]. Because of this, aeration alone accounts for roughly 50% of the energy used in the process[2]. Little research has been done to assess and model the effects of utilizing photosynthetic aeration sourced from algal microorganisms. Because algae are known to produce large amounts of dissolved oxygen in water, it is possible that their implementation would reduce the need for mechanical aeration[2,3].

The objective of this project was to quantify the effects that algae have on wastewater oxygenation and the removal of organic material by bacteria. We hypothesized that algae will supply dissolved oxygen to bacteria, thereby speeding degradation of organics. To test this hypothesis, a simplified model of a wastewater treatment process was developed that consisted of a synthetic wastewater media, a model bacterial organism, a model algae, and a single carbon source (2 g/L succinate) consumable by bacteria only. *Auxenochlorella protothecoides* (*A. protothecoides*) and *Escherichia coli* (*E. coli*) were used for the model algae and bacteria, respectively.

Studies were conducted in a 1-L bioreactor equipped with probes to monitor pH, dissolved oxygen, dissolved carbon dioxide, and temperature throughout the trials. This system was then tested both with and without the presence of algae, while monitoring the probe readings over time by use of a Mettler Toledo® M800 transmitter and data loggers. The collected experimental data were then analyzed with MATLAB® using a model that quantified net microbial gas production and consumption. High-pressure liquid chromatography (HPLC) was used to measure changes in succinate, acetate, and fumarate in the medium over time. The latter two acids are generated through cellular metabolism of succinate. After completing analyses on the synthetic system, trials were conducted on primary wastewater acquired from a municipal wastewater treatment facility in Columbus, Georgia. The main difference with these experiments was that our media now contained a plethora of organic compounds and bacterial organisms, making the system much more complex.

The results from our synthetic wastewater experiments indicate that *A. protothecoides* stimulated faster consumption of succinate by *E. coli*. This was likely driven in part by oxygen provision from algal photosynthesis. Dissolved oxygen levels initially depleted in all cultures but recovered 33% faster when algae were present in comparison to bacteria alone (Figure 1). This result indicates that the bacteria were able to consume the organic carbon at a faster rate when cultured with algae. Analysis of organic acids also indicates that more acetic acid, an anaerobic bi-product, was produced in cultures with bacteria than those supplemented with algae. This result, too, confirms that photosynthetic oxygen facilitates the breakdown of organics by bacteria.

As for the experiments regarding real wastewater, observations seem to indicate that the system behaved similarly to that with synthetic wastewater, but the declines in oxygen were much smaller, indicating a lower total organic load. Further analysis by chemical oxygen demand (COD) assay will reveal the extent and rate of organic degradation in the wastewater in the presence and absence of algae. Measurement of nutrient transformation and removal are also needed to determine if algae have a future in the wastewater treatment process. That said, the results from these experiments are conclusive that bacteria were able to perform more efficiently when algae are present, confirming the potential of further research to create a more energy efficient approach to wastewater treatment.

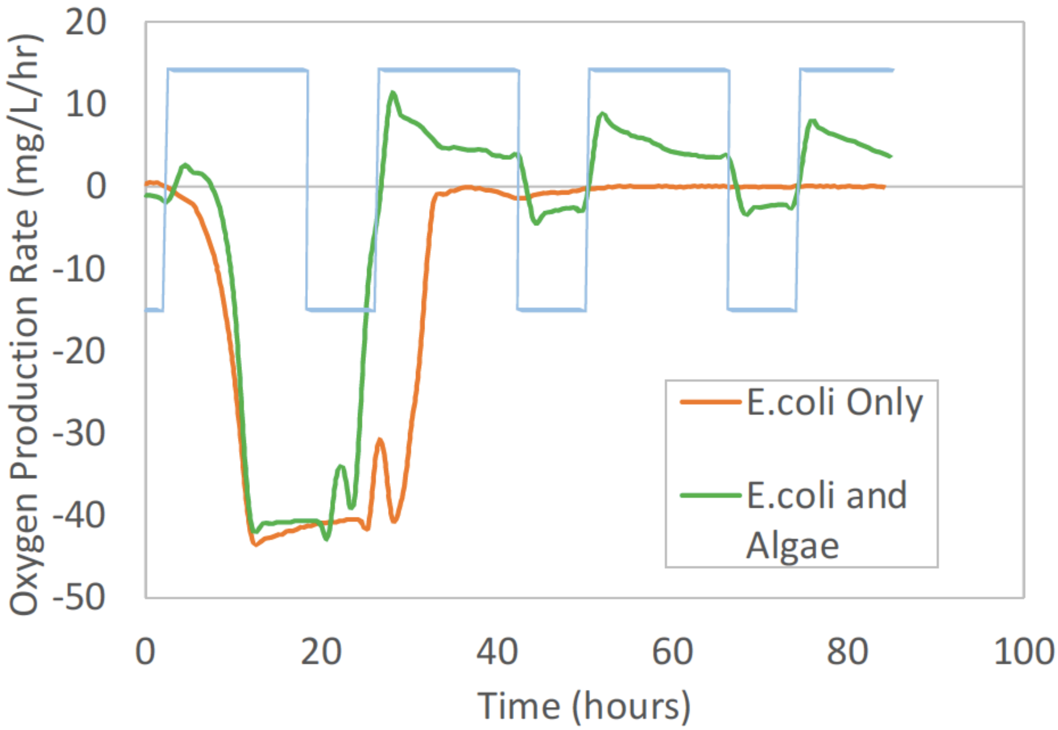

Figure 1. Net dissolved oxygen production (positive) or consumption (negative) by cells in a batch culture. The light was operated on a 14:10 on/off cycle, as designated by the blue line.

Statement of Research Advisor

Bryan's research has laid the groundwork for more in-depth study of gas exchange between algae and bacteria in wastewater treatment processes. This research holds the potential to significantly reduce aeration requirements in wastewater treatment plants while also producing algal biomass which has potential value for biofuel and protein production.

– *Brendan Higgins, Biosystems Engineering*

References

[1] EPA, *US GHG Inventory 2013 Chapter 8 Waste*. 2014, EPA: Washington DC.

[2] Muñoz, R. and B. Guieysse, *Algal-bacterial processes for the treatment of hazardous contaminants: A review*. Water Research, 2006. **40**(15); p. 2799-2815.

[3] Green, F.B., et al., *Advanced Integrated Wastewater Pond System for Nitrogen Removal*. Water Science and Technology, 1996. **33**(7): p. 207-217.