Analytical and Data-driven Models to Predict Algae Biofilm Growth

Students names, Faculty advisor and industry mentor

Background

Utah State University (USU) is collaborating with the Central Valley Water Reclamation Facility (CVWRF), the largest water treatment plant in Utah (60 MGD), and WesTech-Inc. to innovate ways to reduce nitrogen and phosphorus levels in wastewater before being discharged into receiving waters. By 2018, in the state of Utah, there were 25 major sites of algal blooms that were primarily caused by excess nutrients [1]. The Rotating Algae Biofilm Reactor (RABR) provides an innovative way of removing nutrients from wastewater. Compared to standard raceway ponds, the RABR increases biofilm productivity up to 300%. No referred literature exists on mathematically connecting RABR biofilm productivity with actual data.

Research Goals and Significance

The purpose of this research is to formulate a model of the mass production of the RABR as a function of sunlight and rate of exposure.

- Identify factors (such as light intensity) maximize biofilm production
- Develop a data-driven model to accurately predict biofilm growth

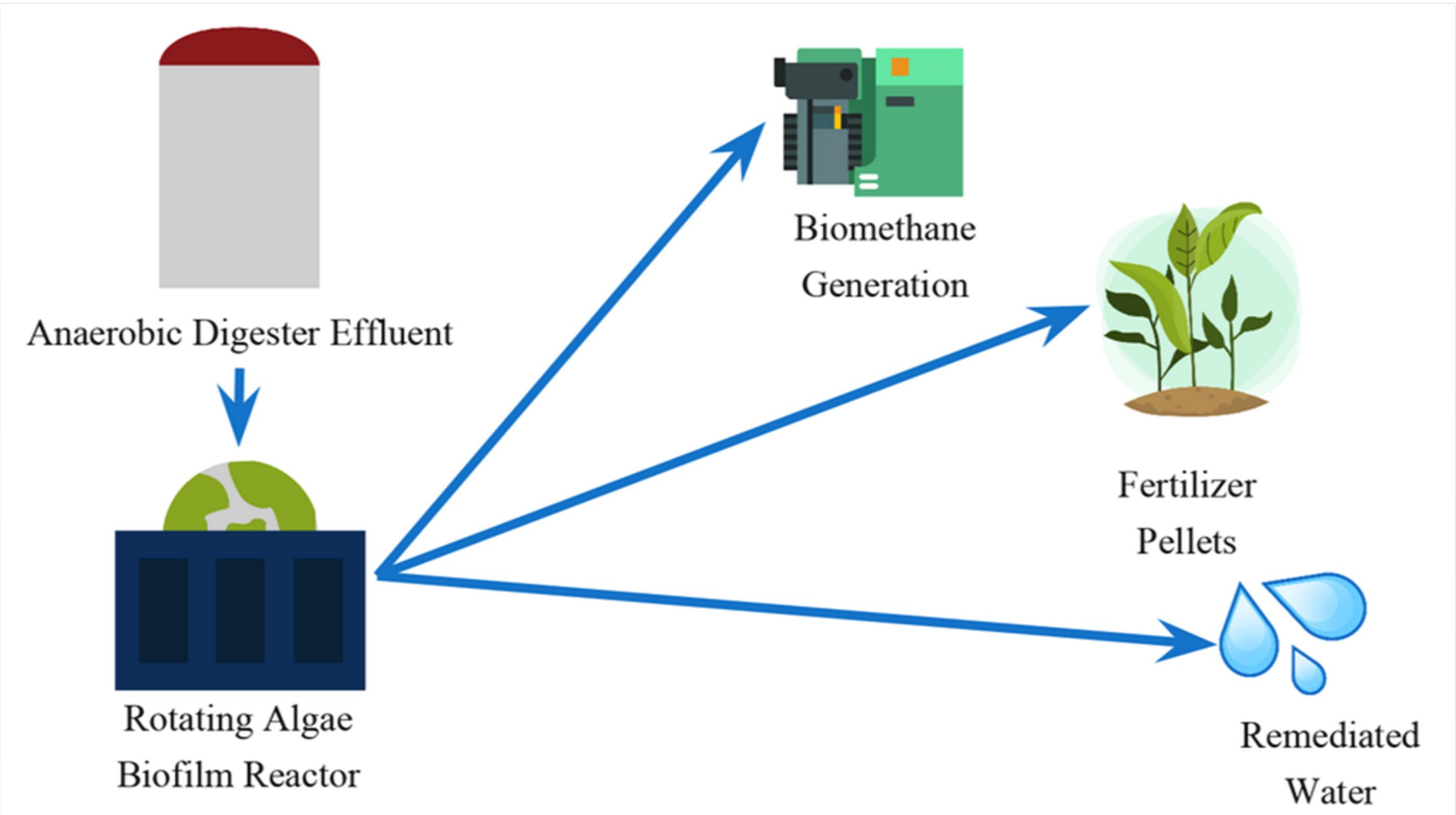

Figure 1: While treating wastewater, the biofilm harvested from the RABR also has significant potential for bioproducts such as biofuel, fertilizer, medicine, bioplastics, and livestock feed [2].

Methodology

To accurately model biofilm growth, it is necessary to use both an analytical and data-driven approach. Sparse Identification of Nonlinear Dynamics (SINDy) is a recently data-driven method that uses linear regression to produce governing equations of a nonlinear system [3]. The approach is enumerated in steps 1-4 below:

1. Propose an analytical approach to modeling algae biofilm growth according to literature review and observations of the RABR.

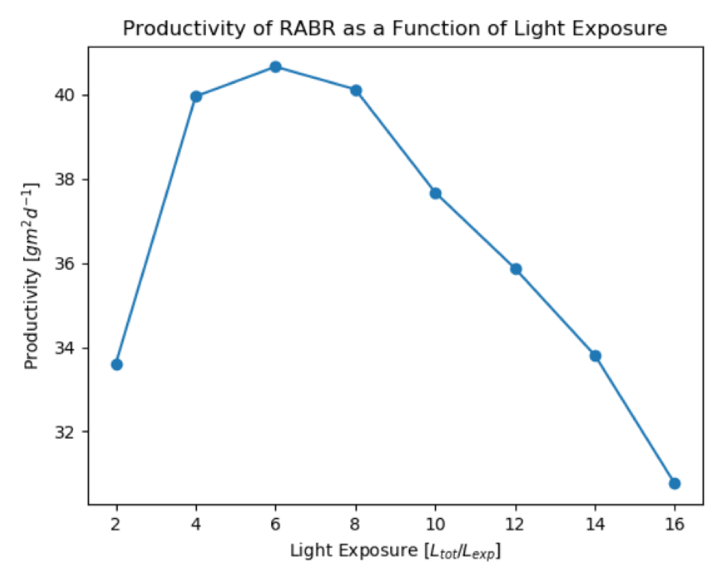

Figure 2: Our model suggests that optimal productivity occurs when 1/7 of the RABR is exposed to sunlight.

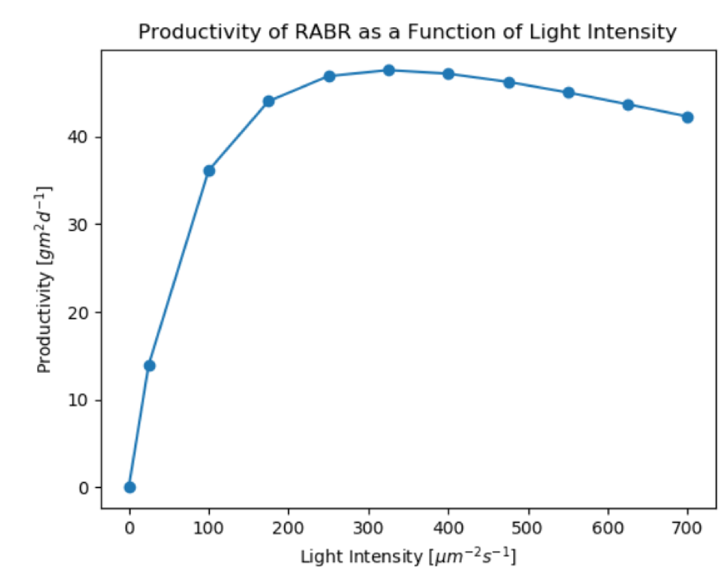

Figure 3: Our model suggests that optimal productivity occurs at approximately 15% of sunlight.

$$\begin{cases} \dfrac{dh(t)}{dt} = \displaystyle\int_0^h \Big[(1 - C(z,t))\dfrac{k\sigma I(z,t)}{1+\tau\sigma I(z,t)}\Big]dz - Rh(t). \\ \dfrac{\partial C(z,t)}{\partial t} = -\Big(\beta(z,t) + k_r\Big)C(z,t) + \beta(z,t), \quad \beta(z,t) = k_d\tau\dfrac{(\sigma I(z,t))^2}{\tau\sigma I(z,t)+1}, 0 < z < h. \end{cases}$$

Figure 4: Model for the change of height and photoinhibition of the biofilm based on Bonneford's and Bara's work [4].

2. Conduct controlled laboratory testing combined with outdoor pilot testing to collect data to adjust the analytical model.

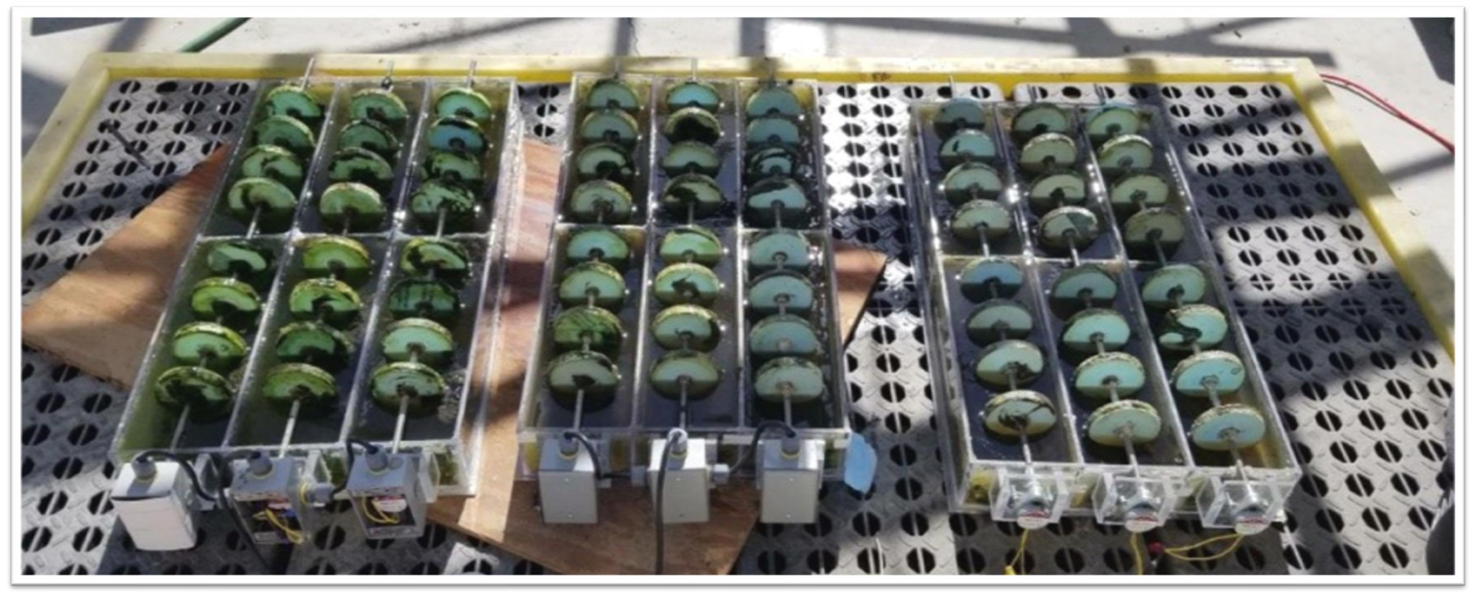

Figure 5: Inoculated laboratory scale Rotating Algae Biofilm Reactors at USU.

3. After sufficient data collection and processing, the analytical model will be scrutinized by data-driven methods with SINDy.

4. Continue to adjust the analytical model, collect data, verify the model with SINDy and make necessary adjustments.

Expected Outcomes

- Develop a robust equation that can be applied to current and future biofilm production
- Harmonize classical and newfound data-driven methods to discover underlying mechanics of biofilm growth
- Assist the efforts of CVWRF, WesTech-Inc., and the state of Utah in reducing nutrient pollution in discharged waters
- Demonstrate the power of SINDy with biological engineering applications

Figure 5: Pilot scale rotating algae biofilm reactor ,manufactured by WesTech-Inc. at Central Valley Water Reclamation Facility in Salt Lake City, Utah

References

[1] Harmful Algal Blooms (HABs) 2018 State of the Environment Report (WQ). Utah.gov. https://deq.utah.gov/communication/state-of-the-environment-report/harmful-algal-blooms-habs-2018-state-of-the-environment-report-wq. Published 2019. Accessed October 1, 2019.

[2] Christenson L, Sims R. Rotating algal biofilm reactor and spool harvester for wastewater treatment with biofuels by-products. Biotechnol Bioeng. 2012;109(7):1674-1684. doi:10.1002/bit.24451

[3] Brunton S, Proctor J, Kutz N. Discovering governing equations from data by sparse identification of nonlinear dynamical systems. Proceedings of the National Academy of Sciences. 2016. doi:10.1073/pnas.1517384113

[4] Lamare P, Aguillon N, Sainte-Marie J, Grenier J, Bonnefond H, Bernard O. Gradient-based optimization of a rotating algal biofilm process. Automatica. 2019;105:80-88. doi:10.1016/j.automatica.2019.02.043

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