Department of Biosystems
and Agricultural Engineering
MICHIGAN STATE UNIVERSITY

BE 487 - Spring 2025
Biosystems Design Projects

Phosphorus Removal Column System using TimberChar™ (Under NDA)

Praneeth Dattagupta, Renae Kenney, Shayla Le, & Catherine Maurer

Client: Eden Lakes   Faculty Advisor: Dr. Younsuk Dong

Background

Excess phosphorus in lakes causes eutrophication, leading to harmful algal blooms that deplete oxygen. The Lake Leslie wastewater lagoons are currently experiencing this, shown in Figure 1.

Figure 1. Lake Leslie algal blooms due to eutrophication.

Lake Leslie's managing municipality is unable to safely discharge effluent into natural waterways under NPDES and EGLE phosphorus regulations[1]. Lagoon effluent discharge must be <1 mg/L total phosphorus (TP). Levels are current at ~7 mg/L soluble reactive phosphorus (SRP). Figure 2 shows an overview of the wastewater lagoon system.

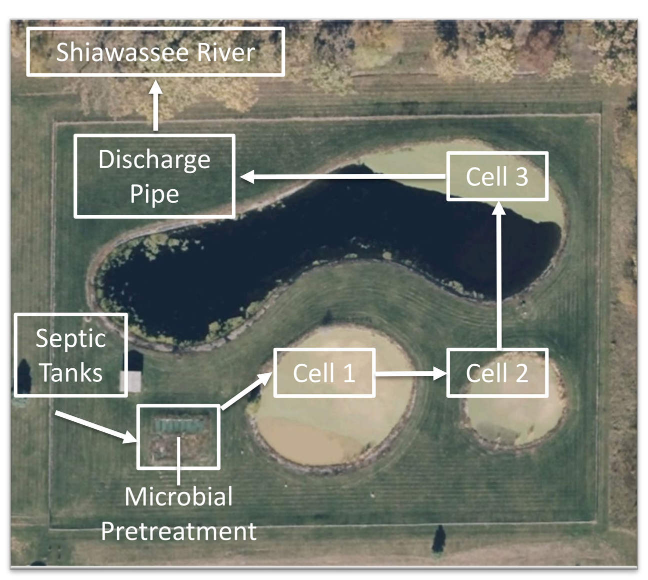

Figure 2. Lake Leslie wastewater lagoon cells.

Biochar is a new technology in the wastewater, health, and agricultural industries[2]. Eden Lakes' biochar product, TimberChar™ is made through slow pyrolysis, which heats biomass 400 to 800°C in an environment with little to no oxygen[3]. Phosphorus adsorption is improved by porosity, surface area, and cation exchange capacity. A microscopic image of the TimberChar™ is found in Figure 3.

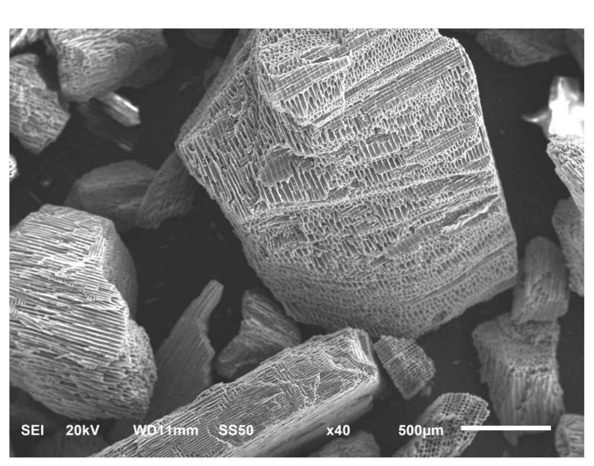

Figure 3. TimberChar™ image taken at MSU Center for Advanced Microscopy.

Eden Lakes implemented a mesh bag design containing TimberChar™ with 25 bags in cell 1 and cell 3. After implementing these bags, the municipality recorded a 55% reduction in P but still was not able to meet permit requirements. Eden Lakes has requested that the MSU senior design team design a filtration system using the TimberChar™ product. Eden Lakes specializes in lake restoration and wastewater lagoon treatment. They provide consulting services for lake owners, lake associations, and municipalities[4].

Objectives

Objectives for the project included:

1. Characterize Lake Leslie wastewater
   - Identify P form and concentration
2. Characterize TimberChar™'s physical & chemical properties
   - Adsorption isotherm experiments
   - Low Vacuum Scanning Electron Microscopy (LV SEM)
   - Energy Dispersive X-Ray Spectroscopy (EDX)
3. Design filtering system using TimberChar™

Constraints

Lake Leslie wastewater lagoon's discharge permit is based on 125,000 gal/day flowrate. Phosphorus levels from point source discharge out of cell 3 must be controlled to achieve EGLE standards. The design must be compatible with the discharging permit[1]. Constraints are found in Table 1.

Table 1. Constraints breakdown.

Criteria	Value	Unit
Flowrate (Q) out of Cell 3	<1	ft depth/day
Maximum effluent P conc.	<1	mg/L SRP
Time to achieve P conc.	<24	weeks
Char particle loss	<5	% (g/g) dw

Design Alternatives

A decision matrix weighed which design alternative was chosen. The criteria was determined by client, team and faculty advisor conversations. Criteria rating in descending order included: P adsorption efficiency, transport, scalability, maintenance, implementation cost, and environmental impact. The design alternatives included:

1. **Partitioned Bag**: Uses internal partitions to increase surface contact between TimberChar™ and SRP. This design relies on diffusion to have phosphorus contact the biochar, making P adsorption low. Retention time is not controlled for this design.
2. **Beaded Biochar Mat:** Encapsulates biochar in alginate gel on a permeable mat; passive system with potential nutrient leaching. New infrastructure would be required to produce the beads, adding to cost.
3. **CSTR:** A continuously stirred tank reactor that pumps and agitates lagoon wastewater with biochar to ensure adequate phosphorus uptake. This is the second most expensive design to implement since it requires a large tank, a motor, and pump. It is not easily transportable. Design would have highest P adsorption.
4. **Biochar Packed Columns (selected design):** PVC columns filled with biochar, where water is pumped at a steady rate to control contact time and maximize P removal. This design is already applied in the wastewater treatment industry. It has the capability of being detachable, making it easy to scale and transport. Retention time can be controlled based on flow rate.

Design Testing

Six adsorption isotherm experiments informed P adsorption capacity (mg P/ g TimberChar™) and empty bed contact time (EBCT). Figure 4 is an example of one isotherm experiment conducted.

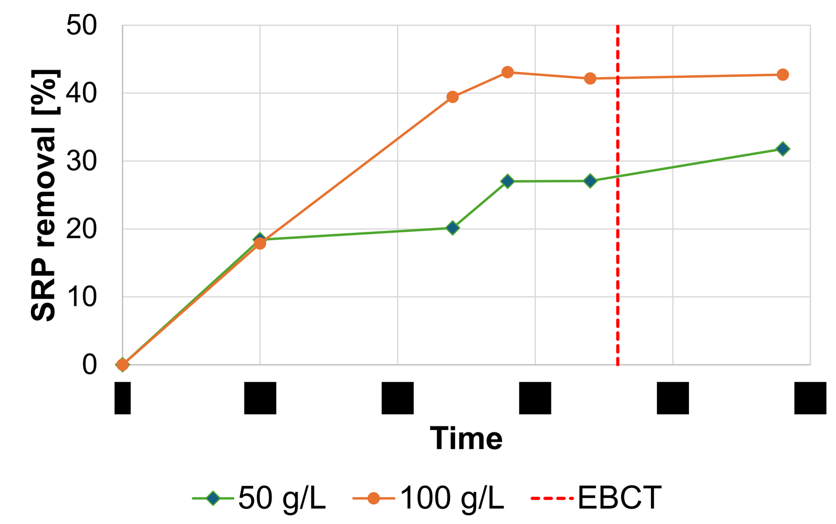

Figure 4. Isotherm adsorption experiment at 50 and 100 g/L.

The selected design is a packed column system filled with TimberChar™ and a pebble layer at inlet and outlet of column. A prototype was tested; flow schematic is represented by Figure 5. Synthetic wastewater at 7 mg/L SRP was delivered to the system by peristaltic pumps simulating the Lake Leslie lagoon. Column P concentrations were tracked through partitioned bins.

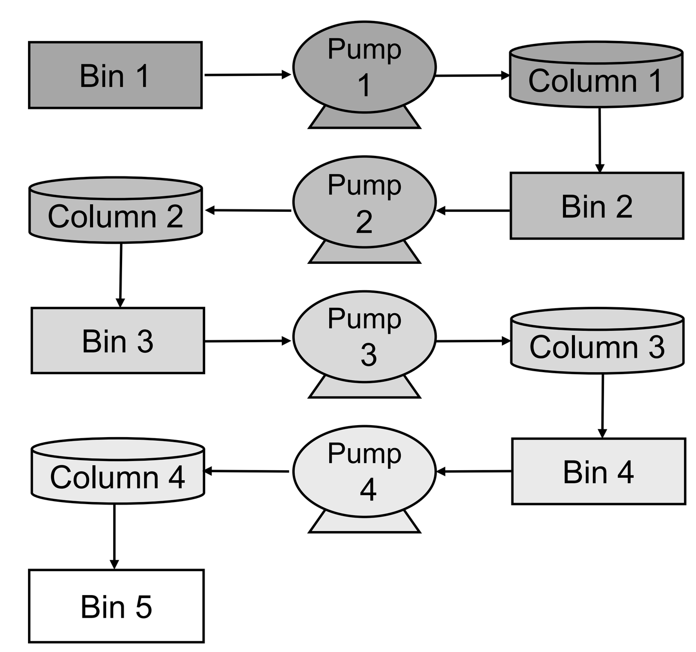

Figure 5. Prototype wastewater flow diagram.

Figure 6 are results of column experiment. One line of 4 TimberChar™ columns can achieve a 1 mg/L SRP loading and continuous delivery of 7 mg/L SRP was achieved. Inter-column data and time are blocked out due to NDA. The breakthrough point (when all biochar is loaded and can no longer adsorb phosphorus) was also determined.

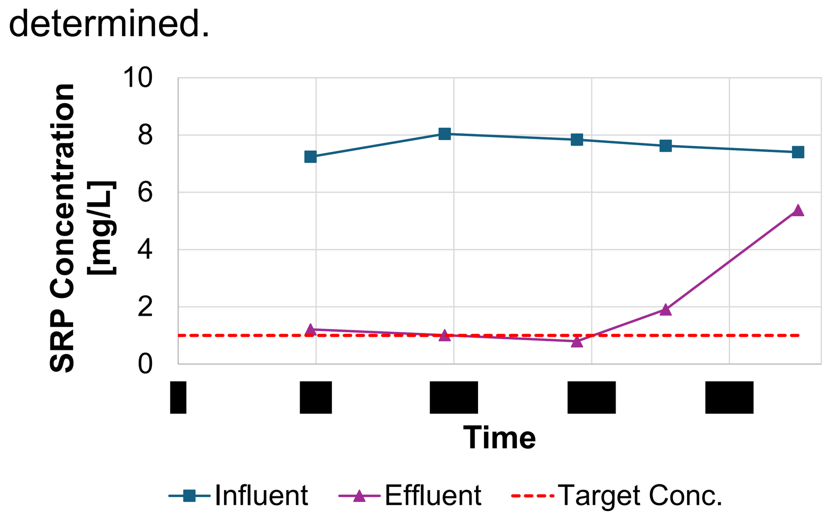

Figure 6. Influent (Bin 1) and effluent (Bin 5) SRP concentrations.

The biochar loss through the columns was found through vacuum filtration out of the last column. This value did not exceed 5%.

Design Parameters

The final design utilizes a "unit", defined as 12 rows of 4 columns. This reduces material costs by requiring less frames. The unit's frame is made from welded aluminum, a corrosion resistant material. The implementation plan includes 24 week (6 month) treatment periods where:

- 3 four-channel peristaltic pumps per unit feed the 1 million gallons wastewater from cell 3 into the design's column lines and recirculate water into cell 3
- TimberChar™ is replaced (at rate determined by column experiment) when exhausted throughout treatment periods
- Wastewater is discharged, the 2ft remaining at 1 mg/L SRP mixes with the 3ft depth at 7 mg/L SRP from cell 2
- P levels then drop from 7mg/L SRP to 4.6 mg/L SRP in the subsequent periods, requiring fewer refills than the initial

Figure 7 shows the CAD drawings of column prototype and final design.

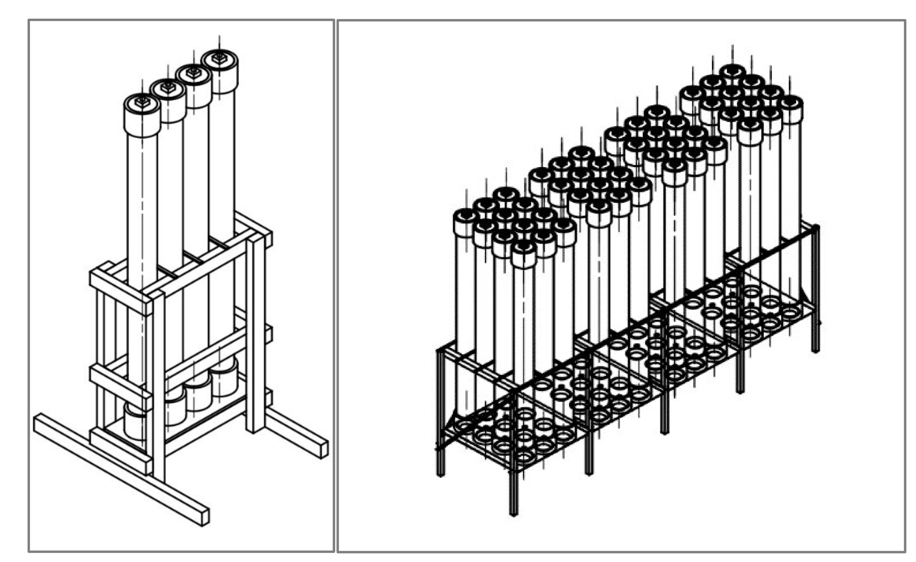

Figure 7. Column prototype (left) and final column design (right).

Economic Analysis

A 10 year economic analysis, represented by Table 2, based on 6-month treatment periods was conducted. The actual scale analysis is unavailable due to NDA.

Table 2. 10-year economic analysis of final design based on (hypothetical) TimberChar™ adsorption.

Year	Period	Factor Table	Capital Cost [$]	Maintenance & Labor Cost [$]	Cost [$]	Rev. [$]	Profit [$]
1	1	1	~$195,000	$115,000	$300,000	$96,000	-$204,000
	2	1		$58,000	$58,000	$48,000	-$10,000
2	3	0.94	~$67,000	$55,000	$122,000	$45,000	-$77,000
	4	0.94		$55,000	$55,000	$45,000	-$10,000
3-10	5-20	n/a	~$413,000	$683,000	$1,096,000	$562,000	-$534,000
				Total	**$1,640,000**	**$796,000**	**-$844,000**

The following analysis is based on hypothetical TimberChar™ adsorption capacity. The capital costs included material costs, welding and the labor for setup. Recurring costs includes electricity for the pump, materials for TimberChar™ refills, and the labor for refills. The pump chosen is a recurring capital cost as its lifespan is only 10,000 hours. There is revenue from the loaded biochar if sold as an agricultural amendment. The scale for hypothetic economic analysis is:

- 20 column design units
- Initial period: 10 TimberChar™ refills
- Subsequent period: 5 TimberChar™ refills

This example system has a return on investment if priced at $112,000 per year. This means the system uptakes a pound of phosphorus for ~$7,600 while other systems can do the same for $42-61[5].

Conclusions

All constraints and objectives were met. Future recommendations to improve the economic viability include:

1. Biochar particle sieving to increase hydraulic conductivity and flowrate
2. Treating only the 3 ft discharge required by the permit reduces the number of units but would require a separate holding reservoir
3. Improvement of biochar adsorption through chemical treatment
4. Industry grade pumps that would not need to be replaced

As phosphorus resources decline, the need for sustainable water treatment methods becomes essential for ecosystem health. TimberChar™ offers a promising solution to reducing phosphorus runoff and combatting harmful algal blooms.

Select References

1. State of Michigan Department of EGLE. (2023). Authorization to discharge under the national pollutant discharge elimination system, Permit NO. MI0059156. NPDES permits. https://www.michigan.gov/egle/maps-data/mienviroportal
2. Sizmur, T., Fresno, T., Gokcen, A., Frost, H., & Moreno-Jimenez, E. (2017). Biochar modification to enhance sorption of inorganics from water. *Bioresource Technology, 246.* /https://doi.org/10.1016/j.biortech.2017.07.082
3. Weber. K. & Quicker. P. (2018). Properties of biochar. *Fuel, 217.* https://doi.org/10.1016/j.fuel.2017.12.054
4. Eden Lakes. (2024). *TimberChar™*. Eden Lakes Technologies. https://www.edenlakes.co/timberchar
5. Bashar, R., Gungor, K., Karthikeyan, K., & Barak, P. (2018). Cost effectiveness of phosphorus removal processes in municipal wastewater treatment. Chemosphere, 197. https://doi.org/10.1016/j.chemosphere.2017.12.169