

To: Dr. Christine Cranford, CEO

From: Student B

Date: 11/15/2018

Subject: Ecological Treatment of Brewery Wastewater Proposal

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## **Introduction**

Craft and microbreweries are a fast-growing industry in North Carolina. Currently, there are over 260 breweries and brewpubs in the state. They are becoming a large part of local economies, and an integral part of local culture in towns and cities across the country. By nature, breweries produce around three to ten liters of wastewater as a byproduct of brewing one liter of beer (Simate et al. 2011). This wastewater contains high amounts of organics such as sugars and alcohols, can have an acidic pH, and may contain high amounts of solids (Simate et al. 2011). In municipalities with strict regulations on dumping wastewater into municipal sewer systems, breweries must either pay a fee to dispose of their wastewater to be treated offsite at a wastewater treatment plant or expend a larger monetary cost to treat their water locally. Mechanical treatment devices, often consisting of several large (1000+ gallon) tanks, have been proven to effectively treat wastewater and are currently the common model for a treatment system in the brewing industry. For large breweries with the infrastructure and land to accommodate these treatment systems, the size of the necessary treatment systems is not an issue. However, for microbreweries, the majority of which are located in highly populated metropolitan areas, land is often a limiting factor.

Ecological Treatment of Brewery Wastewater is a research and design project that examines the physical and chemical loading in wastewaters generated as a byproduct of the brewing processes in microbreweries and recommends a low-cost ecological wastewater treatment system that could be implemented in small-scale breweries to reduce the costs of on-site wastewater treatment. This project will target Total Suspended Solids (TSS), pH, and Biological Oxygen Demand (BOD), which is a relative measure of the number of organics in the water, as the key parameters to treat, as these are what parameters breweries are currently regulated on in their wastewater. As the craft beer industry grows, it is expected that breweries will face more strict wastewater regulations, and the research conducted by this project may help alleviate some of the external costs this will bring to breweries.

## **Problem**

Brewery wastewater is a serious problem to ecological health and stream water quality. Brewery wastewater has high concentrations of suspended solids and nutrients in the form of organic compounds, as well as being acidic in pH.



Figure 1. Examples of brewery wastewater

In ecosystems, nutrients such as nitrogen and phosphorus limit the production of autotrophs such as photosynthetic algae. When brewery wastewater enters streams with high nutrients (nitrogen and phosphorus), these photosynthetic algae can produce more biomass through photosynthesis, which results in an algal bloom and eutrophic conditions. This large algal population consumes much of the dissolved oxygen in the water, and blocks sunlight from penetrating into the water column. As a result, dissolved oxygen levels decrease, and aquatic life will die off in large numbers, such as in a fish kill (Figure 2).



Figure 2. An example of a fish kill from eutrophication

Through the design of an ecological treatment system that relies on biological principles, brewery wastewater pH can be regulated, solids can be removed from suspension, and organic compounds can be broken down into an inert form that doesn't negatively impact water quality without introducing harsh chemicals into the system.

## Background

Past attempts to develop a small-scale treatment system have determined TSS, pH, and BOD are key properties of raw brewery wastewater needing to be addressed by the designed wastewater treatment system (Simate et al. 2011). There are three basic modes of treatment currently used in

the brewing industry: chemical, physical or biological. Physical treatment processes target the removal of solid matter from the system. Physical treatment alone tends to yield little success in the treatment of organics, resulting in incomplete removal and/or separation of contaminants. These processes may include sedimentation to allow suspended pollutants to settle out or a filtration that will remove solids through a porous media. Chemical processes use a series of chemicals that may be added to brewery wastewater to alter the chemistry of the water. These processes can either involve altering the pH or coagulation and flocculation, which clumps smaller solid particles together to be more easily removed from the solution. In order to protect the organisms where treated brewery wastewater will eventually end up, and to protect the degradation of sewer lines, the pH of wastewater should remain between 6 and 9. Lastly, biological processes are based on microorganisms that aid in the decomposition of organic substances. Biological methods tend to be a lower investment cost and have higher BOD removal but require a high energy input. Biological processes can either be anaerobic or aerobic and include membrane filtration or trickling filters (which promote bacteria growth on the filtration media), woodchip bioreactors, or constructed wetlands (Simate et al. 2011). The proposed system for this project will expand on the physical and biological modes and be a two-stage treatment system exploiting aerobic and anaerobic processes. By using a two-stage treatment system, a higher efficiency for removal can be obtained at a lower cost.

## **Objective**

This project is focused on the development of a system that applies biological principles to treat brewery effluent. pH, BOD, and TSS are the properties of the brewery wastewater which the treatment system will target. The system will use naturally occurring biological process to treat brewery wastewater and will be more cost-effective (only requiring the cost of the electricity input and replacing filter media) than current treatment practices, which require breweries to continually purchase chemicals for treatment. At the conclusion of the experimental trials, a cost-benefit analysis will be conducted of the treatment system compared to commonly used chemical treatment regimens to defend the prediction that the final system is a more cost-effective method to treat brewery wastewater.

The design criteria of the proposed project include:

- Creation of an ecological treatment system that relies on biological processes to reduce the TSS and BOD, and to regulate the pH in the brewery wastewater to levels required by municipal wastewater treatment plants in North Carolina.
  - Includes aerobic filter that nitrifies ammonium, takes solid waste out of suspension, and facilitates aerobic respiration to break down more complex organic molecules.
  - Includes anaerobic woodchip bioreactor that denitrifies nitrate.
- Low maintenance system that requires minimal management during extended use.
- Construction of a 1/100 scale model system that will handle and treat wastewater generated from brewing processes

## Solution

*Objective 1. Design a system that uses biological principles to remove organic material from wastewater effluent.*

The design of the treatment system will include two separate processes: aerobic nitrification and respiration, and anaerobic denitrification. For the aerobic filter, the current plan is to use a combination of media to promote the growth of a biofilm which will break down organic compounds. Figure 3 shows the present setup of the aerobic filter prototype. This media (2) will reside in a hollow cylindrical piping (1), which will be filled with #67 gravel, and a layer of K1 Moving Bed Biofilm Reactors (MBBR). A ½ hp centrifugal pump (7) will provide the pressure head to move the water from the holding tank (4) through the flexible hosing (6) into the pump and out through another flexible hose (8) and recirculate back to the top of the filter. Water samples will be taken after several days of the system running to assess the TSS, BOD, and pH. If unfavorable results return, modifications to the system will be made until these parameters are within the design criteria.

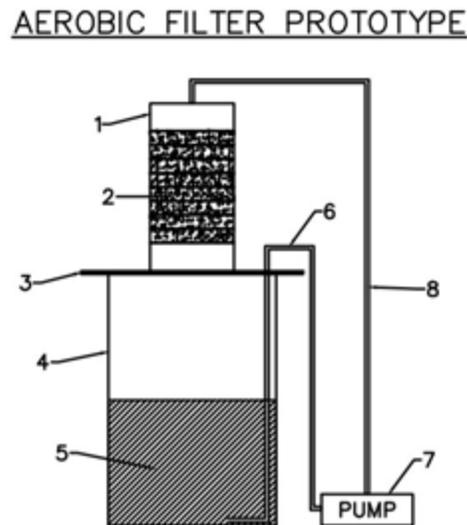


Figure 3. Initial schematic for the aerobic filter prototype

Once the desired water quality parameters are met, the construction of the anaerobic side of the system will begin. A woodchip bioreactor will receive outflow from the aerobic filter, where anaerobic bacteria will denitrify nitrate in the water. Optimization of the residence time will be achieved through a recirculating pump to ensure nitrate removal efficiency meets design criteria. Previous research groups found that bioreactors for brewery wastewater were more prone to clogging (Christianson et al. 2016), but this will be addressed only if the project encounters this issue. Brewery effluent entering the system will have variable concentrations of nutrients, but prior research found that biological systems were able to handle variable concentration strength while maintaining its treatment efficiency (Shepherd et al. 2001).

Additionally, five ¾ inch throttling valves have been included to allow for both the movement from the aerobic system to the anaerobic system without having to change the piping setup, and

for proper throttling of the pumps to reduce the flow rate of the system. When the aerobic reactions are complete, the valve closest to the aerobic filter will be shut, and the valve leading to the anaerobic bioreactor will be open (see Figure 4). Both valves above the bioreactor will be open, allowing for the water to enter the bioreactor and recirculate. Last, when the anaerobic process is complete, the far-right valve will be opened, and the rightmost valve above the bioreactor will be closed to allow water to drain from the system to the stormwater system.

The scale of this project has been decided to be a 1/100 model. From talking with Trophy Brewing, the head brewer said that they use approximately 3000 gallons of water per day, with approximately 3 gallons of water used for every gallon of beer, which translates to 2 gallons of wastewater produced for every gallon of beer. Applying this knowledge, it is estimated that Trophy Brewing generates 60,000 gallons of wastewater per month. At a 1/100th scale, this project must handle and treat 600 gallons a month, or 20 gallons per day. This translates to a water holding tank size of 200 gallons as a conservative estimate, which would require new brewery effluent to be loaded into the system every 10 days. Additionally, the hydraulic residence time (HRT), which is the length of time that the water is in the treatment system, must be optimized to effectively treat the wastewater at this rate. An HRT of 48 hours was cited as obtaining a 90% BOD and nitrate removal efficiency from previous research (Lepine et al. 2016).

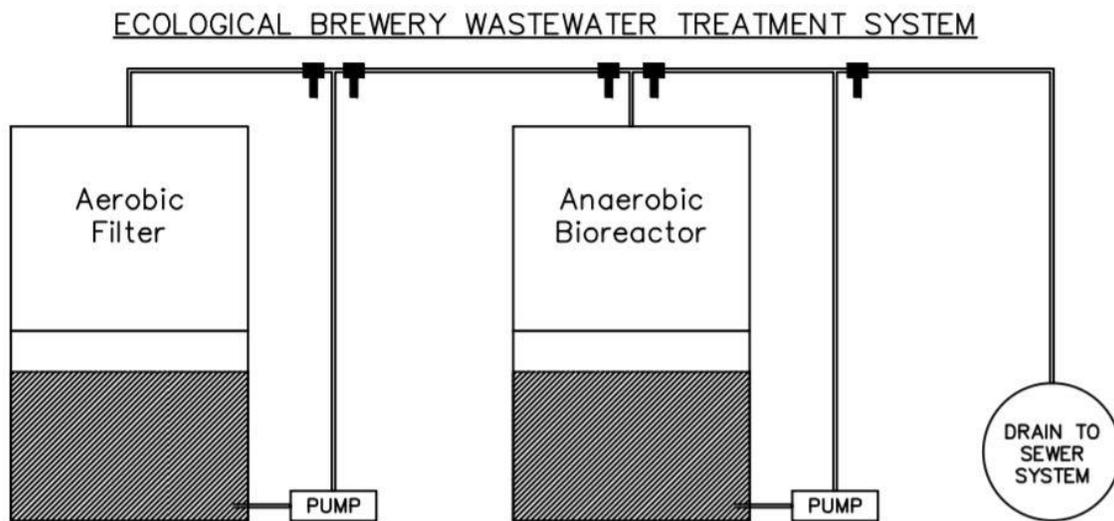


Figure 4. Schematic for proposed final treatment system

The advantage to using a recirculating treatment system versus a linear system is that there is a greater treatment capacity for the system. Recirculation allows for a more complete breakdown and transformation of organics and chemicals present in the raw brewery wastewater in the aerobic filter and the transformation of inorganic compounds into a chemically inert form in the anaerobic bioreactor. Additionally, a recirculating system allows for a significantly smaller model to treat the target volume than if a linear system was designed that only passed the effluent through once. The disadvantage for a recirculating treatment system is the high energy input to the system to power the pumps.

Gravel used in the aerobic filter is a heavy material, but it provides the adequate surface area and void space to promote the growth of a dense biofilm and therefore decomposition of organic compounds. K1 MBBR (Figure 5) are commonly used in aquaculture tanks to treat waters with high concentrations of organics. For the purpose of the aerobic filter, the K1 MBBR plastics alone do not provide an adequate surface area to achieve adequate treatment (Lekang, Odd-lvar., Kleppe, Helge, 2000).



Figure 5. K1 MBBR filter media

Paired with the gravel filter, these plastics will improve the aerobic filter by promoting circulation and mixing of wastewater as it is applied to the filter, as well as providing additional surface area on which aerobic bacteria can grow.

Choosing the correct carbon source to use in the designed anaerobic bioreactor is important. In the design, a softwood (e.g. pine) was decided upon to fuel the anaerobic processes of the bioreactor. Softwoods are more easily broken down than hardwoods, promoting a more rapid growth and a shorter acclimation period for the microbial community in the bioreactor. When the microbial population has reached its maximum by consuming the softwood materials, they will begin to decompose the tougher hardwood fibers in the wood chips. The disadvantage of using a softwood carbon source is that the wood chips will have to be replaced at a higher frequency.

Plastic PVC piping was chosen to convey wastewater within the system rather a metal piping to prevent the introduction of metals into the system due to chemical deterioration processes. Wastewater is often highly acidic which could cause metal pipes to oxidize. PVC piping will be inert to the wastewater and its associated chemical properties. The disadvantage of using PVC piping is that plastic is not as structurally rigid as metal. Nevertheless, for the low flow rates projected that the treatment system will require, PVC piping will suffice. For larger scale systems, piping made of a different material may be required.

*Objective 2. Design a system that is cost effective.*

The brewery wastewater treatment system will be designed with the intention that input and maintenance costs are lower than the long-term cost to pay for wastewater disposal fees by the city. In order to design to this specification, information needs to be collected on municipal water disposal fees, which vary greatly between brewery, type of beer, and the amount of effluent produced. Additionally, media with a high quality of carbon and longer lifespan will be used to increase the treatment efficiency of the system. A cost-benefit analysis will be performed to

determine the effectiveness of the final treatment system in comparison to commonly used systems within the industry to measure the practicality of the system.

### Schedule

The Gantt Chart (Figure 6) gives a detailed timeline for the projected completion for major project deliverables throughout the remainder of the academic year. The aerobic trickling filter prototype is set to be constructed throughout November, and the bioreactor prototype to be constructed into December. Wastewater analysis testing from the prototypes will be completed during December and January, as well as the planning of the full-size design. Construction and testing of the full-size system will take place from February to April, and finally, a cost-benefit analysis and a presentation of final results will take place April and into May.

	November	December	January	February	March	April	May
Aerobic Trickling Filter Prototype Construction	█						
Anaerobic Bioreactor Prototype Construction		█					
Wastewater Analysis Testing		█	█				
Full-Size System Design		█	█				
Construction of Full-Size Model			█	█	█		
Treatment System Testing and Modification				█	█	█	
Cost-Benefit Analysis						█	
Presentation of Results						█	█

Figure 6. Gantt Chart that details a timetable of proposed completion dates for deliverables

### Budget

Description	Unit Price	Quantity	Cost
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#### Equipment Cost:

Centrifugal Pump (1/2 hp)	\$90	2	\$180
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#### Materials Cost:

#67 gravel	\$25.50/ton	1	\$25.50
Woodchips	\$1.63/ft <sup>3</sup>	28	\$45.50
K1 Moving Bed Biofilm Reactors (MBBR)	\$11/gal	10	\$110

#### Supplies Cost:

Water storage container (200 gal)	\$210	1	\$210
Recirculation Chambers (40 gallon)	\$20/chamber	2	\$40
PVC Piping	\$9/20 ft	4	\$36

Throttling Valves	\$13	5	\$90
Pipe fittings (assorted)	-	-	\$60
Plastic Grate	\$40	1	\$40
Filter Housing (10" PVC)	\$200	12 ft	\$200

**Travel Cost:** N/A

**Misc.:** N/A

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**Total Cost : \$1037**

### *Budget Justification*

The filter housings will hold the materials used make up the aerobic filter and anaerobic bioreactor. #67 gravel and K1 MBBR will be used as media in the aerobic filter on which bacteria will grow. The gravel will also act as a mechanical filter to remove solids from the brewery wastewater. The filter media will be held in using a plastic grate at the end of the vertical filter column. Wood-chips will be used as the carbon source for anaerobic bacteria to use in their respiratory process while treating the wastewater in the anaerobic bioreactor. Recirculation chambers will be used by the aerobic filter and the anaerobic bioreactor to hold the liquid each setup is treating. The water storage will house raw wastewater until it is ready to be introduced to the treatment system. Centrifugal pumps will be used to drive the recirculation and movement of wastewater through the treatment system. PVC piping, with associated joint fittings, will convey the flowing water within the treatment system during treatment and to the drain connected to the municipal sewer system following treatment. Throttling valves will be used to control the volumetric flow rate of wastewater through the treatment system as well as control the flow path of the wastewater. By opening and closing valves, the person regulating the treatment system can pass treated water from one stage of the system to the next, and then reclose the appropriate valves to allow the water to recirculate through the treatment system.

### **Recommendation**

It is recommended that the proposed two-stage ecological treatment system for brewery wastewater be constructed to help improve downstream water quality once effluent is disposed of. This will decrease the solids and organic nutrients entering the water following wastewater disposal and therefore prevent eutrophic conditions from occurring. Additionally, this system will decrease the cost of treating brewery wastewater to local microbreweries. A scale model should be implemented as soon as possible to monitor the treatment efficiency and effectiveness of the system. Following this, a full-scale model may be designed to fit the specific needs of a brewery looking to implement the system to handle the entire volume of their wastewater

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## Memorandum

To: Dr. Cranford  
From: Student B  
Date: 11/15/2018  
Subject: Project 4 Reflective Statement

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Within Project 4, the problem I am trying to address is the rising costs to small breweries to treat their wastewater, with the desired outcome being a scalable biologically-based treatment system that can be used by breweries instead of paying higher costs to have municipal wastewater treatment plants process their wastewater. The intended audience is local breweries, and the message I'm trying to get across is that there is a cheaper way to treat brewery wastewater, that also reduces negative impacts that wastewater would have on the environment.

This is an important problem to address because of the implications that untreated wastewater has on the environment, such as eutrophic conditions and fish kills, which was mentioned in the proposal. It's also important to preserving the expansion of micro and craft breweries in the state, by offering a cheaper way to treat their wastewater. This is an original idea- other research has looked at the treatment efficiency of aerobic filters or bioreactors separately, but never in a combined, scalable system that can be used by local breweries.

I assumed that there would be much heavier regulations in place currently for the wastewater coming from breweries, but as I conducted research, I found that pH, TSS, and BOD are the only real parameters that are being monitored now. However, as the craft beer industry expands, it is likely that these regulations will expand and become stricter.

An alternative solution that I considered was designing a small constructed wetland that could be placed on the property of a brewery and fed a mixture of the brewery effluent to be treated. I decided against this solution because of the space that would be required to build a constructed wetland on the property, as well as needing to be outside rather than a contained indoor system that I documented in the proposal.

To persuade my audience to approve my proposal, I included information about the growing beer scene in the state, the negative impacts of untreated wastewater, as well as highlighting the cost-savings that my proposed solution projects. In deciding what information needed to be represented visually, I tried to put myself in the position of someone who has no background knowledge of the information being presented in the proposal. I realized that schematics of my proposed system would be helpful, as well as pictures of what brewery wastewater looks like, what excessive nutrients do to an ecosystem (fish kills), and what K1 MBBR looks like.

In completing this assignment, I took the risk of picking a very specific topic to my major that had the potential to be confusing to those trying to give me feedback in the peer review. I tried to address this by using technical terms only when necessary and defining terms that could be confusing when possible.