Treatment of Winery Wastewater with an Aerobic Sequencing Batch Reactor

[redacted]

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Abstract

Treatment of winery wastewater presents a unique challenge. Biological Oxygen Demand (BOD) and Total Suspended Solids (TSS), both contaminants of concern, may exceed raw human sewage by a factor of ten or more. Flows are also highly variable, fluctuating seasonally, weekly, or even daily (Laginestra, n.d.; Schneider, 2011). Scion Design developed

a system to improve on-site winery wastewater treatment by optimizing the pre-aeration and clarification steps of the traditional treatment process. The working prototype aimed to reduce BOD and TSS to less than 1,000 and 100 mg/L, respectively, and be resilient enough to accommodate for varying seasonal flows.

This report outlines the construction and application of an aerobic sequencing batch reactor (SBR) coupled with a self-aspirating turbine aerator. SBRs treat wastewater in batches, utilizing treatment stages separated temporally rather than spatially. Thus, five treatment stages are carried out within a single tank: fill, react, settle, decant, and idle. During the fill stage, the system has continuous inflow to fill the tank. In the react stage, the wastewater is aerated so that aerobic microbes can degrade the BOD. During the settle phase, aeration and mixing are halted to allow for sludge separation. Throughout the decant stage, the treated water is gradually skimmed from the surface, minimizing disturbance, and thus discharge, of the settled sludge at the bottom of the tank. Finally, an idle stage is built into the sequence to allow for maintenance such as collection of excess sludge. The treatment of wastewater in batches and the use of a completely quiescent settling stage minimizes the retention time needed for treatment in an SBR.

Our design is a two-tank system utilizing aerobic SBR principles that meet the needs of the problem statement, which is to be outlined in this report. The two-tank design will have a total capacity of 43,200 L (11,400 gallons) to allow for continuous treatment of variable flows over the span of a three-day cycle. To clarify, each tank will have a volume of 21,600 L (5,700 gallons). Both tanks will be aerated via a micro-bubble, self-aspirating turbine, designed for mixing and maximizing oxygen transfer efficiency. These turbines will be driven by a low horsepower motor which will turn off when aeration is not needed, thus minimizing system power consumption.

This report outlines general SBR technology before discussing the specifics of the custom design. The prototype discussion section considers aeration, structure, decanter, electrical motors, Arduino, and economics. The testing methods and rendered results are presented. Additionally, system limitations and recommendations for future design are discussed.

Background

Wastewater treatment is the partial reduction or removal of impurities present in the water. Wastewater did not receive treatment past the primary stage until the early 1970s (USEPA, 2017). Primary treatment removes the contaminants that can be settled out, or screened easily. Secondary treatment, the focus of our bioreactor, removes BOD and in some cases, includes disinfection. This stage primarily aims to reduce organic materials like sugars and fats. During the tertiary treatment, dubbed the 'polishing stage,' temperature is reduced and final filtration occurs. When designing a system, it is pertinent to consider the strength and characteristics of the wastewater to ensure treatment efficiency is maximized. The pollution load from wastewater varies depending on its previous application or use. This report focuses on winery wastewater treatment.

Wine production is categorized into two major seasons: vintage and non-vintage. The vintage season is associated with grape harvesting and pressing (Tofflemire, 1972). The non-vintage season entails the fermentation process (Tofflemire, 1972). More than half of the yearly wastewater load is generated in the vintage season, though this season only lasts three months (Tofflemire, 1972). Ideally, treatment system effluent is reused on site for irrigation. This minimizes transportation and treatment costs (Chapman et al., 2001).

Like many other companies, the unique challenge of treating winery wastewater is being addressed by Orenco Systems Incorporated. Orenco treats winery wastewater with an onsite treatment system, AdvanTex® (**Figure 1**), which has multiple unit processes to address high pollutant loads and accommodate surge flows. In addition, the system design considers such issues as flow equalization, solids removal, and pH neutralization (Bounds 2010). The system also aims to minimize operations and maintenance, as well as cost.

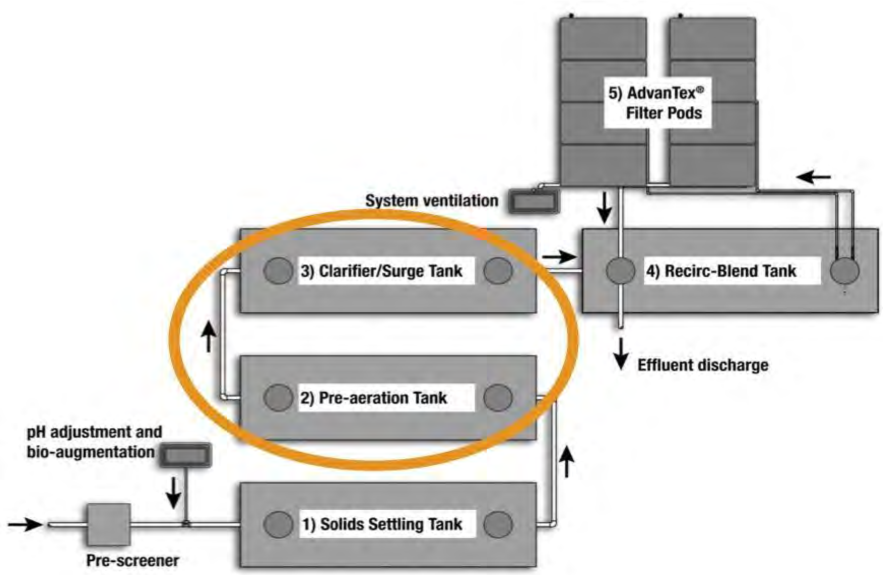

Figure 1 *The treatment train associated with the Orenco AdvanTex® System demonstrates the five unit operations. The highlighted area represents the two stages that will be addressed by Scion Design (Orenco, 2016)*

Problem Statement

Scion Design has been contracted to explore possible adaptions to the aeration and clarification steps of the AdvanTex® system. Aeration is the most energy intensive unit process, significantly increasing operational costs. Efficiency in this process is thus desirable. Furthermore, winery wastewater treatment is a peripheral focus of wineries, and treatment plant operators are mostly non-existent at small wineries. Therefore, winery wastewater treatment systems should be relatively self-regulating and low-maintenance. Our problem statement, based upon additional criteria, is as follows:

"Scion Design partnered with Orenco Systems Incorporated to improve on-site winery wastewater treatment. Our design aimed to reduce influent BOD and TSS to less than 1000 and 100 mg/L, respectively. Also, the system needed to be resilient enough to accommodate for varying seasonal flows within the standard range. Construction of a working prototype was capped at $500. The design minimized capital and maintenance costs while emphasizing efficiency."

Technology

Technology Overview

Currently, Orenco uses venturi aspirators and fine bubble diffusers to aerate the AdvanTex system. A comparative analysis was conducted on alternative standalone treatment systems and aeration systems. The treatment systems evaluated included trickling filters, lagoons, aerobic and anaerobic sequencing batch reactors. The aeration units compared were microbubble turbine aerators and fine bubble diffusers. To determine the top choice technology to construct for our prototype, we ranked all the alternative technologies based on a variety of parameters (**See Appendix D**). Based on our decision matrix, we decided on constructing an aerobic sequencing batch reactor coupled with a microbubble turbine aerator.

Aerobic SBR

An SBR uses biological floc as the fundamental driver of treatment. Biological floc is composed of microbes such as bacteria, fungi, and protozoa (Sanitaire, 2012). These organisms feed on suspended organic material such as BOD. As they grow, they conglomerate into a mass of flocculated particles which can settle under gravity. For municipal wastewater (BOD level 400 to 500 mg/L), an average system can produce effluent of less than 10 mg/L BOD (USEPA, 1999).

There are numerous advantages to an SBR system. For one, performance of an SBR is not hindered by weather fluctuations. A study in 1996 led by Torrijos and Moletta found that the temperature inside the SBR rose rapidly despite external fluctuations (1996). The use of SBRs have been found capable of reducing TSS without the use of additional clarifier units (Pace and Harlow, 2000). Another benefit associated with this technology is the ability to retrofit older wastewater treatment facilities to accommodate an SBR due to preexisting basins.

The basic SBR design can be adapted to either an aerobic or an anaerobic environment (**Table 1**). One of the main disadvantages associated with an aerobic system is the cost of an aeration unit. Microbes in aerobic wastewater treatment systems require sufficient oxygen to degrade the organic material. Advantages of aerobic SBRs include a faster start-up time, reduced cost, and increased effluent quality when compared to an anaerobic SBR.

Table 1 *A comparison between aerobic and anaerobic SBRs outlines the costs/benefits associated with them (Chang et al., 2009)*

Feature	Aerobic	Anaerobic
Organic Removal Efficiency	High	High
Effluent Quality	Excellent	Moderate to poor
Organic Loading Rate	Moderate	High
Sludge Productions	High	Low
Nutrient Reduction	High	Low
Alkalinity Requirement	Low	High for certain industrial waste
Energy Requirement	High	Low to Moderate
Temperature Sensitivity	Low	High
Startup Time	2-4 weeks	2-4 months
Odor	Less opportunity for odors	Potential odor problems
Bioenergy and nutrient recovery	No	Yes
Mode of Treatment	Total	Essentially pretreatment

There are four essential stages in an aerobic SBR: fill, react, settle, and decant; the fifth stage of idle is not mandatory for the operation of many SBR systems (**Figure 2**). Each stage is thoroughly analyzed in Design Overview.

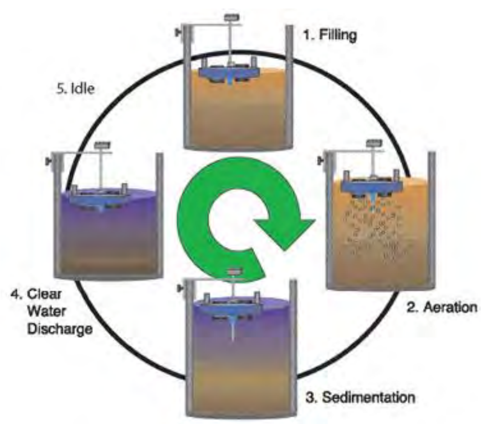

Figure 2 *There are five stages in an SBR (Lipp, 2016).*

Design Overview

Scion Design's system is an SBR with two tanks of identical size (**Figure 3**). Each tank is outfitted with a motor, aerator, and decanter. While one tank is filling, the other tank is either reacting, settling, or decanting (**Figure 4**). Once the second tank has been decanted, it will begin to fill while the first tank starts to react. It allows for dependable processing levels while managing incoming flow.

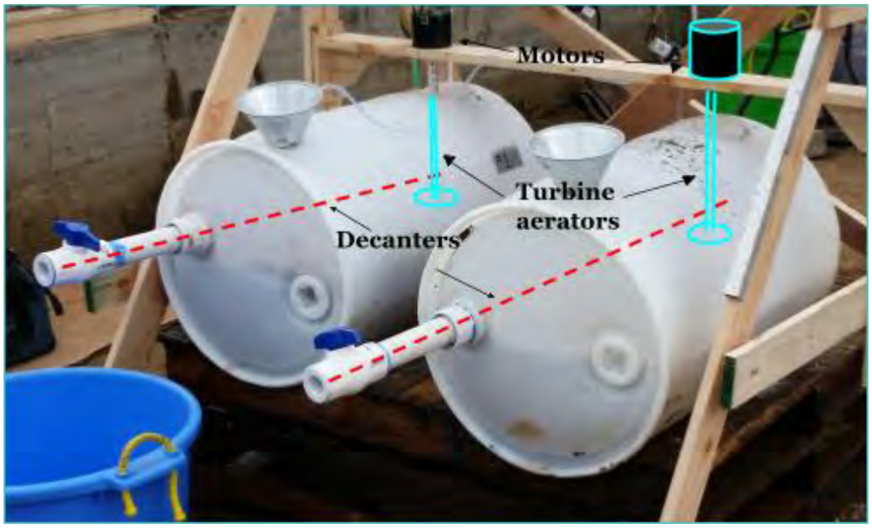

Figure 3 *The prototyped system consists of two tanks, each furnished with a motor, aerator, and decanter.*

Tank 1	Fill			React	Settle	Decant
Tank 2	React	Settle	Decant	Fill		

Figure 4 *The two-tank system is set-up such that one tank is always being filled, allowing for continuous flow into the system*

Phase 1: Fill

Inflow into the system is continuous. Wastewater enters the first tank, where the microbubble turbine is aerating to prevent the development of anaerobic conditions. The aerator follows a pattern of aerating for 15 minute increments and resting for 15 minutes. This allows for motor cooling. Once the tank is filled, it will begin the react phase while the second tank begins to be filled.

Phase 2: React

Once the tank is full, the react phase begins. The turbine aerator continues to aerate in the same 15-minute start-stop pattern. This process takes 1.5 days to reduce the BOD of incoming wastewater (**See Appendix A, I**).

Phase 3: Settle

The settling phase allows particles to fall to the bottom of the tank. Particles must be, on average, larger than 0.5 mm in diameter to settle properly in this time frame (Howe et al., 2012). The optimum settling time for any system is based on the particle size distribution. Lighter particles will increase the required settling time. For the prototyped system, total settling time is 0.76 hours (**See Appendix A, II**). To be conservative, one hour was chosen for the prototype, a number corroborated in literature (AquaSBR, 2007).

Phase 4: Decant

The decanter phase withdraws treated influent while excluding the settled particles and sludge. Our decanter is a simple pipe with holes drilled along the bottom and sides.

Microbubble Turbine

A microbubble turbine provides increased aeration compared to many conventional approaches. It provides smaller bubbles, which maximizes the surface area to volume ratio. This delivers more oxygen for the microbes to consume. A motor connects to a shaft with holes open to the atmosphere that in turn connects to a microbubble turbine. The turbine rotates in the water, creating a vacuum that pulls air into the system and disperses it into the wastewater (**Figure 5**).

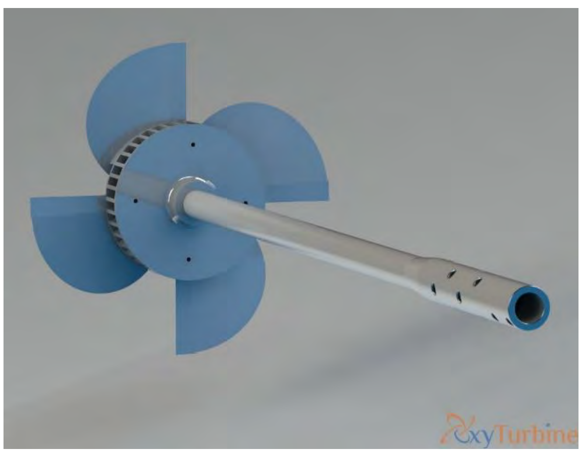

Figure 5 *A micro-bubble turbine creates a vacuum that pulls air through the holes at the top of the turbine (the right side of the picture, near where the system would attach to the motor) and pushes the air out of the slits at the bottom. Propellers increase the effectiveness by pushing the water away (Oxyturbine, n.d.).*

Prototyping

System Sizing

Scaling

The full-scale system must accommodate the average small-scale winery flow of 1500 GPD (5680 LPD; Orenco, 2016). If needed, the system can be scaled up to accept greater flow rates by adding more units. The prototype sizing was based upon linearly scaling down the flow associated with the full-scale system (**See Appendix A, III**).

Retention Time/BOD Considerations

Further sizing calculations were performed based upon rates of BOD degradation via microbes. Due to the difficulty in gathering BOD values in a timely manner, calculations used a ratio to compare BOD to COD (Carbonaceous Oxygen Demand). The ratio is based upon a study that considered winery wastewater with a BOD range from 100 to 1000 mg/L (Quayle et al 2009). Calculations assumed that the ratio remained constant throughout the system.

The use of the ratio outlined in Equation 1, results in a value of 8065 mg/L COD (BOD=5000mg/L) reduced to 1169 mg/L COD (BOD=1000mg/L).

$$COD = \frac{BOD_5 - 322}{0.58} \text{ (Equation 1, Quayle et al 2009)}$$

If BOD degradation is the rate-limiting factor, the system retention time can be calculated (Silva et al., 2011). Silva and others (2011) performed assays to determine the biodegradation kinetics of microbial degradation from port wine production (**Figure 6**). This study predicted the rate of microbial degradation at different biomass and contaminant concentrations. The Monod model was used to validate results (**Figure 6**).

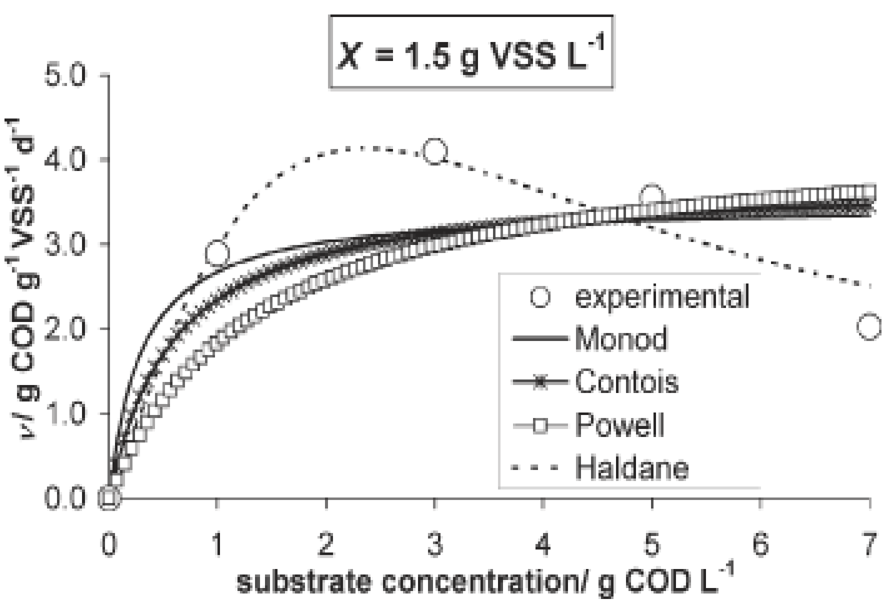

Figure 6 *Kinetic models fitted to experimental data (Silva et al. 2011).*

It was assumed that the microorganism concentration would be low in our prototype. This is a valid assumption because time constraints would possibly eliminate the necessary acclimation periods required for stabilization of the microbial population. It is conservative to assume a small microbial population as this results in longer retention times compared to systems with higher microbial populations. A low microbial concentration of 1.5 g Volatile Suspended Solids (VSS)/L was assumed. Calculations using the Monod model demonstrated that the total time to breakdown BOD is 1.4 days (**See Appendix A, I**).

System sizing was initially based upon the assumption that BOD degradation was the rate-limiting step. However, oxygen transfer and/or oxygen uptake is more commonly the rate-limiting factor. In assessing the time for BOD degradation assuming oxygen limits the reaction rate, the specific oxygen uptake rate (OUR) and the oxygen transfer rate (OTR) are needed. Initial calculations, assuming conservative values, suggested that the aerator could provide sufficient oxygen to the system in as little as 15 hours (**See Appendix A, V**). This was a key consideration during the testing stage and was later re-calculated to assess the validity of assuming BOD degradation was the rate-limiting step (**See Appendix A, VII**).

Construction

Two microbubble turbine aerators were designed in Solidworks and 3D printed with acrylonitrile butadiene styrene (ABS) plastic. These were attached to ½ inch (outer diameter) pipes (schedule 40, 600 psi) used as shafts. These were mounted to two Fasco motors (1500 RPM, 115 V, 1.8 A).

Two 30-gallon barrels had 8" holes cut into the top to provide entry points for the aerating turbines. A wooden frame to support the motors and aerators was constructed and fit around the two tanks. The entire apparatus was assembled on top of a raised platform, made of wooden pallets, to allow for gravity fed decanting. The decanted effluent was collected by a 60-liter bucket. The entire system was on a three-day cycle where each tank filled for 36 hours followed by 34 hours of time to react. Following the react stage, the aerators were turned off to allow for a two hour stretch of time for system settling and decanting. An Arduino was coded to turn the motor on and off at 15 minute increments during filling and reacting stages. After these two stages, the motor turned off for two hours to allow for settling and decanting.

Structure

A foundation for the tanks, two 30-gallon barrels, was assembled by stacking three wooden pallets. After the foundation was in place, a mounting structure was built around the tanks. The structure provided a central location for all electrical components, as well as a place to mount the motors (**Figure 7**). The vertical track ensured that the motor mount was placed at the optimal level (**Figure 8**).

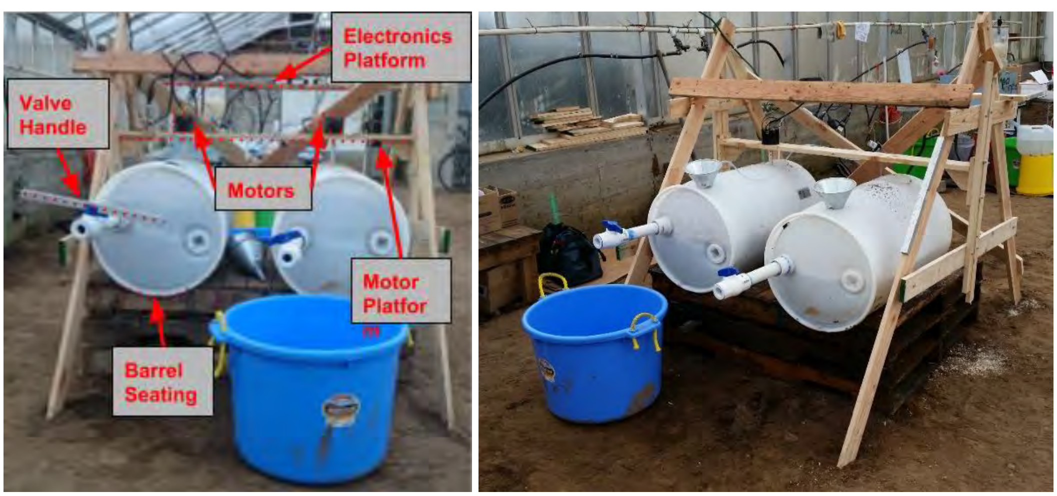

Figure 7 A *wooden structure was built around the tanks to hold electrical motors, Arduino units, relays, and other electronic accessories.*

Figure 8 A *variable height track for the motors allowed for adjustments.*

Decanter

A basic decanting system was designed that considered cost, maintenance, and feasibility. The small size of the prototype and the budget limited the decanter options. It was more cost effective to fabricate a custom system than to purchase a manufactured decanter.

Two sections of a 3.8 cm (1 ½") diameter PVC pipe were cut to .91 m (36") lengths. A threaded adapter was then glued at one end of each pipe so that it could be threaded directly into the barrel inlet. The decanter was built by drilling 1.3 cm (½") holes spaced 5.1 cm (2") apart. The drilled pipe was then capped and inserted into each tank by threading it into the barrel inlets. This was sealed into place using PVC nylon tape. The drilled holes were situated on the underside to prevent clogging. 90-degree ball valves for manual flow control were then attached to the decanter using PVC cement. (**See Appendix A, VI**)

Aerator

The turbine used for Scion Design's prototype was 3-D printed with ABS plastic. This method allowed for rapid revisions to the design of the aerator. The turbine was printed in two separate pieces that were later bolted together. There were several variations of the turbine design. Four parameters were adjusted to increase turbine efficiency based upon visual assessments of the quantity of bubbles produced by the aerator.

(1) Angle and orientation of the vanes

(2) Method of attachment between the turbine and the motor

(3) Height and diameter of the turbine

(4) Number and size of the openings in the turbine

When the vanes were set at an angle of 5 degrees, expected aeration was not achieved. The vane angle was increased to improve efficiency. In addition, the vanes were curved to further decrease the rotational resistance on the motor (**Figure 9**).

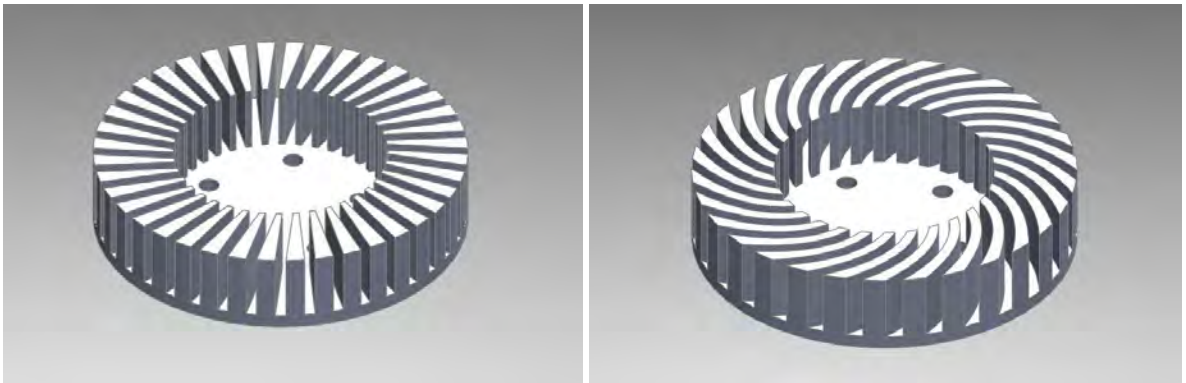

Figure 9 *Angled and curved vanes within the turbine body were tested for aerator optimization.*

A 1.3 cm (½") diameter, schedule 40 PVC pipe was inserted through a hole in the center of the top piece of the turbine. Both female and male threaded fittings were used to hold the turbine in place (**Figure 10**).

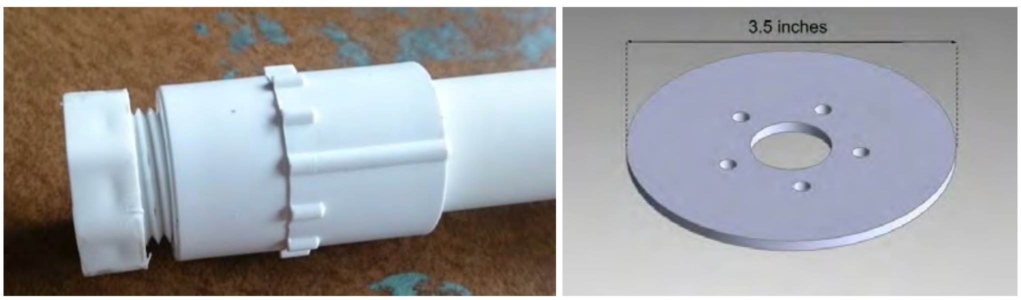

Figure 10 *The disk (right) is screwed in place in the gap between the male and female fittings (left) to provide a more secure fitting.*

A connector piece (**Figure 11,** left) transferred torque from the shaft of the motor to the hollow shaft on the turbine (**Figure 11,** right). Like the turbine, this component was 3-D printed. Metal set screws were used to secure the aerator shaft to the rotor of the motor.

Figure 11 *The components used to transfer torque from the rotor to the hollow PVC shaft.*

To maximize aerator efficiency, a propeller fixed to the bottom achieves three functions:

(1) facilitates vertical mixing and suspension of the activated sludge in the solution

(2) forces bubbles downward to increase their residence time; and

(3) forces water to rush past the edge of the turbine, creating a pressure gradient which aids gas induction (Saravanan and Joshi, 1995).

At one point during the design process, fins made from aluminum cans were affixed to the bottom of the turbine to create gas induction. This was later replaced with a 3-D printed propeller (**Figure 12**).

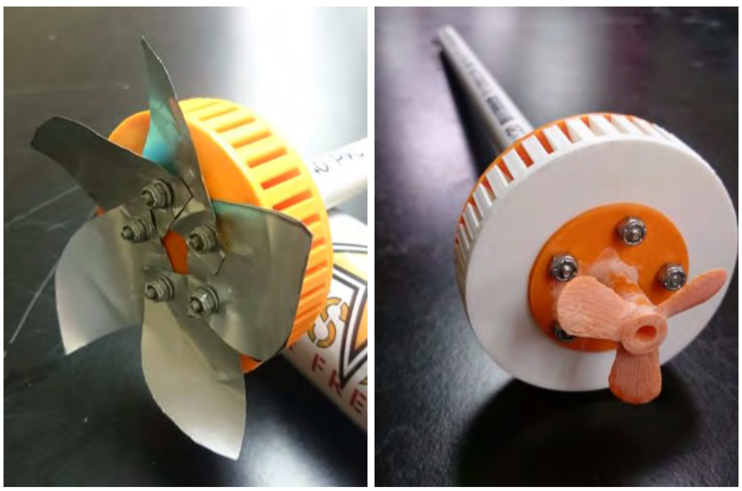

Figure 12 *A propeller increased the turbine efficiency. Early tests (left) utilized aluminum cans while the final design (right) utilized 3D printing.*

It is optimal for the aerator to be positioned near the bottom of the tank so that bubbles have a greater contact time with the effluent. As such, the turbines were positioned to be slightly below the decanter to ensure they are always submerged. The additional depth of submergence results in increased water pressure above the aerator, creating a greater force for the motor to overcome. This can be counteracted by increasing the diameter of the turbine, which causes the outer edge to move faster, assuming a constant rotational speed. The final turbine design had a diameter of 8.9 cm (3.5 inches), which is smaller than those typically used in bench scale experiments (Heim et al., 1995). Despite this, the system was aerated effectively and testing has validated that the turbines do provide sufficient oxygen transfer levels (**See Appendix A, VII**).

Motor

The motor needed to provide 24.6 Watts (0.033 horsepower), assuming a low maximum oxygen efficiency (**See Appendix A, IV**). The initial motor was sized at 24.6 Watts (1/30 HP) and 3000 RPM (rounds per minute). When the motor was attached to the aerator, it did not provide sufficient power to turn the turbine. As such, the motor was increased in strength to 37.3 Watts (1/20 HP) and 1500 RPM motor. In reducing the RPM, an increased amount of power is provided to rotate the shaft. The motor was mounted on a board above the tanks (**Figure 13**).

Figure 13 *The motor was attached vertically to a board to ensure sufficient stabilization.*

Arduino

The Arduino unit directs the motor to run for 70 hours. During this time, the motor shuts off every fifteen minutes for fifteen minutes to prevent overheating. It then shuts off for two hours for settling and decanting at the end of the 70-hour cycle. To ensure the system is working, an LED on the Arduino board turns on whenever the motor is off. This allows for a visual validation that the system is working (**See Appendix B**).

Testing

Methods

Test Performance

To seed the system, five gallons of sludge from Corvallis Wastewater Treatment Plant was colonized in our tanks for three days. It was treated with a sugar dose of two cups of powdered sugar per tank. This was aerated intermittently. After a trial testing period of four days, testing began on 02/20/17 and continued until 3/10/17. Testing was done twice a day, twelve hours apart (7am and 7pm). Each shift had assigned tasks along with testing (**Figure 14**). Due to shortage of testing materials, some days did not have test results.

Day	Date	Time	Responsible	Tasks	Waste Water Composition
1	2/16/2017	Morning	Rachel	1) Start Motor in Tank 1 2) Plug in pump to begin nutrient feeding 3) Take Influent and Effluent Measurements	Ethanol - 7.5 mL Sucrose - 2.4 g Citric Acid - None
		Evening	Liz	1) Create 30 mL of solution using the recipe to the left. 2) Take Effluent Measurements	
2	2/17/2017	Morning	Jordan	1) Take Influent and Effluent Measurements	Ethanol - 7.5 mL Sucrose - 2.4 g Citric Acid - None
		Evening	Jessy	1) Switch influent to tank #2 2) Take effluent measurements	
3	2/18/2017	Morning	Jordan	1) Create 60 L of Solution by doubling the quantities of nutrients, i.e 30 mL Ethanol, 9.6 g Sucrose, and 0.06 g Citric Acid in 60 L of water 2) Take Influent and Effluent Measurements	Ethanol - 15 mL Sucrose - 4.8 g Citric Acid - 0.03 g
		Evening	Jessy	1) Take effluent measurements	
4	2/19/2017	Morning	Rachel	1) Decant tank #1 2) Switch influent to tank #1 3) Take Influent and Effluent Measurements	Ethanol - 15 mL Sucrose - 4.8 g Citric Acid - 0.03 g
		Evening	Jessy	1) Take effluent measurements	

Figure 14 *The schedule outlines the time, person responsible, necessary tasks, and the current wastewater composition. Note that while Micco's name does not appear on our snippet of schedule, he was responsible for many other shifts, including weekend slots.*

Every twelve hours, Dissolved Oxygen (DO), Chemical Oxygen Demand (COD), pH, and temperature were tested in each tank. Influent COD was tested every twenty-four hours while temperature, pH and DO were tested every twelve. Whenever decanting occurred, the decanted fluid's COD was tested rather than the fluid contained in the tank. Each COD test contained two replicates.

Every thirty-six hours a new mixture of influent was made. The initial influent concentration contained around 71% ethanol, 28% sucrose and about 1% citric acid. The final influent recipe contained about 99% glucose, and 1% citric acid. The influent concentration was originally 500 mg/L of COD, and was increased over the course of a week to 5000 mg/L.

The COD samples were three parts dichromate and two parts sulfuric acid. The tubes were placed on a hot plate at 66°C for two hours. Following heating, the samples were placed in a Spectramax Plus to analyze absorbance at 620 nm. This had been calibrated from a concentration of glucose and tartrate ranging from 39-5000 mg/L.

To assess the oxygen uptake rate (OUR), the aerator was turned off and the decreasing DO was recorded every 2 seconds until it reached a negligible rate of change.

Similarly, measurements of the oxygen transfer rate (OTR) were gathered by shutting off the aerator, and then similarly recording the DO every 2 seconds until the DO readings stabilized.

Data Analysis

The percent reduction in each tank was determined by comparing the COD concentration of the influent during the filling stage to the COD concentration of the effluent during the decant stage. Since the tank filled over a period of 1.5 days, the influent concentration was averaged between the respective days during which the filling stage occurred.

The OUR and OTR data was plotted with the time on the x-axis, and DO on the y-axis. A linear tread-line was fitted to the data, and the slope was assumed to be the degradation rate constant. To assess the OTR, the aerator was turned on, and the DO recorded every 2 seconds until it reached a negligible rate of change. The data was plotted similarly to the OUR graph. The portion of the graph that portrayed a linear trend was used to determine the transfer rate constant.

Samples were analyzed by considering COD degradation over time. This considered the influent concentration compared to the effluent concentration in both tanks. More specifically, the change in COD from the influent during the fill stage was compared to the COD in the effluent at the decant stage, for each individual tank. System variables, including pH, temperature, and DO, were also considered to assess how constant the parameters were

Results

COD Degradation

The COD percent reduction was plotted over time in the two tanks (**Figure 15, Figure 16**). The percent reduction was only analyzed at the end of the wastewater's three-day cycle to allow for the proper retention time. This would give us the best estimate at how effective our system is.

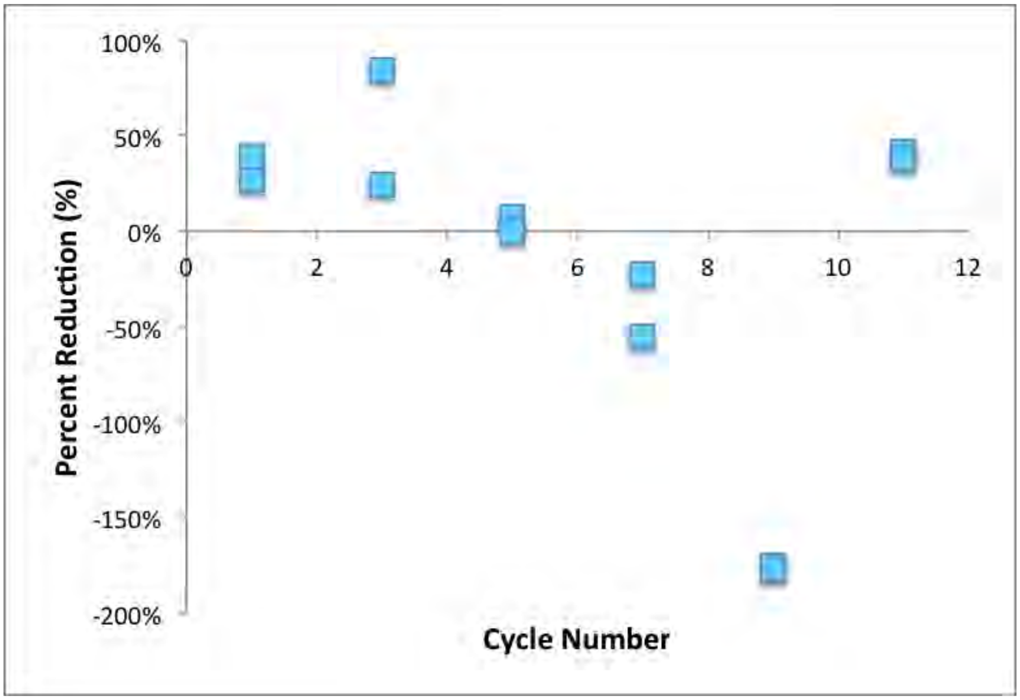

Figure 15 *The COD Percent Reduction in Tank #1; cycle 9 is probable outlier.*

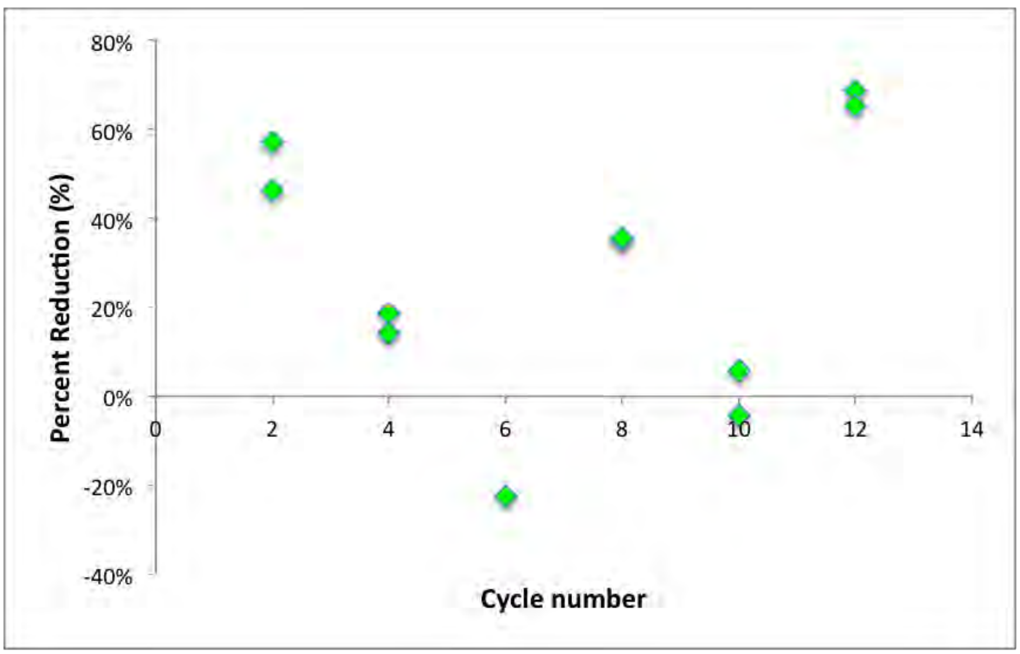

Figure 16 *The COD Percent Reduction in Tank #2.*

The most reliable data points (cycle 11, 12) show an average of 40% and 67% COD reduction in Tank 1 and 2, respectively.

pH, Temperature, and DO

Environmental factors within the tank were recorded and analyzed to assess system efficiency. pH, temperature, and DO were considered independently. The change in COD was found by subtracting the influent COD value from the processed effluent's COD. The pH readings were taken from the processing tank and compared to change in COD to determine if pH and the system's COD reduction were correlated (**Figure 17**). Temperature was collected and graphed using the same parameters (**Figure 18**). DO readings were also taken from the effluent tank prior to decanting and assessed in the same manner (**Figure 19**).

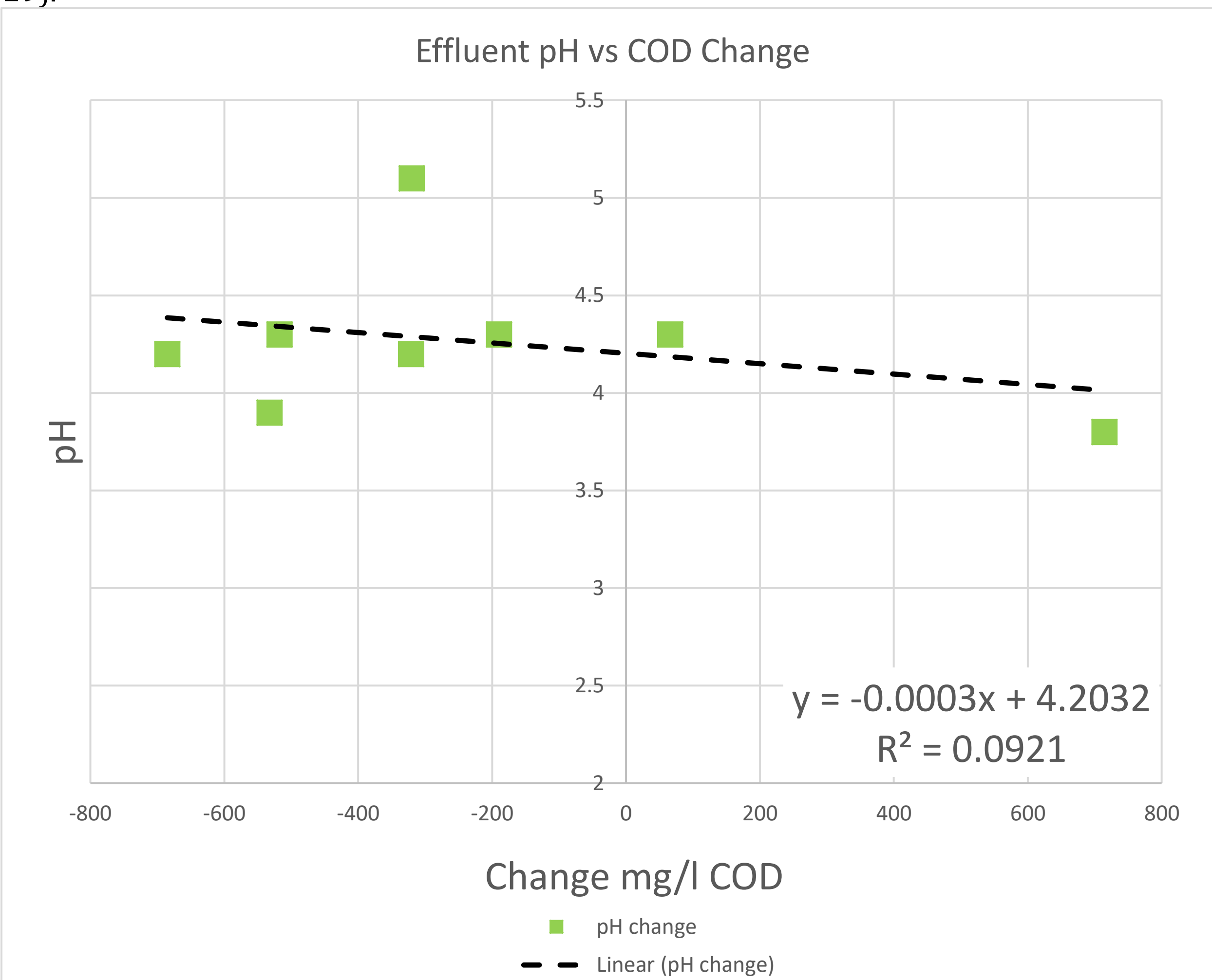

Figure 17 *The system pH remained relatively stable regardless of the change in COD.*

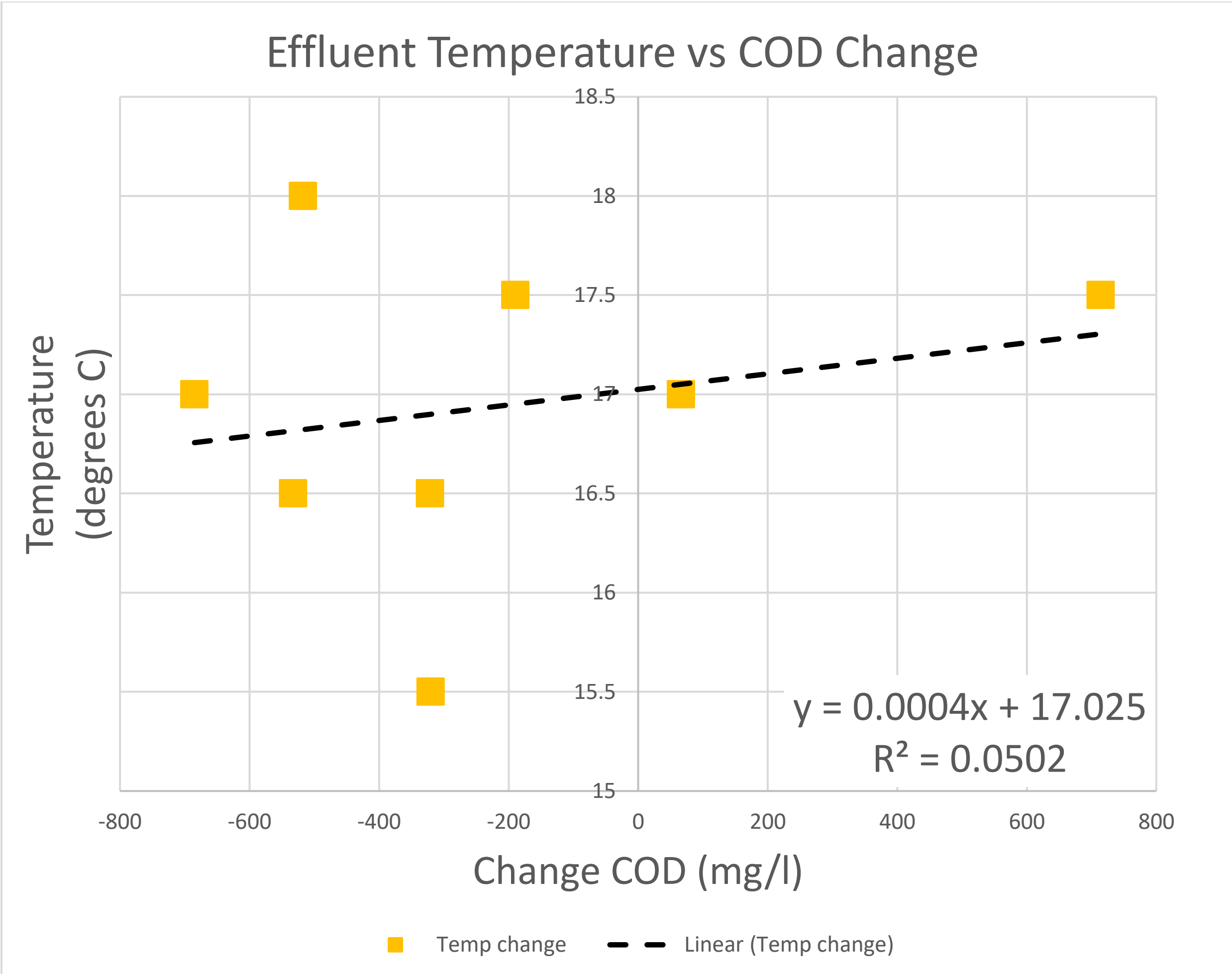

Figure 18 *The system temperature remained consistent regardless of the observed change in COD.*

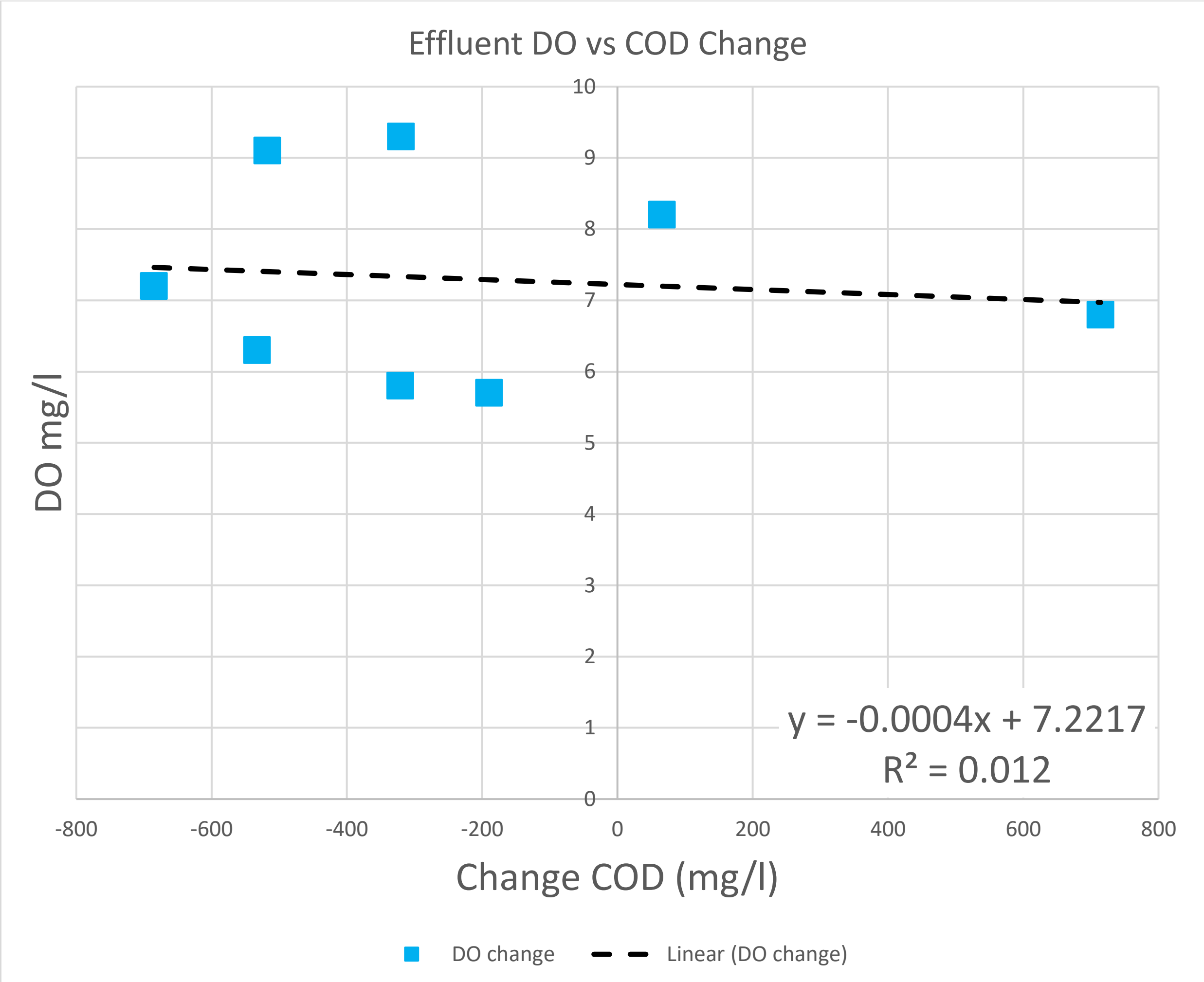

Figure 19 *The system DO remains relatively consistent regardless of the observed changes in the COD.*

Oxygen Transfer and Uptake Rates

To assess aerator efficiency previous to OTR and OUR testing, a visual test was conducted to ensure bubbles were providing aeration (**Figure 20**). The oxygen transfer rate (OTR) was determined to be 250 mg O_2/(L*hr) (**Figure 21, Figure 22, See Appendix A, VII**). The OUR was determined to be 20 mg O_2/(L*hr) (**Figure 23, See Appendix A, VII**). Since OTR is greater than OUR, it suggests that sufficient oxygen is entering the system. The oxygen transfer efficiency of the turbine, given the energy output of the motor, is 0.4 kg/(O_2*hr). (**See Appendix A, VII**). This is comparable to other turbines, per Kumar and Mal (2010).

Figure 20 *The micro-bubble turbine aerator produces many bubbles in the system, indicating a visual validation of providing sufficient oxygen to the system*

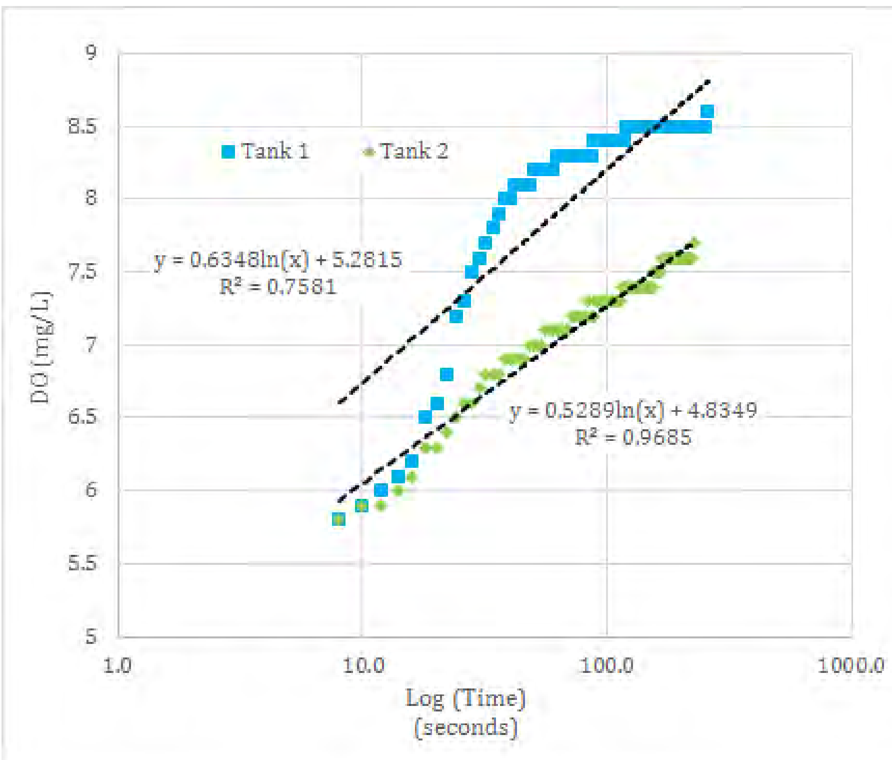

Figure 21 *Empirical data was determined and used to assess the oxygen transfer rate*

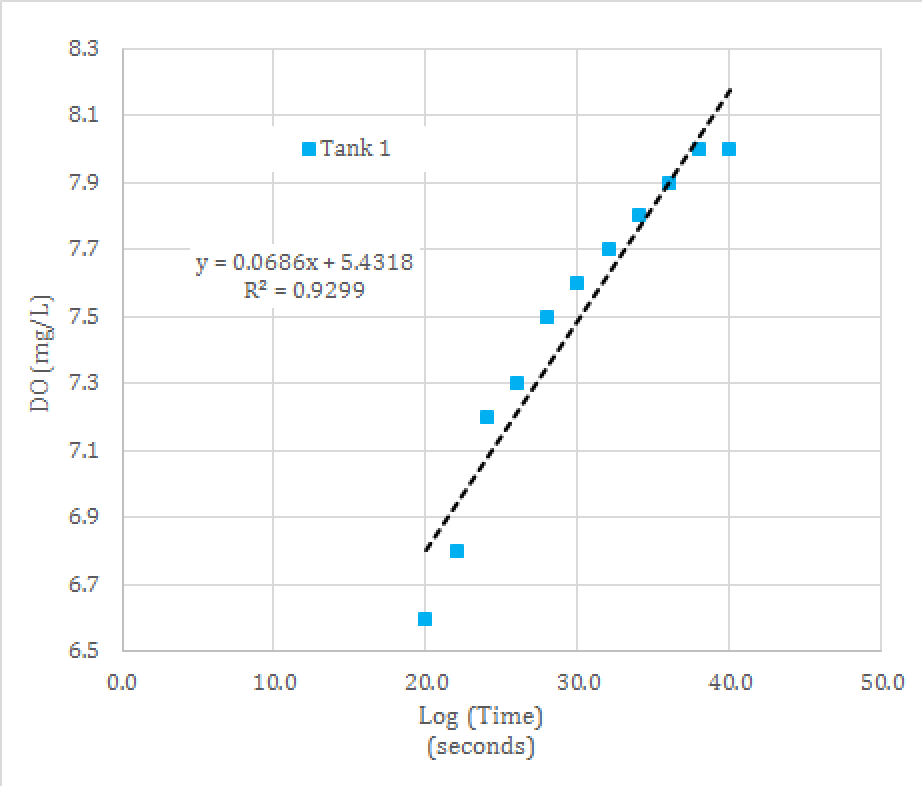

Figure 22 *This graph provides a closer view of the oxygen transfer rates for the linear section of Tank 1.*

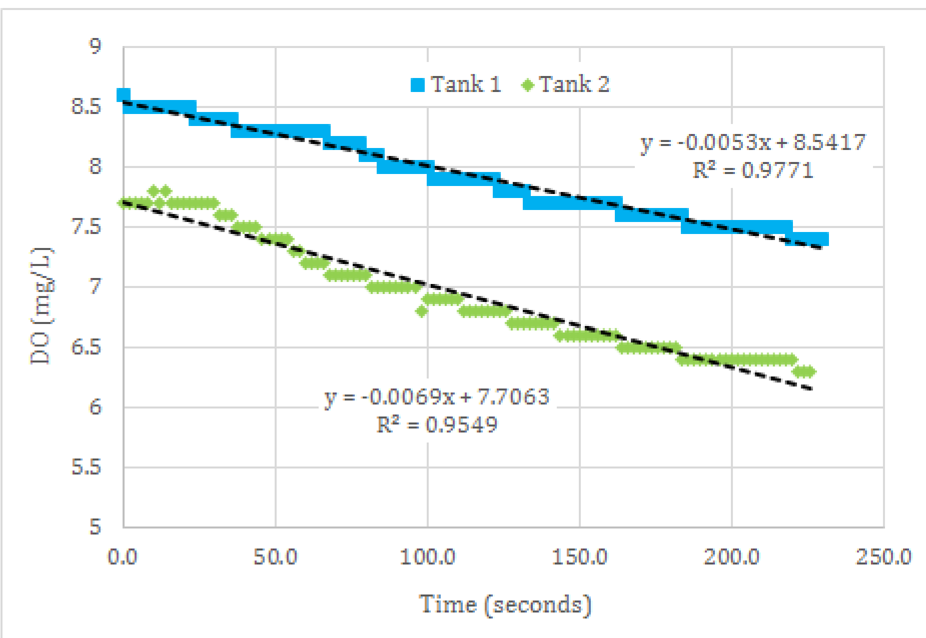

Figure 23 *The empirical data was used to determine the oxygen uptake rate.*

Discussions

Data Analysis

While neither graph (**Figure 15, 16**) shows any trend in the COD reduction data, there are some points to consider. It is important to note that our results for Tank 1 during Cycle 9 are likely inaccurate due to testing errors (**Figure 15**)**.** Also, it is recognized that the last two complete cycles of results are more accurate because the old influent recipe contained ethanol, which was evaporating out of our testing vials. This was providing for inaccurate data.

Parameter results from testing were inconsistent. DO and pH stayed steady even as the tank's COD processing success varied widely. Comparing temperature to change in COD yielded a less consistent trend than the parameters of DO and pH. This inconsistency could have resulted from extreme external temperature fluctuations outside of the tank. Testing occurred in a greenhouse where temperature was intended to be maintained at 77°F. However, external temperatures transitioned from 30°F to 60°F during testing, causing the greenhouse to be incapable of maintaining a steady temperature always. This change may have affected the temperature within the tank on certain days.

Economic Considerations

Prototype

The prototype materials cost $434.07 (**See Appendix C**). This does not include labor, power, or testing supplies. Additionally, during the construction phase, there was free access to machinery and tools, eliminating additional costs associated with borrowing, renting, or buying tools. Scion Design was given free materials, including wood for the motor support, pallets for the elevated base, power to run the Arduinos and motors, and supplies for testing system efficiency. These would have added additional costs.

The annual costs associated with the prototyped system are based upon operations and maintenance costs. The cost to run the motor (0.74kW, $0.20/kWh, 325d/yr) would amount to $1560.

Full-scale System

The capital investment required to construct an SBR varies drastically depending upon location and scale of the system. Most current applications apply to systems in the range of 3-5 million liters per day (USEPA, 1999). Extrapolating from the cost of building a system of this size, we can arrive at the cost for a scaled-down version. Using this method, the construction of a smaller unit, 3-5 thousand liters per day, typically costs around $100,000 (USEPA, 1999).

Annual system costs vary depending on flow, tank type, aeration device, effluent requirements and the site constraints. Operation and maintenance costs may range from $800 to $2,000 per million gallons treated (USEPA, 1999). This cost range may be reduced if the system does not require clarifiers and return activated sludge pumps.

Another estimate including maintenance, power, chemicals and sludge removal, totals to $94,767 annually for an SBR with two 15,700 gallon tanks (Applied, 2013). It assumes that:

- Minimum projected wastewater flows shall be greater than or equal to 30,000 GPD.
- Labor and maintenance is based on one operator performing site visits 3 times per week, plus costs for repair or replacement.
- Power cost is calculated on a service rate of $0.2/kWh.
- Sludge hauling cost = $0.12/gal
- Estimates are conservative and reflect the worst-case scenario

This means that the annual cost for this system comes out to closer to $8,000/million gallons as opposed to the lower EPA estimate (Applied, 2013). This variation demonstrates how much impact design and efficiency can have on a system.

Nevertheless, Scion Design attempted to perform a more specific cost analysis considering the use of proprietary technology, such as fiberglass tanks and custom-built microbubble turbines. In scaling the costs associated with the prototyped system, the capital investment for a full-scale system would be $1261 for a 5625-gallon system that accommodates 1500 GPD (See Appendices C**). This is material cost and does not account for machinery, tools, or labor.Limitations**

The SBR outlined in this report is a small-scale prototype. The largest limitation we faced was the amount of time required to transition from the design phase to the implementation phase. Through trial and error, the prototype construction lead us to improve our design.

One of the limiting factors was that some of the COD data was inconsistent due to absent testing materials. This limited our COD analysis. Another limitation was that the testing equipment was often uncalibrated. With multiple users of the testing equipment, the DO probe was sometimes left out or calibrated incorrectly. This led to some incorrect values in our testing.

Another limitation was the fact that our initial influent recipe contained ethanol which was found to be evaporating out of our COD samples. This evaporation gave us inconsistent and incorrect data. For the last five days of testing, the influent recipe was changed to contain more sucrose and eliminated ethanol. Therefore, the last five days of data are a more accurate representation of our system efficiency.

After data analysis, we hypothesized that the individual quality of our sludge influenced each tanks performance. Each tank was seeded differently based on inoculant availability. One tank was seeded with 5 gallons of sludge (inoculant) from Corvallis Wastewater Treatment Plant. The other tank received about 2 gallons of fresh sludge and approximately one gallon of diluted sludge. This difference could explain some of the variation between results in the two tanks.

Conclusions & Recommendations

It was found that cost to build and maintain were within an efficient range. It was also found that the production of the turbine aerator was largely successful and replicable. The SBR and turbine aerator were found to be a low-maintenance and easily maintained system.

Scion Design recommends proceeding with further testing to assess the designs ability to meet the desired parameters. Further testing must be performed to realize whether BOD was reduced to the appropriate amount. This would enable system optimization of retention time. Additionally, testing should consider the pH. The team has reason to believe the system might have started fermenting toward the end of the testing period. As such, through the addition of a neutralizing agent, fermentation could be avoided and potentially system OUR improved. Through assessing further system testing results and determining whether desired BOD degradation rates are met, an analysis could be provided assessing the suitability of adding our system to Orenco's system.

Acknowledgements

This project would not have been possible without the contributions of numerous individuals from the class, campus, and greater Corvallis community:

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Appendix A: Calculations

I. BOD Degradation

<u>Goal:</u>

- Determine the time required for BOD to degrade

<u>Constants:</u>

- C_i = 5,000 mg/L BOD
- C_e = 1,000 mg/L BOD
- $Q = 30\frac{L}{d}$
- $v_{max} = 3.48$
- $K_s = 0.35$
- $SSE = 2.74$
- $X = 1.5\frac{gVSS}{L}$
- $V_{max} = 113L$

<u>Assumptions:</u>

- The entire volume of the tank is considered in regards to the volume of liquid that needs treating, despite part of the water remaining in the tank after decanting.
- Monod Model represents the degradation rate of the BOD (Silva et al 2011)
- $COD = \frac{BOD_5 - 322}{0.58}$
    - Study considered winery wastewater ranging from BOD=1000-1000mg/L, considered >100 samples, and determined the above relationship (Qualye et al 2009)
    - The calculations assume that this relationship remains constant throughout the entire degradation process.
    - $COD_{BOD_5=5000\frac{mg}{L}} = \frac{5000\frac{mg}{L} - 322}{0.58} = 8065\ mg/L$
    - $COD_{BOD_5=1000\frac{mg}{L}} = \frac{1000\frac{mg}{L} - 322}{0.58} = 1169\frac{mg}{L}$

<u>Calculations:</u>

- $v = v_{max}\left(\frac{S}{K_s + S}\right) = 3.48\left(\frac{\left(8065\frac{mg}{L} - 1169\frac{mg}{L}\right)}{0.3 + 8065\frac{mg}{L} - 1169\frac{mg}{L}}\right) = 3.47\frac{mgCOD}{mgVSS*d}$
- $\Theta = \frac{S}{X*v} = \frac{\left(8065\frac{mg}{L} - 1169\frac{mg}{L}\right)}{\left(1.5\frac{gVSS}{L}*1000\frac{g}{kg}\right)*3.47\frac{mgCOD}{mgVSS*d}} = 1.32d$

In following the assumptions from above and using the Monod model with variables gathered from studies run at wineries, the total time to breakdown BOD is 1.38 days (31.5 hours).

This assumes that microbial degradation is the limiting factor. However, literature suggests that the limiting factor in microbial reactors is more commonly oxygen.

In considering oxygen being the limiting factor:

- Specific oxygen uptake rate:
  - Considering a range of microbes, this ranges between $0.5 - 31\frac{mgO_2}{g\,X*h}$. As the microbes in the mixture are unknown, a value of 5 was assumed representing both an average value as determined from a list of typical microbial values and an ideal, liberal value in an MBR (Garvia-Ochoa 2010, Yoon 2016)
- Using the previously defined variable, X=1.5 gVSS/L
- Required oxygen:
  - $O_{required} = \left(5\frac{mg\ O_2}{g\ MLVSS*hr}\right)\left(1.5\frac{gVSS}{L}\right) = 7.5\frac{mgO_2}{L*hr}$ (Want 2006)
  - $118L * 7.5\frac{mgO_2}{hr} * \frac{1\ kg}{1000\ g} = 0.885\frac{kgO_2}{hr}$

The calculations for the input of oxygen into the system are difficult to calculate due to the uncertainty associated with knowing the micro-bubble turbine efficiency. Data analysis will assist in providing a more accurate representation of the oxygen the aerator is providing to the system.

  - Assume a turbine efficiency of 0.42 ($Kumar\ and\ Mal$, 2010).
  - $0.42\frac{kgO_2}{kW*hr} * 0.03729kW = 0.0157\frac{kgO_2}{hr}$
  - $118L * 1.5\frac{mgO_2}{hr} = 0.18\frac{kgO_2}{hr}$

Amendment

Due to system construction, the final design kept half of the winter from the previous cycle in the tank. This meant that half of the water was at a value of 1000mg/L and the second half was at the maximum BOD level of 5000 mg/L. This would adjust the values of the above calculations as follows:

- $S = \frac{\left(\frac{113}{2}*5000\frac{mg}{L}+\frac{113}{2}L*1000\frac{mg}{L}\right)}{113L} = 3000\frac{mg}{L}BOD = 4617\frac{mg}{L}COD$
- $\nu = 3.48\left(\frac{\left(4617\frac{mg}{L}-1169\frac{mg}{L}\right)}{0.3+4617\frac{mg}{L}-1169\frac{mg}{L}}\right) = 3.48\frac{mgCOD}{mgVSS*d}$

II. Particle Settling

Goal:

- Determine the length of time required for particles to settle

Constants:

- 2 (qty.) 30 gallon barrels = 60 gallons
- $Q = 30\frac{L}{d}$
- $h = 0.76\ m$

Assumptions:

- Floc settles based upon gravity
- Average floc settling rate=1 m/hr (Janczukowicz 2001)

Calculations:

- $Settling\ time = \frac{0.76m}{1\frac{m}{hr}} = 0.76hr$

To ensure sufficient settling, a factor of safety was added. As such, the system was allotted 1 hour for settling. Due to not knowing the particles in the system, the density, diameter, and settling rates were assumed to be constant and homogenous and particles were assumed to be large enough to settle under gravity.

III. System Sizing

Goal:

- Size of the full-scale system to meet the same treatment goals with a flow of 1500 GPD (5682L)

Constants:

- 2 (qty.) 30 gallon barrels = 60 gallons
- $Q = 30\frac{L}{d}$
- C_i = 5,000 mg/L BOD
- C_e = 1,000 mg/L BOD

Assumptions:

- Linear relationship between full scale system and prototype
- The treatment goal of reducing BOD from 5,000 to 1,000 mg/L is achieved during a 3-day batch cycle.

Calculations:

- Inflow:
  - $1500\ \frac{gallons}{day}\left|\frac{1\ liter}{0.264\ gallon}\right| = 5{,}681.8\ liters\ \cong\ 5{,}682\ liters$
  - $\frac{5{,}682\ L}{30\ L}$ = 189.4 ≅ 190
  - The full-scale system needs to be ~ 190 times larger than the prototype
- Upscaling the volume:
  - $190\ x\ 60\ gallons = 11{,}400\ gallons\ \left|\frac{1\ m^3}{264.2\ gallons}\right|$ = 43.1 m^3
  - This volume is comparable to the 40 m^3 sequencing batch reactor used in a study during a seven-week harvest period with Q_{avg} = 8 m^3 $\left|\frac{264.2\ gallons}{1\ m^3}\right|$ = 2113.6 gallons ~ 2100 gallons.

Though our SBR is estimated to be larger while treating less water, in this study, $65m^3$ storage tanks were used in addition to the $40m^3$ SBR (Torrijos and Moletta 1997).

IV. Motor Sizing

Goal:

- Determine the motor power required to sufficiently aerate the system

Constants:

- 2 (qty.) 30 gallon barrels = 60 gallons
- $Q = 30\frac{L}{d}$
- C_i = 5,000 mg/L BOD
- C_e = 1,000 mg/L BOD

Assumptions:

- Maximum BOD concentration of wastewater is being used to size the motor for our system
- Turbine efficiency
  1) Low turbine efficiency = 0.42 kg O_2/kWhr (Kumar and Mal 2010)
  2) High turbine efficiency = 4.7 lb O_2/hphr (Wastewater Aeration Systems n.d.)

Calculations:

- Determine the oxygen produced per kilowatt hour:
  - $4.7\ lb\ O2 * \left(1\ \frac{HP}{0.7457kW}\right) * \left(\frac{0.454kg}{1lb}\right) = 2.86\ \frac{kgO_2}{kWh}$
- Determine the grams of BOD per day:
  - $30\ \frac{liters}{day} * \left(\frac{4000\ mg\ BOD\ removed}{1\ L}\right) * \left(\frac{1\ g}{1000\ mg}\right) = 120\frac{g}{day}BOD$
  - $\frac{120\ g\frac{BOD}{day}}{\left(24\frac{hrs}{day}\right)*\left(\frac{1000g}{kg}\right)} = 0.005\ kg\frac{BOD}{hr}$
- Assuming low efficiency aerator (Kumar and Mal 2010)
  - $\frac{0.005\ kg\frac{BOD}{hr}}{0.42\frac{O_2}{kwhr}} = 0.0119\ kW\ needed\ for\ low\ efficiency$
- Assuming higher efficiency (Wastewater Aeration Systems n.d.)
  - $\frac{0.005kg\frac{BOD}{hr}}{2.86\ \frac{O_2}{kwhr}} = 0.00175\ kW\ needed\ for\ higher\ efficiency$
- Convert kW to Horsepower
  - $0.0119kW\ \left(1.341\frac{HP}{kW}\right) = 0.016\ HP$
  - $0.00262kW\ \left(1.341\frac{HP}{kW}\right) = 0.0033\ HP$

Thus, a motor that is higher power than 0.024 HP is needed. To ensure adequate aeration, a 1/20 HP motor was used.

V. Turbine Gas Induction Calculations

Goal:

- Whether the given impeller design will result in gas outflow.
- How long it will take to provide the required amount of Oxygen to the wastewater.

Constants:

- Rotational Speed (N) = 3000 rpm
- Impeller Diameter (d) = 3.5 inches
  - Typically, impeller diameters range from 4-6 inches (Heim et al., 1995).
- Liquid height above impeller (H') = 15 inches
- Motor is 1/20th HP.
- A conservative estimate of the oxygen transfer rate for propeller-aspirator-pumps is 0.42 kg O_2/kW-hr (Kumar et al., 2010).

Assumptions

- A propeller-aspirator-pump is used to provide oxygen to wastewater containing of 5,000 mg/L of BOD. The flow rate of wastewater is 30-60 L/day. The BOD in the effluent must be reduced to 1,000 mg/L. The specifications and assumptions used in the design for the aeration system are as follows:
- Critical Froude number (Fr*) = 0.230 (Heim et al., 1995).
  - For disk impellers, the onset of suction is a function of 1) Rotational Speed, 2) Impeller Diameter, (3) liquid height above the impeller and (4) viscosity or surface tension of the mixed liquid (Heim et al., 1995).
  - The critical Froude number incorporates the first three parameters to describe the point at which gas outflow occurs.
    - $Fr^* = \frac{N^2 D^2}{gH'}$ (Heim et al., 1995).

    Where N = rotational speed (s^{-1})

    D = impeller diameter (ft)

    G = gravitational acceleration = 32.17 ft/s^2

    H' = liquid height above the impeller (ft)

- Outlet clearance of the impeller has no effect on gas outflow (Heim et al., 1995).

Calculations

- Gas Outflow
  - $Fr^* = \frac{N^2 D^2}{gH'} = \frac{(3000\ rpm * \frac{1\ min}{60\ s})^2 (3.5\ in * \frac{ft}{12\ in})^2}{(32.17\ ft/s^2)(15\ inches * \frac{ft}{12\ in})} = \frac{(\frac{2500}{s^2})(0.0851\ ft^2)}{40.21\ \frac{ft^2}{s^2}} = 5.29$

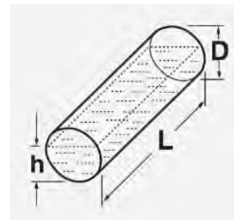
The Froude number for the given parameters are much greater than the critical Froude number required for gas outflow (Fr*= 0.230). Thus, adequate aeration should take place.

VI. Decanter Calculations

Goal:

- Determine the time required to empty the tank and ensure the decanter size is sufficiently sized

Constants:



- h = elevation of tank = 9.5 in = 0.79 ft
- D = diameter of tank = 19 in = 1.58 ft
- D_{orf} = diameter of orifice = 1.5 in
- L = length of tank = 29 in = 2.42 ft
- A = orifice area (ft^2) =?
- G = gravitational acceleration = 32.2 ft/sec^2

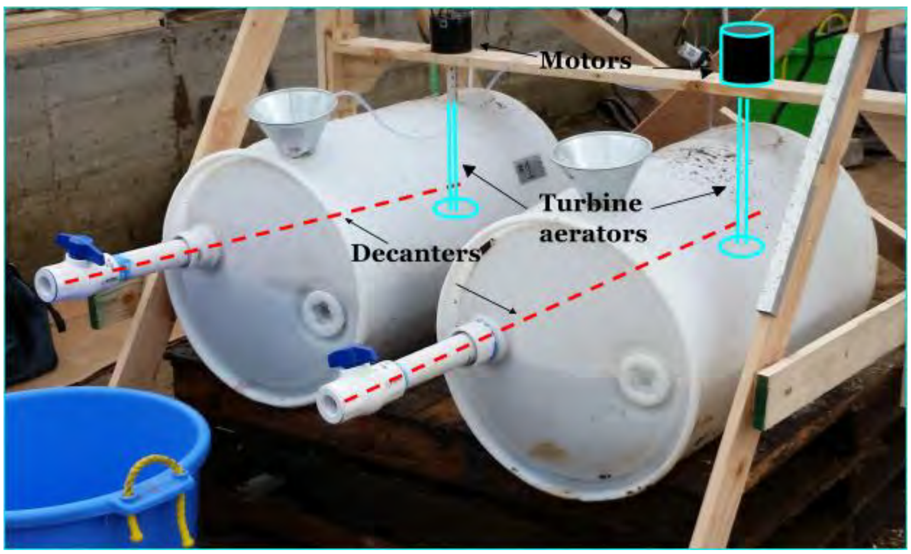


Figure A.1 *Decanter Visual, tank layout used in assumptions*

Visuals/Assumptions:

- After the settling phase, the cleanest of the effluent is at the top end of the tank and can be removed.
- The prototype has the decanter placed at half of the barrel height (h), thus a maximum of 56 liters can leave the tank(s) during the decantation process.
- Decanter height in prototype will not reflect its location in the full scale system. It is our recommendation that a standalone system be purchased to add to each SBR tank. This custom design was made to fit our small tank size and daily flow rates.

Calculations:

- Area of the outlet:
  - $\frac{\pi D^2{}_{orf.}}{4(144)} = \frac{\pi 1.5^2}{576} = 0.012\ ft^2$

- If the tank is filled with wastewater to a height of 19" (1.58 ft) and we assume turbulent flow, the approximate time to empty the tank:
    - $\Delta t = \frac{L\{D^{\frac{3}{2}} - (D-h)^{\frac{3}{2}}\}}{3C_d A}\sqrt{\frac{8}{G}} = \frac{2.42ft\{1.58ft^{\frac{3}{2}} - (1.58-0.79)ft^{\frac{3}{2}}\}}{3(0.61ft)(0.012\ ft^2)}\sqrt{\frac{8}{32.2\frac{ft}{s^2}}} = 168\ sec$

Δt ~2 min 48 *seconds*

The minimum time requirement to empty each tank is 168 seconds. This suggests that the system is sufficiently sized. To prevent turbulent flow conditions induced by rapidly decanting that could disturb the settled sludge; the system will be emptied at a slower rate. A typical system has no flow rate but rather a time that decanting can occur. In an example by Wang, the decanting occurred over a period of an hour at a rate of 8,333 gallons per minute. The smaller system described above in contrast, has a decanting rate of approximately 5.2 gallons per minute.

VII. Oxygenation Calculations

Goal

- Calculate the oxygenation parameters

Assumptions

- Tank #1 was ~50% full (~56.8 L) at the time of measurement
- Both the oxygen uptake rates and transfer rates were assumed to be primarily linear, except for exponential behavior when nearing saturation, in the case of OTE, or as DO or BOD reaches very low levels, in the case of OUR.

Calculations

- Based upon empirical data…
- $OTR\ (Oxygen\ Transfer\ Rate) = 0.07\frac{mg\ O_2}{L*s}\left(\frac{3600s}{1hr}\right) = 252\frac{mg*O_2}{L*hr} \sim 250\frac{mg*O_2}{L*hr}$
- $OUR\ (Oxygen\ Uptake\ Rate) = -0.0053\ \frac{mg*O_2}{L*s}\left(\frac{3600s}{1hr}\right) = 19.08\frac{mg*O_2}{L*hr} \sim 20\ \frac{mg*O_2}{L*hr}$
- OTE (Oxygen Transfer Efficiency) = $0.252\frac{g*O_2}{L*hr}\left(\frac{56.8\ L}{tank}\right)\left(\frac{kg}{1000\ g}\right)\left(\frac{motor}{0.0373\ kW}\right) = 0.38\ \frac{kg*O_2}{kW*hr} \sim 0.4\ \frac{kg*O_2}{kW*hr}$
    - This OTE is comparable to other turbine aerators, according to a study by Kumar and Mal (2010).
    - Because the OTR>OUR, there is sufficient oxygen in the system for microbial degradation to occur without being limited by oxygen.
- To reduce BOD from 7,000 mg/L to 1,000 mg/L, we must provide 6,000 mg/L of oxygen. Using the rates calculated in the previous step, let's calculate the amount of time it would take for the aerator to provide this amount of oxygen, and how long it would take for the microbes to utilize this oxygen.
    - Aeration:
        - $6{,}000\ \frac{mg}{L}\left(\frac{L*hr}{252\ mg*O_2}\right) = 23.8\ hrs \sim 24$ hrs
    - Respiration
        - $6{,}000\ \frac{mg}{L}\left(\frac{L*hr}{19\ mg*O_2}\right) \sim 13$ days

According to these rates, it would take only 24 hours to provide the oxygen required to degrade the BOD contained in one high strength batch of winery wastewater, but 13 days for the microbes to utilize this same amount of oxygen. Garvia-Ochoa and others have shown that OUR can vary greatly throughout the duration of a batch cycle (2010). The data used to calculate these rates may have been gathered during a time of reduced microbial activity, skewing the results.

Appendix B: Arduino Logic

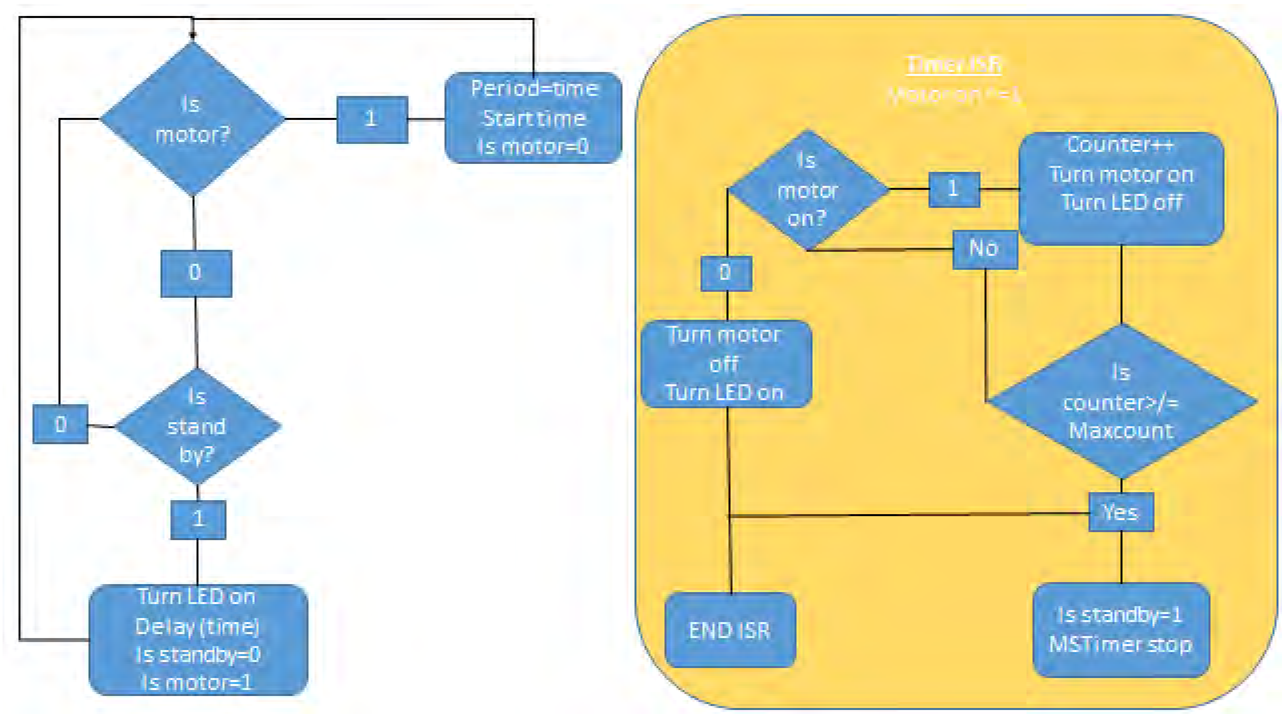


Figure B.1 *The Arduino unit drives the motor to run for 70 hours, shutting off every fifteen minutes for fifteen minutes to prevent overheating, and shut off for two hours for settling and decanting. To ensure the system is work, an LED on the Arduino board turns on whenever the motor is off to allow for a visual validation that the system is working.*

Appendix C: Economic Expenses

Table C.1 *Prototype Materials Cost*

Part	Quantity	Cost	Total
6 ' 2"x4"	1	$0.00	$0.00
50-gallon rain barrels	2	$65.00	$130.00
Funnels	2	$10.00	$10.00
2inch PVC Schedule 40 by 5ft	1	$17.37	$17.37
PVC Cement	1	$6.57	$6.57
Arduino board	1	$0.00	$0.00
Turbine	2	$0.00	$0.00
Fasco Electrical Motor	2	$50.00	$100.00
PVC male threaded fitting	2	$0.67	$1.34
Power Switches	2	$44.04	$88.08
PVC 90° Ball Valve	2	$10.73	$21.46
Hardware, screws & nuts	1	$3.48	$3.48
Power cord (from motor wires to 3 prong)	2	$19.12	$38.24
Plastic Epoxy	1	$5.47	$5.47
Hardware, screws & nuts	1	$6.38	$6.38
1" x 3/4" PVC Bushing	2	$1.32	$2.64
1-1/2" x 1" PVC Bushing	2	$1.52	$3.04
		Grand Total	**$434.07**

Table C.2 *Full-scale Materials Cost (projected)*

Part	Quantity	Cost	Total
Orenco 2000 gallon tank	3		0
3 HP Motor	3	$250	$750
Solenoid Valve	3	$26	$78
Arduino Uno	3	$10	$30
Powerswitch Tail	3	$33	$99
9 lbs aluminum	1	$40	$40
1" PVC pipe, 10 ft	3	$5	$15
Misc. PVC adapters	3	$5	$15
Carbon fiber tube	3	$75	$225
1/4", stainless steel, circular, 5ft	1	$9	$9
	Grand Total		**$1261**

Appendix D: Design Matrix

Economic	Environmental	Regulatory	Social	Technical
Capital Cost Annual Costs Energy efficiency Lifetime Expectancy	Sludge Gas Emissions	Winery needs met Meeting Orenco requirements	Aesthetic Ease of construction Technical know-how	Innovation BOD removal TSS removal Resiliency Modularity Maturity
30%	**10%**	**10%**	**20%**	**30%**

Figure D.1 *This decision matrix assisted in deciding which technology the team wanted to pursue.*

	Criteria	Scale				
		1	2	3	4	5
Economic	*Capital Cost*	Requires long retention time, thus construction and material costs will be great	.	Moderate	.	Material and construction costs are relatively low
	Annual Costs	Requires energy intensive operations	.	Moderate	.	Operates via energy efficiency, passive mechanisms
	Energy efficiency	Minimal difference between energy emitted and energy required	Small difference between produced vs required energy	Moderate efficiency	Efficient	Highly efficient
	Lifetime Analysis	1year<overhaul/replacement needed	~3 years major overhaul or replacement needed	~5 years major overhaul or replacement needed	~7 years major overhaul or replacement needed	10+ yrs major overhaul or replacement needed
Environmental	*Sludge*	Excessive sludge produced, undigested and volatile.	Sludge produced is in between Class A and Class B.	Moderate Sludge produced, Fits Class A category: "exceptional quality"	Class A Sludge produced.	Minimal Class A Sludge produced
	Gas Emissions	Smog check required: The system is very energy intensive and produces massive amounts of methane which is not used for energy production or even flared. Materials used are not sourced from conscientious manufacturers whom may have polluted the environment with considerable emissions during manufacture.	Gaseous: The system produces moderate amounts of methane which must be flared and/or used for energy production. Additionally, energy intensive pumps, materials and turbines are required for successful operation.	Acceptable: Emulates the industry standard for pre-aeration and clarification. Energy requirements are similar to those required by most similarly sized systems and parts are purchased from industry-trusted manufacturers whom may or may not emphasize environmental responsibility during manufacture.	Ecologically friendly: Anaerobic digestion may be practiced, but all the methane is flared. Energy may be required for the operation, construction and materials manufacture but the system is optimized to reduce the amount of materials required, as well as the operational energy requirements.	Zero impact: Only emissions are from aerobic microbial respiration (i.e. carbon dioxide). There is no methane released to the atmosphere from anaerobic digestion and there are no fossil fuels burnt for the production of energy, for the running of pumps or even for the construction and materials production.
Regulatory	*Winery needs met*	Fails to meet all regulations	Meets some, but not all, regulations	Passes	Passes with minimal factors of safety	Passes all regulations
	meeting Orenco regulations	Fails to meet all regulations	Meets some, but not all, regulations	Passes	Passes with minimal factors of safety	Passes all regulations+exceeds expectations
Social	*Aesthetic*	Eye sore; negatively impacts aesthetic with odor or appearance	Could be considered an eye sore by some; displeasing in terms of odor and/or apppearance at least some of the time	Unobtrusive/necessary looking but not notably ugly or smelly	Adds minor asthetically pleasing qualities; could be considered pleasing visually to some at least some of the time	Visually pleasing or giving off of a pleasing odor or sound; notably adds to the asthetic in some capacity
	Ease of construction	Technical construction knowledge is necessary, parts are intriquite, ambiguios instructions, information missing	Some technical knowledge required, steps to installation are missing or incomplete	Some technical knowledge required, complete instructions, parts require assembly	Complete instructions, unambiguious, some part assembly required	Minimal technical knowledge is required, all parts and components are assembled, unambiguious
	Technical know-how	Full-time on-site position required for effective system operation.	Frequent maintenance and optimization from trained winery personnel.	Seasonal maintenance and optimization from knowledgeable winery personnel or an external entity.	Yearly maintenance from a knowledgeable winery personnel or an external entity. System is self regulating.	Maintenance only every few years. System is self-regulated.
Technical	*Innovation*	Design>30 years old	20-30 years old	10-20 years old	Design <10 yrs old	Brand new
	BOD removal	<50%	50-65%	65-80%	80-90%	90%+
	TSS removal	50%</=x<60%	60%</=x<70%	70%</=x<80%	80%</=x<90%	90%</=x
	Resiliency	Poor; does not meet the need/requirements	Fair	Good; meets basic requirements	Meets basic requirements, min. surge flow	Meets requirements/surge flows
	Modularity	Requires complete overhaul of Orenco's system. Must completely replace the unit with a larger one to increase the capacity of the treatment system.	Requires moderate redesign of Orenco's system. Can be incorporated during increases to plant capacity, but would require some moderate reconfiguration.	Could be integrated with intelligent, but minimal modification to Orenco's treatment system, or during increases to system capacity.	Requires slight modifications which can be easily made to Orenco's system. Can simply add more units to increase the capacity of the system.	Can replace Orenco's current system with no redesign.
	Maturity	Nothing known about the design	Some information about the design	Info. about design/min. data collection	Much known about the design	Extremely well known design/lots of data

Figure D.2 *The scaling of the design matrix was assigned before assessing each technology to ensure all team members were assessing the technology in a similar manner.*

Trickling Filters	Upflow Anaerobic Sludge Digesters/ Sludge Blanket	Turbine Aerators	Diffusers	Lagoons	Aerobic Sequencing Batch Reactors	Anaerobic Sequencing Batch Reactors
64%	47%	73%	73%	69%	72%	73%

Figure D.3 *Seven treatment technologies were considered. Resident experts on each system provided the background information before team members independently ranked the systems. An average of individual scores yielded the chosen technology.*

Appendix E: Influent concentrations

Table D.1 *Initial influent recipe*

		Old recipe (60L)		
Testing Day	**Target COD**	**Ethanol (mL)**	**Sucrose (g)**	**Citric Acid (g)**
1-2	500	15.1	4.7	None
3-4	1000	31.2	9.4	0.06
5-6	2000	62.4	18.8	0.06
7-end of testing	5000	150.9	47.4	0.06

Table D.2 *Final influent recipe*

New Recipe (60 L)	
Glucose (g)	Citric acid (g)
278.4	4