5-2015

Designing a Clarifier to Recover Wastewater Algae Biomass for Production of Biofuels

Elizabeth Martinez
Utah State University

Recommended Citation

Martinez, Elizabeth, "Designing a Clarifier to Recover Wastewater Algae Biomass for Production of Biofuels" (2015). *All Graduate Plan B and other Reports*. 723.
https://digitalcommons.usu.edu/gradreports/723

DESIGNING A CLARIFIER TO RECOVER WASTEWATER ALGAE BIOMASS FOR PRODUCTION OF BIOFUELS

by

Elizabeth Martinez

A technical report submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Biological Engineering

Approved:

Dr. Ronald C. Sims Major Professor	Dr. Charles D. Miller Committee Member
Issa A. Hamud Committee Member	

UTAH STATE UNIVERSITY
Logan, Utah

2015

ABSTRACT

Designing a Clarifier to Recover Wastewater Algae Biomass for Production of Biofuels

by

Elizabeth Martinez, Master of Science

Utah State University, 2015

Major Professor: Dr. Ronald C. Sims
Department: Biological Engineering

The Logan Lagoons, Logan City's Wastewater Treatment Facility ensures 15 million gallons of wastewater are cleaned and filtered each day. With the implementation of new and stricter wastewater effluent standards, the city of Logan now has to guarantee the phosphorous concentration in the effluent is also reduced. Algal biomass produced and harvested from the lagoons has been proven to affect the way nitrogen and phosphorous are removed, while having the potential to be converted to biofuels. Therefore, implementing a secondary type clarifier in the Logan Lagoons would produce treated water with a reduced phosphorous concentration, and algae feedstock for biofuel production.

While several factors influence clarifier design, the settling characteristics of flocculent algae in wastewater were the main focus of this project. Sedimentation columns were used to calculate surface overflow rate, detention time and algae percent settling. The addition of chemicals and variation of zeta potential, to promote flocculation and higher algae percent settling, were also studied.

Preliminary results revealed a large fraction of the algae can be settled by means of sedimentation prior to chemical dosing. A suspended settling efficiency of 40%-60% with a detention time of 2-2.8 hours was attained and a surface overflow rate between 51-69 ft/day was calculated. Furthermore, a pH of 8-11 influenced a neutral zeta potential, increasing algae percent settling and phosphorous removal even further. A brief discussion about other factors that affect algae percent settling and future tests for a complete scale-up procedure are also included in this report.

ACKNOWLEDGMENTS

I would like to thank our team members Alexa Lunt, Zak Dymock and Reese Thompson for helping me conduct the experiments of this project, especially with the chemical induced flocculation experiment. I would like to thank my major advisor, Dr. Ronald Sims, as well as my committee members Dr. Charles Miller and Mr. Issa Hamud for their support and assistance throughout the entire process.

I give special thanks to Dr. Timothy Taylor for being my mentor and for supporting me throughout my entire career. I would have never made it this far without his help, counseling and support. I would also like to thank Anne Martin for her tremendous continued help and support all the years I have been in the biological engineering department.

Special thanks also to my husband, Rodolfo Trujillo for his encouragement, moral support, and patience as I worked on this project. And finally, I would like to thank my family and friends for supporting me all of the time. I could not have done it without all of you.

Elizabeth Martinez

CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

Introduction

Treatment of municipal, industrial, and agricultural wastes that use ponds or lagoons has found an increasing positive effect over the past years. Lagoons have been demonstrated to be the method of choice for dealing with different types of waste materials since they are simpler and more cost effective in operation than other sophisticated treatment facilities (Elder, 2011). The Logan Lagoons, Logan City's Wastewater Treatment Facility ensures approximately 15 million gallons of wastewater are treated each day. However, with the implementation of wastewater effluent standards by water pollution reduction agencies, the city of Logan has to ensure the phosphorous concentration in the effluent is also reduced (Elder, 2011). Algal biomass produced and harvested from the lagoons has been proven to affect the way nitrogen and phosphorous are removed while, having the potential to be converted to biofuels (Elder, 2011). Implementing a clarifier in the Logan Lagoons would produce treated water with a reduced phosphorous concentration, and algae feedstock for biofuel production. The objective of this project was to design a secondary type clarifier that produces water with reduced suspended solids and recovers algae biomass for the production of biofuels.

Literature Review

The Logan Lagoons

The Logan Lagoons are located in Logan Utah (see Figure 1A) and have cleaned and filtered approximately 15 million gallons per day (MGD) of wastewater for about 50 years (Cannon, 2013). This natural and passive system is one of the largest of its kind in North America and it's mainly designed to remove total suspended solids (TSS) and biochemical oxygen demand (BOD) (Cannon, 2013). It consists of a series of seven (A1, A2, B1, B2, C, D, and E) (Figure 1B) open-air, facultative lagoons, covering a total area of 460 acres and 240 acres of wetlands, serving not only Logan but also the cities of Nibley, Providence, River Heights, North Logan, Hyde Park, and Smithfield (Elder, 2011).

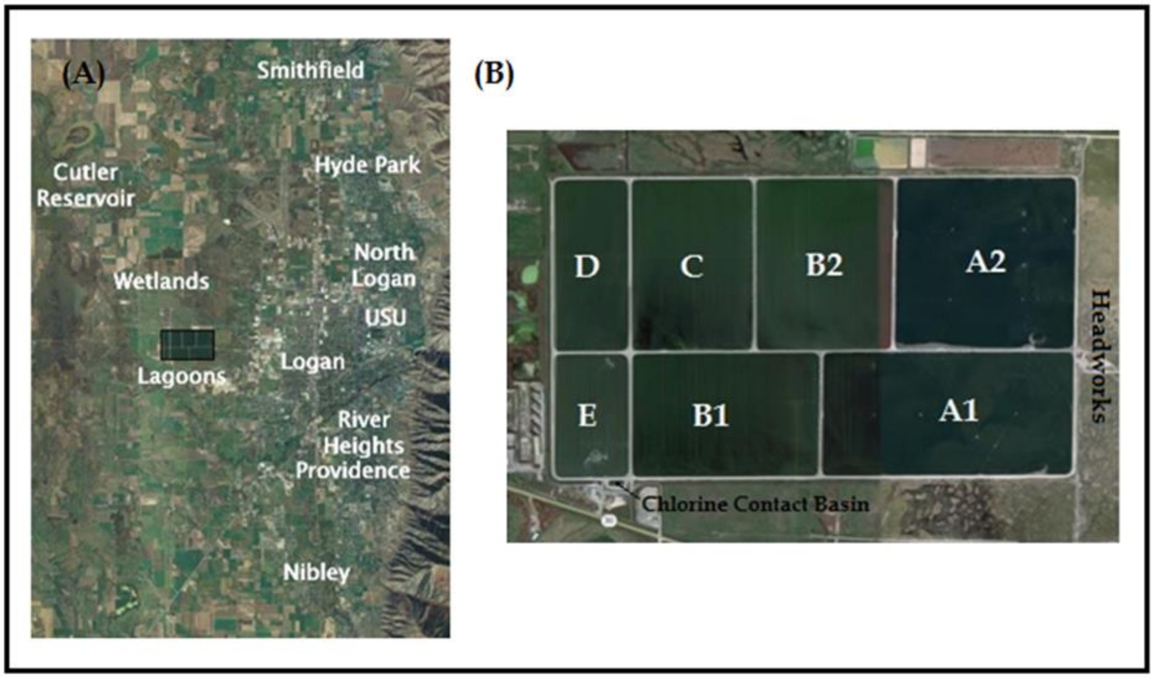

Figure 1. (A) Google map photograph of the Logan City wastewater lagoons. (B) Logan City wastewater lagoons with the ponds labeled.

<u>How the Lagoons Work</u>

The lagoons work through a process of aeration (Cannon, 2013). Wastewater comes in from the facility’s headworks, located at the east end of the lagoons, where some of the solids are removed (Cannon, 2013). As seen in Figure 2, wastewater enters into parallel cells A and B (where the majority of the solids are removed), recombined in cell C following its path to cells D and E where the water is further polished by lowering more solids, BOD, and pathogen levels to below regulatory limits (Griffiths, 2009). The effluent is then chlorinated (at chlorine contact basin) and disinfected, leaving in a slow stream to irrigate fields to the west of the facility during the growing season (City of Logan, 2013). If the effluent is not used as irrigation water, it is carried through the wetlands for additional treatment (enhance ammonia removal), and then discharged to Cutler Reservoir via Swift Slough (City of Logan, 2013).

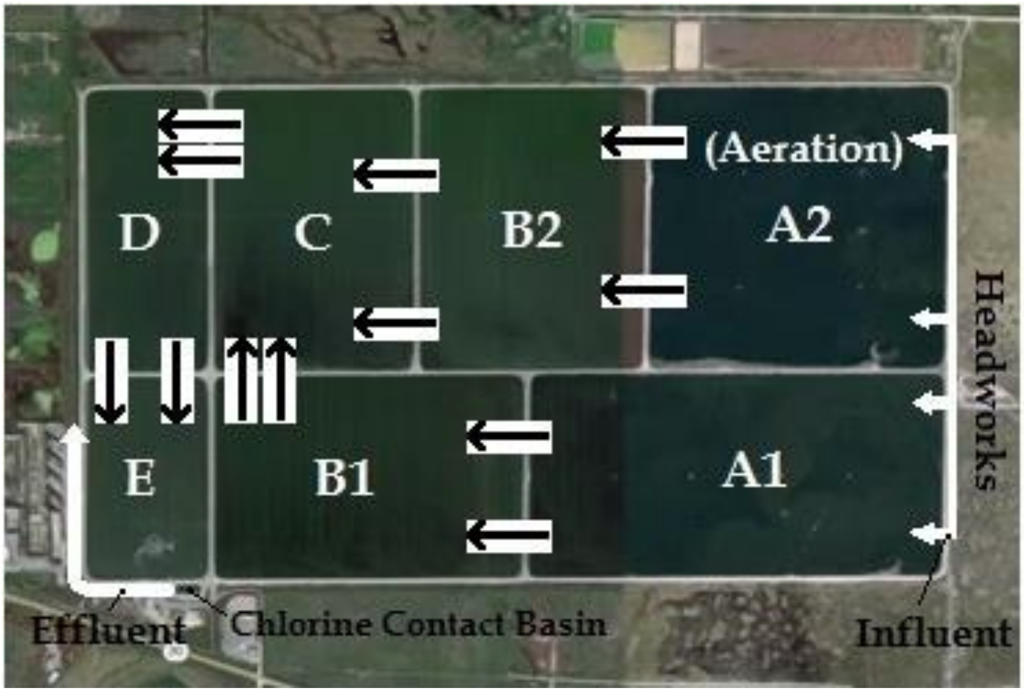

Figure 2. The Logan Lagoons with arrows indicating the direction of wastewater flow (Adapted from Google Maps).

New Effluent Standards

Although this system is able to filter some harmful chemicals, it will not be able to remove phosphorus, nitrogen and ammonia to levels agreed upon by the US Environmental Protection Agency **(**EPA) and the Utah Division of Water Quality

(UDWQ) (City of Logan, 2013). The regular algal blooms that occur in the Logan Lagoons aid in the treatment of the wastewater but they are also the major cause of eutrophication (Elder, 2011). The nitrogen consumed by the algae is eventually volatilized as ammonia and removed from the lagoon system (Elder, 2011). However, phosphorus is non-volatile, and will cycle in and out of the algae as they grow and die (Griffiths, 2009). If algae are not removed from the effluent, the phosphorus in the Logan Lagoons is discharged into Cutler Reservoir, making it impaired due to low dissolved oxygen (DO) concentrations and excess total phosphorus (City of Logan, 2013). Consequently, the city of Logan received notification of a new limit on total effluent phosphorus (see Table 1) that must be met by the year 2017 (City of Logan, 2013).

Table 1. City of Logan Future Phosphorous Limits (adapted from City of Logan, 2013)

Year	Season	Approx. Flow (MGD)	Concentration Limit (mg/L)
2010	Summer	15	1.1
	Winter	10	1.9
2020	Summer	17	0.9
	Winter	12	1.6
2030	Summer	20	0.83
	Winter	14	1.4
2040	Summer	24	0.69
	Winter	14	1.3

Algae Treatment and Nutrient Removal

Research by Utah State University has shown that algal biomass produced and harvested from the lagoons affect the way nitrogen and phosphorous are removed, while having the potential to be converted to biofuels (City of Logan, 2013; Elder, 2011). Algae offer these advantages due to fast autotrophic growth (doubling times as low as 3.5 hours) in a variety of non-potable, poor water sources, including wastewater (Smith & Davis, 2012; Anthony, 2013). Algae are also high in lipid content (approximately 20-50% of their total weight) and have the ability to remove nitrogen and phosphorous, making them simultaneously useful for wastewater treatment and biofuels production (Griffiths, 2009; Danquah et al., 2009).

Biofuels

The production of biofuels that are renewable, locally produced, and environmentally-safe is expected to promote employment in rural areas, to develop long term replacement of fossil fuels and to reduce greenhouse gas emissions (Mata et al., 2010). Furthermore, biodiesel and bio-ethanol, the most common biofuels, can replace diesel and gasoline respectively, with little or no modifications of automobile engines. These fuels can be made using current technologies and can be distributed through the existing distribution system (Mata et al., 2010).

Challenges

Although algae have the potential as biofuel feedstock, being able to concentrate and harvest algae remains an economic challenge. These expenses are estimated at 18.5% of total production costs (Smith & Davis, 2012). Autotrophically-grown algal concentrations, on an ash-free dry-weight are between 0.05-0.1% w/w for raceway pond (Smith & Davis, 2012). These low algal concentrations make extensive dewatering necessary, beginning with primary concentration techniques that require more energy and higher operational costs (Smith & Davis, 2012; Anthony 2013). Therefore, the harvesting of algae needs to be focused upon in order to decrease the overall process costs of producing biofuels (Anthony, 2013). Current techniques employed in algae harvesting and recovery include centrifugation, biofilm, cross flow filtration, and dissolved air flotation (Smith & Davis, 2012; Uduman et al., 2010; Anthony, 2013).

Gravity Settling and Algae Sedimentation

Gravity settling and algae sedimentation seem to be more economically viable than other techniques due to significant decrease in energy expenditure and simplicity of the process (Uduman et al., 2010). Clarifiers are an effective reactor design that take advantage of the settling ability of suspended particulate matter, in this case algae (Water Environment Federation, 2005). Hence, implementing a secondary clarifier, which would receive the effluent from the Logan Lagoons (see Figure 3), would produce treated water that accomplishes the phosphorous limits, and is an energy efficient, low cost method for harvesting algae feedstock for biofuel production (CH2M HILL, 2010).

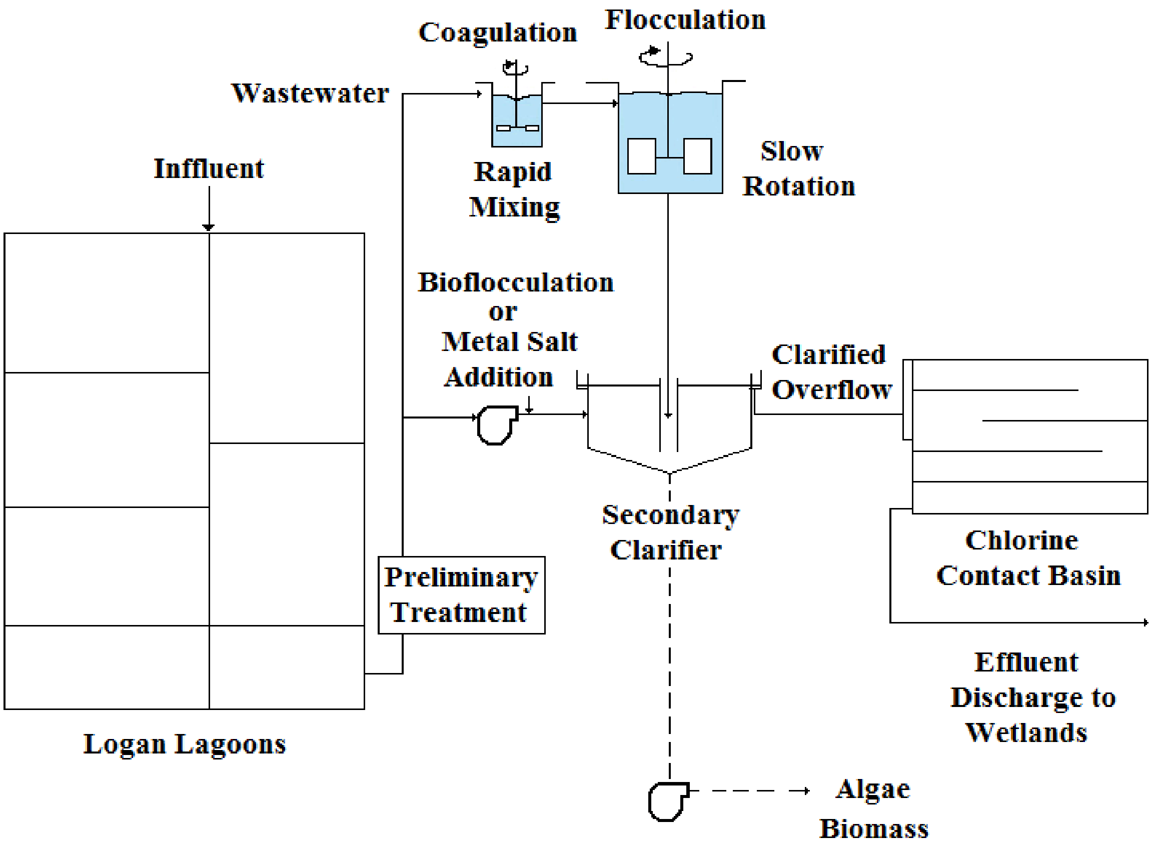

Figure 3. Process flow diagram of the Logan Lagoons with the upgraded approach modifications to include a secondary clarifier (adapted from CH2M HILL, 2010).

Clarifiers

Gravity separation, creating a clarified flow and thickened solids at the bottom, has long been used in wastewater treatment (Water Environment Federation, 2005). The fundamental function of a clarifier is to treat wastewater entering the system by removing particulate matter and other undesirable substances, leaving it as clean treated water in the effluent. Primary clarifiers are designed to remove all of the settleable total suspended solids. (Water Environment Federation, 2005). Secondary clarifiers (also known as final clarifiers), illustrated in Figure 4, Figure 5A and 5B, are mainly used in biological as well as suspended growth systems to remove biological (activated sludge) solids (Water Environment Federation, 2005). In order to properly design a secondary clarifier for the Logan Lagoons, parameters such as volume of water entering the system (Surface Overflow Rate), the detention time of the wastewater, and the addition of chemicals to induce flocculation have to be researched in a laboratory setting. This is because wastewater composition and specific response to remediation methods change for different locations. Table 2 summarizes the key factors that affect the performance of any intended clarifier (Water Environmental Federation, 2005).

Figure 4. Secondary clarifier from Simi Valley, California (Secondary Clarifiers, 2008).

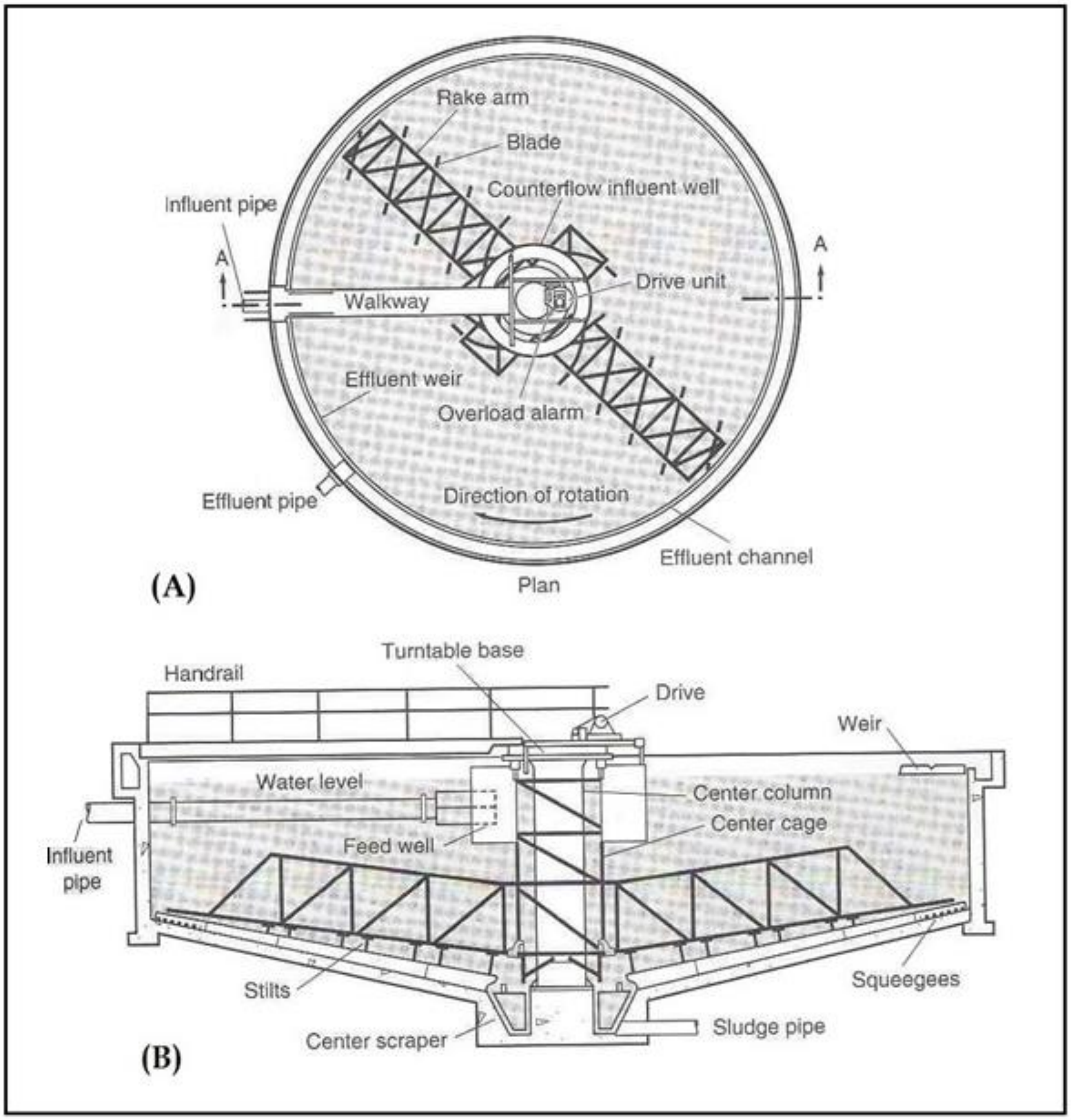

Figure 5. (A) Top view of a circular clarifier. (B) Section view of a circular clarifier (Team Sludge, 2003).

Table 2. Factors that affect clarifier performance (adapted from Water Environmental Federation, 2005).

Category	Factors
Hydraulic and load factors	Wastewater flow
	Surface overflow rate
	Solids loading rate
	Hydraulic retention time
	Underflow recycle ratio
External physical features	Tank configuration
	Surface area
	Depth
	Flow distribution
	Turbulence in conveyance structures
Internal physical features	Presence of flocculation zone
	Sludge-collection mechanism
	Inlet arrangement
	Weir type, length, and position
	Baffling
	Hydraulic flow patterns and turbulence
	Density and convection currents
Site conditions	Wind and wave action
	Water temperature variation
Sludge characteristics	MLSS concentration
	Sludge age
	Flocculation, settling, and thickening characteristics
	Type of biological process

Algae Sedimentation

Since algae have a negative surface charge, the negative charges do not interact with each other making algae remain in suspension and not settle (Henderson et al., 2008). As a result, algae pre-treatment is usually applied prior to sedimentation to increase harvesting ability (Engelhardt, 2013). Coagulation and flocculation are two steps usually used. Coagulation is a method to neutralize (coagulate) charges by the addition of a chemical and then to form a gelatinous mass to trap the algae particles (Engelhardt, 2013). Coagulation is followed by flocculation, a gentle stirring or agitation to encourage the algae colloid to agglomerate (flocculate) into masses big enough to settle and to be more easily separated from the wastewater (Engelhardt, 2013; Anthony, 2013). In essence, coagulants destabilize the charges and surface properties of the algae in suspension, so they do not resist agglomeration and flocculants center on stimulating the formation of larger aggregates from destabilized algal cells (Moheimani et al., 2015).

Coagulation with Metal Salts

Since algae cells are negatively charged, positive ions (cations) can be used as coagulants (Engelhardt, 2013). A sodium compound (e.g., sodium hydroxide), contributes a monovalent ion, Na^{+}, a calcium compound (e.g., calcium hydroxide) contributes a divalent ion, Ca^{2+} (Engelhardt, 2013). Likewise Aluminum (e.g., aluminum sulfate) and iron (e.g., ferric chloride) coagulants contribute trivalent aluminum ions, Al^{3+} and trivalent iron ions, Fe^{3+}, correspondingly (Engelhardt, 2013; Anthony, 2013). It has been demonstrated the greater the charge of the cation, the greater the efficiency of charge neutralization (Engelhardt, 2013). As a result, aluminum and iron compounds are most regularly used as coagulants with Alum (aluminum sulfate) being the predominant coagulant used in the USA (Engelhardt, 2013). Measurement and management of pH and alkalinity is very important when these salts are used. Sodium or calcium salts can be added for pH adjustment purposes which contribute to the coagulation process as well (Engelhardt, 2013).

Flocculation

Once charge neutralization has been successful, flocculation typically takes place by adding a polymer (Anthony, 2013). Flocculation can also be encouraged by changing culture conditions such as varying the pH, nutrient availability, temperature, light conditions and level of dissolved O2 (Salim et al., 2011).

Auto- and bio-flocculation are both methods that take advantage of natural means to make the charge of algae become neutral and no longer repel each other (Moheimani et al., 2015). In wastewater auto-flocculation, rapid algae photosynthesis causes an initial rise in pH (due to CO_2 consumption), then in the presence of calcium and phosphate ions, positively charged calcium phosphate causes precipitation of the negatively charged algae (Smith & Davis, 2012). The precipitates then bridge and flocculate the algae. Other naturally-available precipitating ions include Ca^{2+}, Mg^{2+}, and CO_3^{2-}. Literature suggests that magnesium hydroxide is most promising as a flocculant (Smith & Davis, 2012).

Algae sedimentation due to morphology is considered a form of bio-flocculation (Sérodes et al., 1991). Bio-flocculation is thought to be mainly as a result of the adhesion of particles by gelatinous material excreted by certain algal species, which forms a polymeric network known as extracellular polymeric substance (EPS) (Vatansever, 2005). This polymeric network holds everything together causing algae particles to aggregate (Vatansever, 2005).

Chemical induced flocculation uses flocculating and/or coagulating agents in the algae culture to speed cell aggregation (Moheimani et al., 2015). Examples include Zn^{2+}, Al^{3+}, Fe^{3+} and other chemical flocculants like alum (for flocculation of *Scenedesmus* and

Chlorella, the predominant cultures at the Logan Lagoons) (Salim et al., 2011). The downside to chemical induced flocculation is that it could lead to extra operational cost, since chemical flocculants need to be removed for downstream use of the biomass for feedstock (Salim et al., 2011; Moheimani et al., 2015).

Zeta Potential

Literature review also shows that adjusting the zeta potential, the overall charge that a particle acquires in a specific medium, can significantly improve algae concentration and settling (Henderson et al., 2008). Since Algae cells are negatively charged, they create a negative zeta potential (Khoshnevisan & Barkhi, 2001). Reducing the negative zeta potential means a reduction in the repulsive electrostatic forces. Therefore, a critical zeta potential can be acquired where the attractive van der Waals forces overcome these electrostatic forces and thus make algae come together (Henderson et al., 2008). In water, the pH of the sample is one of the most important factors that influence the zeta potential. A typical plot of zeta potential versus pH is shown in Figure 6. In the case of algae in wastewater, the zeta potential will be positive at low pH and lower or negative at high pH (Khoshnevisan & Barkhi, 2001). When the plot passes through zero zeta potential is called the isoelectric point, where the charge will be neutral (Khoshnevisan & Barkhi, 2001). Therefore, if algae obtain low or zero zeta potential values, there will be no force to prevent them from flocculating (Khoshnevisan & Barkhi, 2001). The degree to which flocculation occurs also varies by over flow rate, depth of the basin, velocity gradients in the system, and concentration of the algae cells (Tchobanoglous et al., 2003).

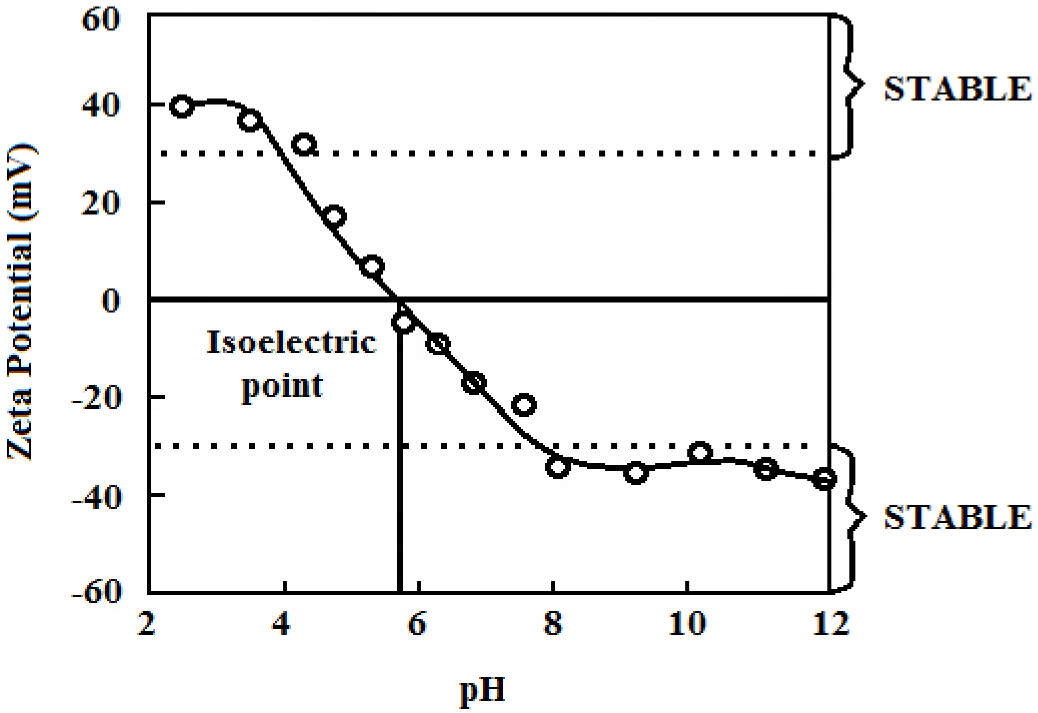

Figure 6. Example of a typical plot of zeta potential versus pH showing the position of the isoelectric point and the pH values where the dispersion would be expected to be stable (Khoshnevisan & Barkhi, 2001).

The Design – Secondary Clarifier

While several factors influence clarifier design, the settling characteristic of suspended algae in wastewater is the most important consideration in this case (Surface Water Quality Bureau, 2007). Other elements that influence the settling characteristics are temperature, detention time, surface overflow rate (SOR), weir overflow rate (WOR), and solids loading (Surface Water Quality Bureau, 2007). The following are secondary clarifier loading equations:

$$\text{Detention Time (hours)} = \frac{\text{Tank Volume, MG X 24}}{\text{Flow into Tank, MGD}}$$

$$\text{Surface Overflow Rate (GPD/ft}^2\text{)} = \frac{\text{Flow, gallons/day}}{\text{Surface Area, ft}^2}$$

$$\text{Weir Overflow Rate (GPD/ft)} = \frac{\text{Flow, gallons/day}}{\text{Length of Weir, ft}}$$

$$\text{Solids Loading } \left(\frac{\text{lbs}}{\text{day}}/\text{ft}^2\right) = \frac{\text{Solids, lbs/day}}{\text{Surface Area, ft}^2}$$

The Settling Process

The Water Environment Federation (WEF) manual of practice for clarifier design indicates that settling basins (clarifiers) handling wastewater must isolate a variety of materials in the clarification zone. Figure 7 shows that depending on the concentration of the suspended solids and the propensity of the particles to flocculate, four distinct types of settling processes are usually recognized in wastewater.

- Type I - Discrete non-flocculent settling: particles are completely dispersed with no tendency to flocculate. These particles settle independently at their terminal velocity.

- Type II - Flocculent settling: particles are distributed but have a strong pull to aggregate. With time, the particles merge and settle as flocculated particles.
- Type III - Zone settling: particles that have a strong affinity to coalesce do so quickly and settle together as a matrix. All of the particles within the matrix settle

at the same velocity and as they settle, the particles retain their relative position to each other (sludge thickening).

- Type IV - Compression settling: as the solids settle to the bottom of the clarifier, the particles come into mechanical contact. The resulting compressive forces squeeze out the water and the sludge is thickened.

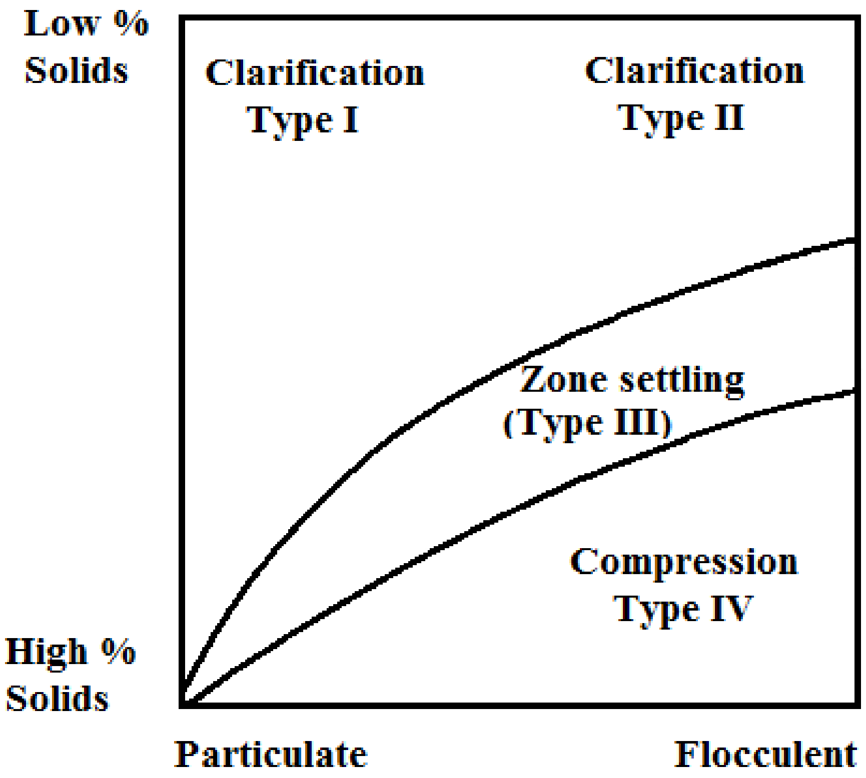

Figure 7. Relationship between solids characteristics and sedimentation processes (Water Environment Federation, 2005).

All four types of settling may occur in secondary clarifiers but type II best describes the way flocculent algae settle. Type II contributes to clarification, the actual separation of algae from the wastewater and for this class of settling, the capacity-controlling factors are the overflow rate and depth (Water Environment Federation, 2005). As a result of flocculation, the settling velocities of the aggregates formed change with time and consequently, laboratory testing is necessary (Water Environment Federation, 2005). A batch-type laboratory technique (included in the Appendix) has been developed to predict or calculate the SOR, detention time or basin depth, and percent settling of suspended solids (Water Environment Federation, 2005). Using this laboratory procedure enables data from settling column tests to be interpreted by a graphical technique. Samples at different times and depths are evaluated for suspended solids concentration and settling rate profiles are physically plotted as a function of time. Hence the results from these graphs are used to determine the desired clarifier parameters.

Materials and Methods

A mixed culture of algae from the Logan Lagoons effluent stream was recovered and grown in 50 liter indoor micro-raceways. Initial testing with sedimentation columns (Figure 8) and jar tests (Figure 9) was used to classify the effectiveness of algae settling and clarifier use viability. The following were assessed: algae settling rates in seven feet sedimentation columns, algae settling in design columns over time and algae settling through chemical dosing in a six 1-L square jar test unit. The following chemicals were used: aluminum sulfate, calcium hydroxide, ferric chloride, sodium aluminate, and aluminum chlorohydrate. The zeta potential was also investigated by varying the pH of water.

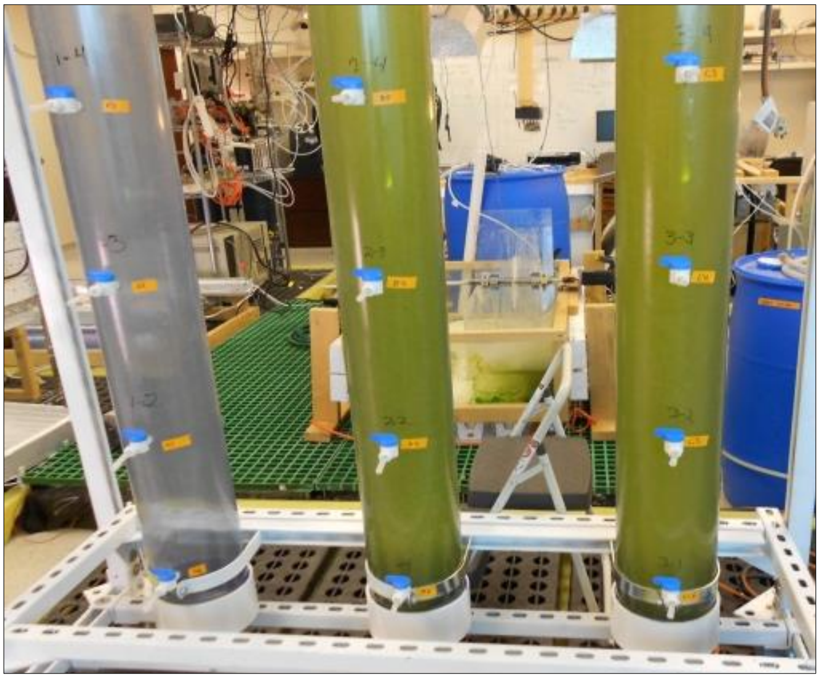

Figure 8. Seven feet settling columns with sample ports spaced at one foot intervals

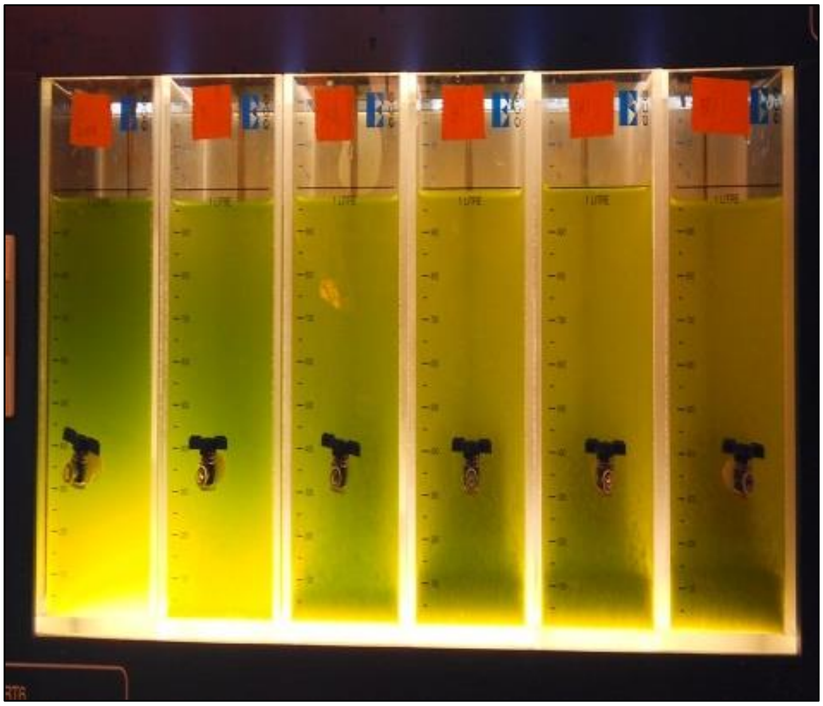

Figure 9. Six 1-L square jar test unit used for chemical induced flocculation procedure

Sedimentation Column Procedure

Water containing a mixed culture of algae was put in sedimentation columns to estimate SOR, detention time or basin depth, and percent settling of suspended solids (technique found in Appendix 1). The columns were seven feet deep and sample ports were spaced one foot intervals (illustrated in Figure 10). The algae samples were well mixed and an initial TSS was taken before transferring the suspension into the columns quickly to ensure a uniform mixture. Samples were collected from each port every half hour, for five hours, while maintaining quiescent conditions. Then the percent settling of TSS was computed for each sample and plotted on a set of coordinate axis with column depth (H) as the ordinate leg and sampling time (t) on the abscissa (illustrated in Figure 11, graphed in Figure 12). Isoconcentration curves were drawn through the points, interpolating where necessary. Then, a series of detention times were selected and percent settling and SOR corresponding to each detention time were computed using the equations in step nine of the appendix 1. The series of overflow rates and percent settling were then used to plot curves of algae percent settling versus SOR (Figure 13) and algae percent settling versus detention time (Figure 14), which were used to size the secondary clarifier. The adjusted SOR value was determined using mathematical extrapolations from the isoconcentration curves graph and the algae percent settling versus SOR graph. The optimal detention time was calculated by graphing algae percent settling versus detention time in the reactor.

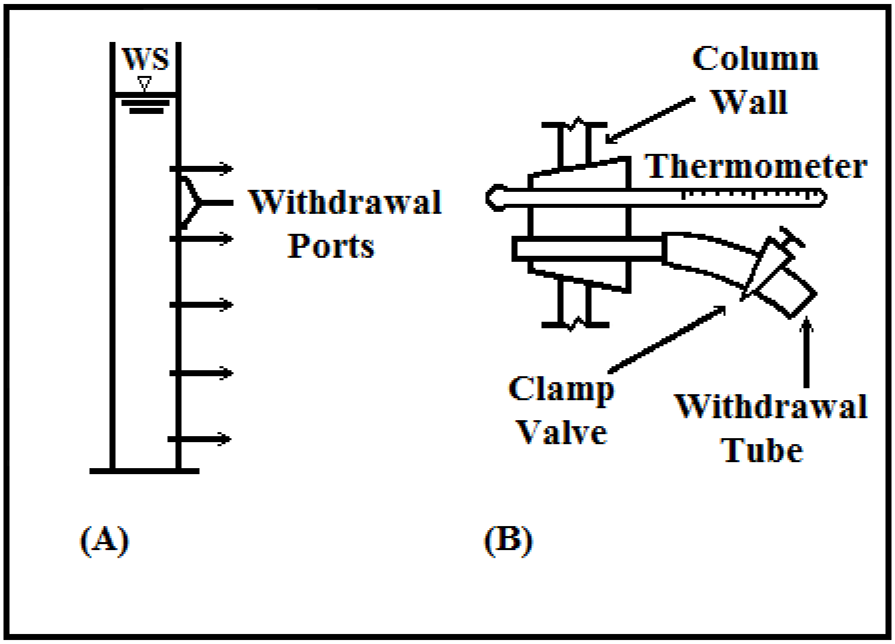

Figure 10. Batch settling test. (A) Column Elevation. (B) Withdrawal port detail (Water Environment Federation, 2005).

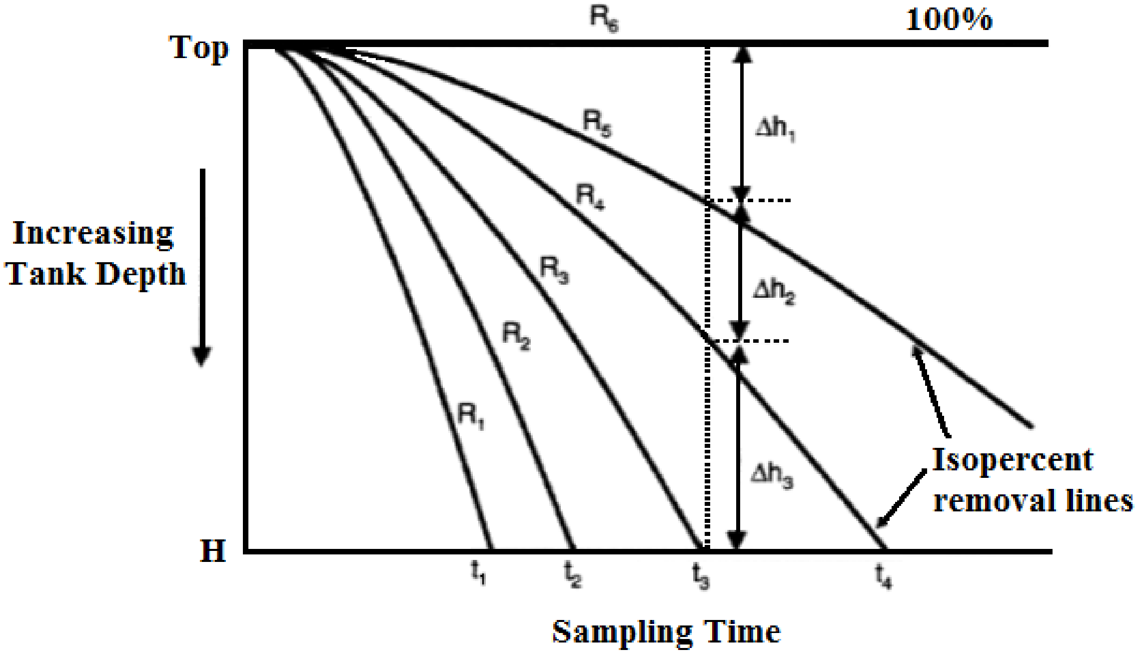

Figure 11. Isoconcentration curves for percent settling (R = percent settling; Δh = vertical distance between adjacent isoconcentration curves; H = total height of settling column; t = sampling time) (Water Environment Federation, 2005).

Chemical Induced Flocculation Procedure

Five of the six 1-L square jar tests were filled with algae solutions (5.5 inches deep) from the micro-raceways and the specified individual chemical dosage of the five different chemicals mentioned before (aluminum sulfate, calcium hydroxide, ferric chloride, sodium aluminate, and aluminum chlorohydrate), was added. The chemical dosage ranged between 10 and 50 mg/L and the samples were conducted in triplicates. The algae was then mixed for 15 minutes and allowed 15 minutes of settling. Samples from each one liter jar were subjected to a TSS test to determine the percent settling of algae at different chemical concentrations by comparing samples from the raceways and post jar test sample levels.

Adjusting the Zeta Potential

The pH levels were monitored three times a week in the 50-liter micro raceways by using Phidgit probe hardware and LABview Software. The pH levels were then monitored over the life time of the raceways to evaluate the formation effects of calcium phosphates and magnesium hydroxides on the charge of algae cells. Additionally, the effect of each chemical on the zeta potential of the samples was noted.

Results and Discussion

Preliminary results demonstrate settling took place without the addition of chemicals (Figure 12). However, the addition of chemicals increased algae percent settling as algae formed flocs and precipitated out of solution as illustrated in Figure 15.

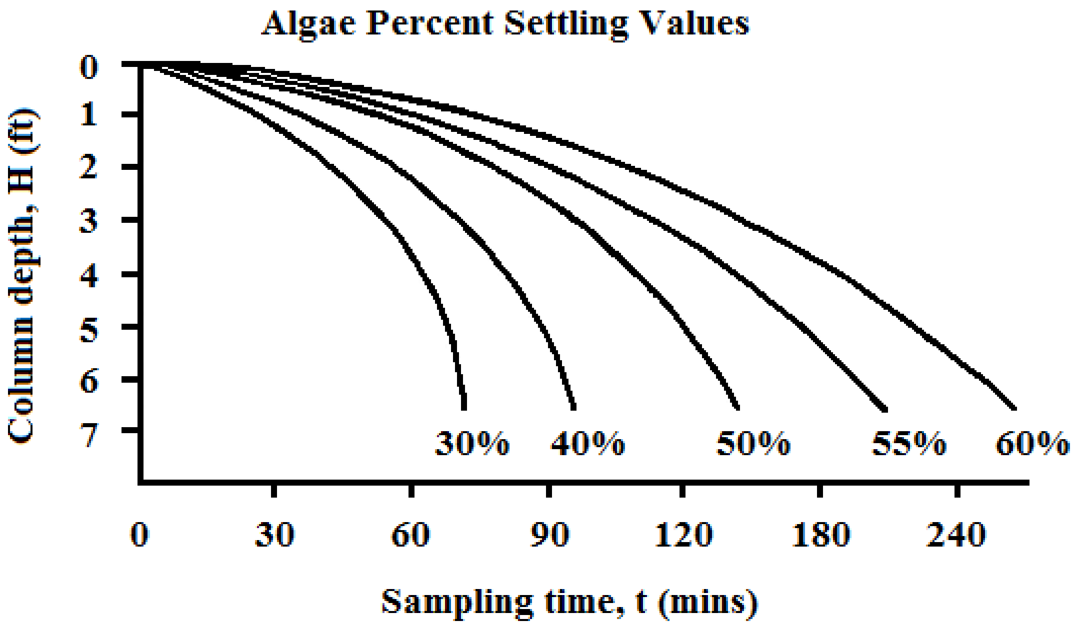

Figure 12. Isoconcentration curves showing algae percent settling values.

The adjusted SOR value was calculated in the time ranges between 51-69 ft/day (Figure 13).

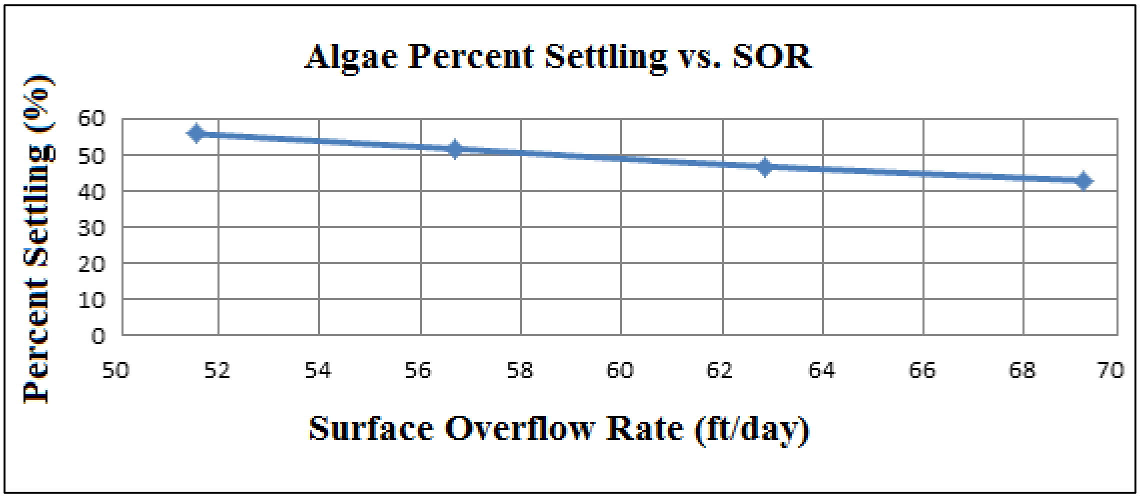

Figure 13. Algae percent settling versus surface overflow rate.

Figure 14 shows that a suspended solids settling efficiency of 40%-60% can be attained with a detention time of 2-2.8 hours.

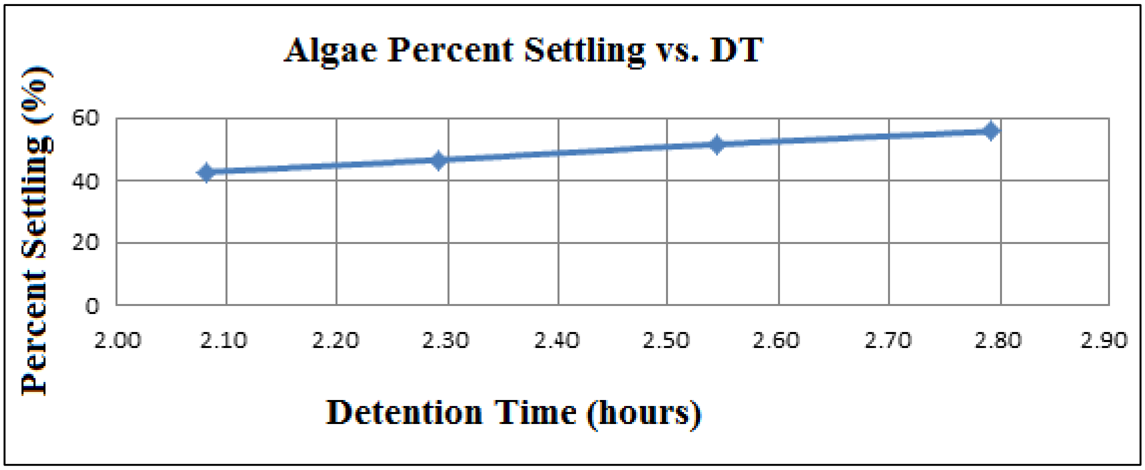

Figure 14. Algae percent settling versus detention time.

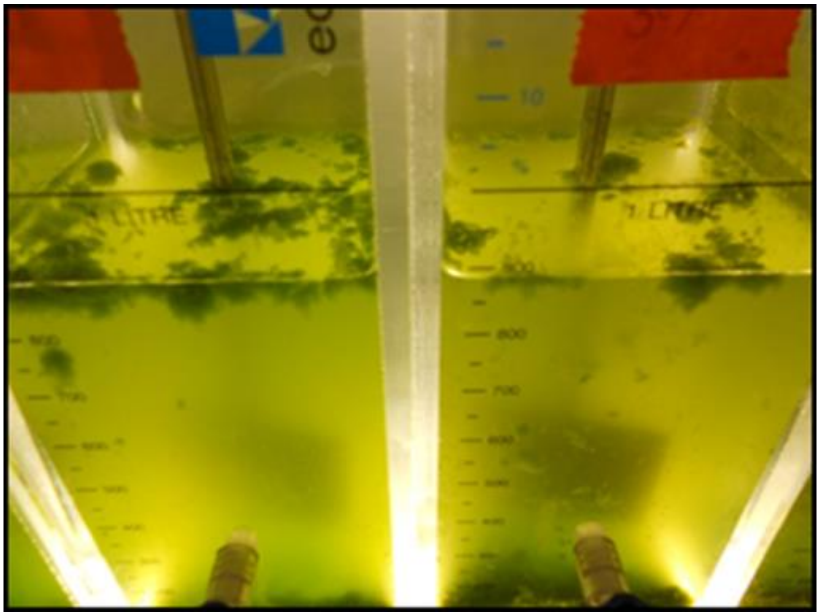

Figure 15. Chemical induced flocculation of algae by aluminum sulfate (Alum). Algae flocs are shown on top and settled algae on the bottom.

Chemical testing showed that aluminum chlorohydrate and iron chloride settled the highest percent of algae, with percent settling between 83%-87%. Figure 16 shows the other chemicals used and their percent settling of algae.

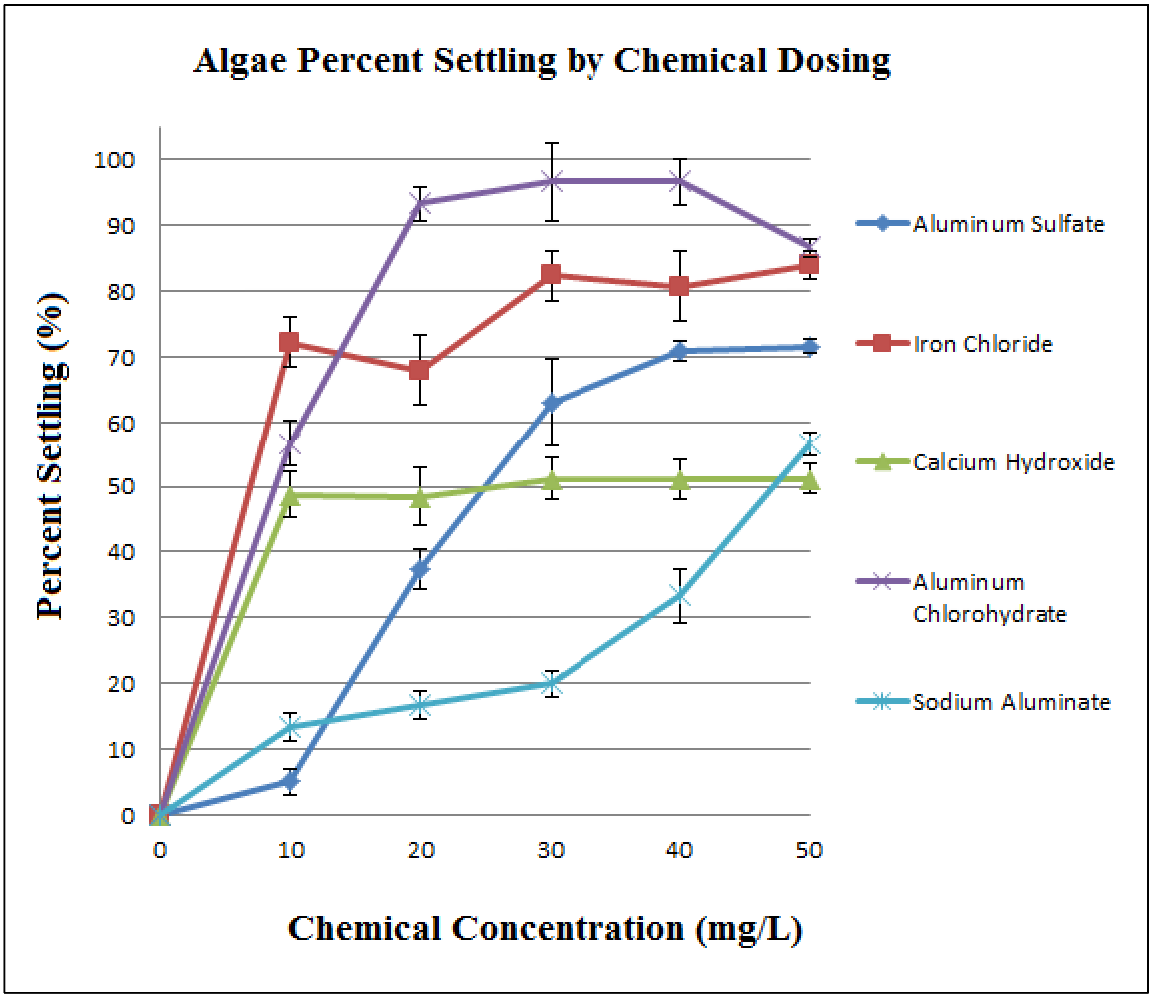

Figure 16. Algae percent settling by chemical dosing conducted in triplicates. Error bars represent one standard deviation.

By means of chemical induced flocculation, the algae was able to develop a more neutral zeta potential or surface charge allowing it to form flocs and settle. Therefore, chemical induced flocculation proved to be effective in increasing the percent settling of algae.

Additionally, it was noted that regular pH levels occurring during the lifetime of the algae were high enough (pH of 8-11) for the formation of magnesium hydroxide or calcium phosphate precipitates on the surface of the algae. The differing levels of photosynthetic activity in the raceways caused an initial rise in pH, which triggered the precipitation of the negatively charged algae and consequently causing the algae to agglomerate and settle.

Future Work

Factors to Consider

Factors such as culture age, nutrient availability, and algae concentration are variables that can affect the amount to which algae settle as well as have an impact on the chemical concentrations needed to increase percent settling. Consequently further testing of these parameters is required. Additionally, after surface overflow rate, detention time and percent settling of suspended solids have been evaluated experimentally, other design parameters such as temperature, weir overflow rate and solids loading are also vital to consider in the scale-up procedure.

Temperature

Overall, as the water temperature increases, the settling rate of algae increases; as temperature decreases, so does the settling rate (Surface Water Quality Bureau, 2007).

Weir Overflow Rate

Weir overflow rate is the flow in gallons per day per linear foot of weir. Weirs are mounted at the clarifier outlet to provide a uniform collection and flow-on of settled water (Surface Water Quality Bureau, 2007). The length and width of the weir has to be designed for maximum flow rate based on optimum sedimentation conditions. In general, secondary clarifiers need lower weir overflow rates than primary clarifiers (Surface Water Quality Bureau, 2007).

Solids Loading

Solids loading indicate the amount of algae that can be removed daily by a clarifier for each square foot of clarifier surface area (Surface Water Quality Bureau, 2007). It is crucial not to exceed the design values or there will be an increase in algae in the effluent. Similarly it is highly essential, for zone and compression type settling specifically, that the effects of solids flux on settling efficiency be considered (Water Environment Federation, 2005).

Conclusions

The successful design of a secondary clarifier for the Logan Lagoons would produce clean treated water that meets new phosphorous limits, and is an energy efficient, low cost method for harvesting algae feedstock for biofuel production.

The settling characteristics of flocculent algae in wastewater were the main focus for the clarifier design in this project. Preliminary results using sedimentation columns revealed that a large fraction of algae can be removed by means of sedimentation prior to chemical dosing. A suspended settling efficiency of 40%-60% with a detention time of 2-2.8 hours was attained and a surface overflow rate between 51-69 ft/day was calculated. Likewise, results demonstrated percent settling can be increased by the addition of chemicals. Aluminum chlorohydrate and iron chloride settled the highest percent of algae, with percent settling between 83%-87%. It was also noted that chemical induced flocculation and a high pH of 8-11 influenced a more neutral zeta potential, allowing algae to flocculate and increase algae settling even further. Others factors such as culture age, nutrient availability, and algae concentration can affect the algae percent settling and consequently, testing of these parameters is needed.

Lastly, for a complete scale-up procedure, other design parameters such as temperature, weir overflow rate and solids loading are also vital to consider in the scale-up procedure of the secondary clarifier.

5. References

Anthony, R. J. (2013). Cationic Starch Synthesis, Development, and Evaluation for Harvesting Microalgae for Wastewater Treatment. *All Graduate Theses and Dissertations*. Retrieved from http://digitalcommons.usu.edu/etd/2005

Cannon, K. (2013, June 29). So long lagoons? New Logan wastewater plant seems inevitable despite hefty price tag. *HJnews*. Retrieved from http://news.hjnews.com

CH2M HILL. (2010). *UDWQ POTW Nutrient Removal Cost Impact Study: Analysis of City of Logan's Wastewater Lagoon Facility* [Technical Memorandum].Logan Wastewater Treatment Plant.

City of Logan. (2013). *Wastewater Treatment Master Plan Update* (8621A00). Carollo Engineers…Working Wanders With Water. Retrieved from http://www.loganutah.org/Environmental/Waste%20Water%20Treatment/pdf/Logan%20City%20Wastewater%20Treatment%20Master%20Plan.pdf

Danquah, M. K., Gladman, B., Moheimani, N., & Forde, G. M. (2009). Microalgal growth characteristics and subsequent influence on dewatering efficiency. *Chemical Engineering Journal*, *151*(1–3), 73–78. doi:10.1016/j.cej.2009.01.047

Elder, A. (2011). Optimization of Dissolved Air Flotation for Algal Harvesting at the Logan, Utah Wastewater Treatment Plant. *All Graduate Theses and Dissertations*. Retrieved from http://digitalcommons.usu.edu/etd/1072

Engelhardt, T. L. (2013). Coagulation, Flocculation and Clarification of Drinking Water. In G. V. Bommel, *Coagulation, Flocculation and Clarification in waste water treatment.* [Pdf]. Retrieved from http://www.scribd.com/doc/183514649/Coagulation-Flocculation-and-Clarification-pdf#scribd

Fair, G.M., Geyer, J.C., & Okum, D.A. (1968). *Water and Wastewater Engineering 2*(1), New York: Wiley

Griffiths, E. (2009). Removal and Utilization of Wastewater Nutrients for Algae Biomass and Biofuels. *All Graduate Theses and Dissertations*. Retrieved from http://digitalcommons.usu.edu/etd/631

Henderson, R. K., Parsons, S. A., & Jefferson, B. (2008). Successful Removal of Algae through the Control of Zeta Potential. *Separation Science and Technology*, *43*(7), 1653–1666. doi:10.1080/01496390801973771

Henderson, R.K, Parsons, S. A., & Jefferson, B. (2008). The impact of algal properties and pre-oxidation on solid–liquid separation of algae. *Water Research*, *42*(8–9), 1827–1845. doi:10.1016/j.watres.2007.11.039

Khoshnevisan, K., & Barkhi, M. (2001). Information about Zeta Potential. *Institute of Agricultural Biotechnology*. Nano Department, Karaj, Tehran, Iran.

Mata T. M., Martins A. A., & Caetano N. S. (2010). Microalgae for biodiesel production and other applications: A review. *Renewable and Sustainable Energy Reviews, 14(1),* 217-232. http://dx.doi.org/10.1016/j.rser.2009.07.020.

Moheimani, N., McHenry, M., De Boer, K., & Bahri, P. (2015). *Biomass and biofuels from microalgae: Advances in engineering and biology*, (pp. 25-296). Springer International. Retrieved from http://books.google.com

Salim, S., Bosma, R., Vermuë, M. H., & Wijffels, R. H. (2011). Harvesting of microalgae by bio-flocculation. *Journal of Applied Phycology*, *23*(5), 849–855. http://doi.org/10.1007/s10811-010-9591-x

Secondary Clarifiers. (2008). Retrieved September 15, 2015, from http://www.simivalley.org/index.aspx?page=375

Sérodes, J. B., Walsh, E., Goulet, O., Noue, J. de là, & Lescelleur, C. (1991). Tertiary treatment of municipal wastewater using bioflocculating micro-algae. *Canadian Journal of Civil Engineering*, *18*(6), 940–944. doi:10.1139/l91-116

Smith, B. T., & Davis, R.H. (2012). Sedimentation of Algae Flocculated Using Naturally-Available, Magnesium-Based Flocculants. *Algal Research*, *12*(2), 1-8. doi:10.1016/j.algal.2011.12.002

Surface Water Quality Bureau. (2007). *New Mexico Wastewater Systems Operator Certification Study Manual - Chapter 6, Sedimentation.* Retrieved from https://www.env.nm.gov/swqb/FOT/WastewaterStudyManual/06.pdf

Tchobanoglous, G., Burton, F. L., Stensel, H. D., & Eddy, M. &. (2003). *Wastewater engineering: treatment and reuse*. McGraw-Hill.

Team Sludge HQ. (2003). Retrieved September 15, 2015, from http://www.calvin.edu/academic/engineering/senior-design/SeniorDesign03-04/Team17/st.html

Uduman, N., Qi, Y., Danquah, M. K., Forde, G. M., & Hoadley, A. (2010). Dewatering of microalgal cultures: A major bottleneck to algae-based fuels. *Journal of Renewable and Sustainable Energy*, *2*(1), 012701–012701–15. doi:doi:10.1063/1.3294480

Vatansever, A. (2005). *Bioflocculation of Activated Sludge in Relation to Calcium Ion Concentration* (Master’s thesis). Retrieved from https://etd.lib.metu.edu.tr/upload/12606304/index.pdf

Water Environment Federation. (2005). *Clarifier Design: WEF Manual of Practice No. FD-8* (Second ed.). McGraw-Hill Professional.

Appendix 1

Procedure needed to estimate SOR, detention time or basin depth, and percent settling of suspended solids (Water Environment Federation, 2005).

1. Use a batch settling column equal to the proposed clarifier depth and 120 mm by 200 mm in diameter, with sampling ports at equal intervals (Figure 10).
2. Determine the initial suspended solids concentration of the suspension.
3. Mix the suspension thoroughly and transfer into the column quickly to ensure a uniform mixture. Care should be taken to avoid shearing of particles.
4. The procedure should be carried out under quiescent conditions and the temperature within the column should not vary by more than 1 ^{o}C.
5. Samples are collected from each port at selected intervals. The total time that samples are collected should be at least equal to the detention time of the clarifier.

6. The percent settling of total suspended solids is computed for each sample by using:

$$R\% = 1 - \frac{C_t}{C_0}(100\%)$$ (Equation obtained from Fair et al., 1968)

Where

R% = percent settling at one depth and time, %

C_t = Concentration at time, t, and given depth, mg/L

C_0 = Initial concentration, mg/L

7. Percent settling values are plotted as numbers on a set of coordinate axes labeled tank depth (H) on the ordinate and sampling time (t) on the abscissa (Figure 11).
8. Curves of equal percent settling (isoconcentration curves) are drawn through the points, interpolating where necessary.
9. A series of detention times are selected. The percent settling and surface overflow rate (SOR) corresponding to each detention time are computed according to

$$SOR = V_c = H/t$$

Where

H = the settling column height (m);

t = the detention time selected (min), and

V_c = settling velocity (m/min).

And percent settling is defined as

$$R = \sum(\Delta h/H)\{(R_n+R_{n+1})/2\}$$

Where

R = overall settling (%),

Δh = distance between adjacent isoconcentration curves (m), H = total height of settling column (m), and

R_n and R_{n+1} = isoconcentration curve numbers n and n+1

10. Plot computed SOR versus percent settling. Knowing SOR, percent settling can be obtained from the graph.
11. Adjust the SOR by appropriate scale-up factors. The EPA suggests that the prototype SOR be adjusted as follows:

$$\text{SOR} = \text{Laboratory value} \div \text{Scaleup factor (1.25 to 1.75).}$$