MCGILL UNIVERSITY – DEPARTMENT OF BIORESOURCE ENGINEERING

SENIOR DESIGN BREE 495 – FINAL REPORT

COAGULATION-FLOCCULATION SYSTEM FOR THE TREATMENT OF CHEESE PRODUCTION WASTEWATER

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Executive Summary

We worked with Saputo, a large dairy product company, to find the optimal treatment solution for one of their wastewater streams. To achieve this goal, a primary treatment system of coagulation and flocculation was chosen for the removal of fat, oil and grease (FOG). Aluminum sulfate was selected as the coagulant because of its favourable characteristics, with regards to cost, efficiency, and methods of disposal. The system was then designed with considerations of space and budget constraints, as well as additional pollutant removal. The design consists of a balancing tank to address the issue of a batch inflow, a pipe system for the addition of the coagulant, another pipe system to drive the flocculation, and finally a settling tank for the removal of the sludge through gravity sedimentation. Due to the lack of comprehensive software available to run simulations of the system, Matlab and Excel were used in conjunction to model the component dimensions and pollutant removal efficiencies. Through a cost analysis, the payback period was determined to be between four to seven years, with the variation being dependent on the exact savings from reduced municipal sewage fees for the pollutant levels end-stage wastewater.

Acknowledgements

We would like to express our gratitude to our professor, Dr. Grant Clark, whose expertise, understanding, and patience, added very valuable suggestions to our design. We appreciate him lending us his vast knowledge, skills and comments in guiding us through this final year design project.

A very special thanks goes out to George Znoj, manager of sustainability project in Saputo. Without his help, support and kindness, we wouldn't get information and direction to finish this wastewater treatment project. His professional guidance in this field added considerably to our project management experience.

Finally, we would like to thank Dr. Zhiming Qi from the Department of Bioresource Engineering for taking time out from his busy schedule to discuss the project with us, and provided assistance and suggestions in details when we first came up with the design concept.

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1. Introduction

One of the most important lessons for engineering students to learn is that client's needs can change throughout a project, and that engineers must be flexible with design process to adapt to those changes. In this case, municipal decisions on wastewater bylaw revisions led to our design goals being changed entirely. We worked with a large dairy product company, Saputo, to design a biological secondary treatment system for one of their wastewater streams. In BREE 490, our client's focus was on the removal of Total Kjeldahl Nitrogen (TKN) because their wastewater contained TKN levels far exceeding municipal limits, and thus requiring them to pay fines. However, shortly following the completion of the Fall semester, the city informed Saputo that they were revising the bylaws with regards to TKN and would not be enforcing fines for foreseeable future as the revisions were done. As a result, TKN removal was no longer a priority for Saputo and at the beginning of the Winter semester we instead charged with designing a primary treatment system that removed fat, oil, and grease (FOG). This required us to put aside the biological system we had originally proposed and design a system that fit with these new constraints and goals. A system using coagulation and flocculation was selected as the ideal system to design because of its high FOG removal rates, as well as strong removal rates for a broad array of other wastewater pollutants.

2. Key Parameters & Specifications

A number of the constraints and parameters presented in the Fall semester are still relevant to our design and inform the decisions made about the coagulation/flocculation system. Many of them are related to the ongoing operational costs of the system. Electricity, labour, and replacement and maintenance of the parts are all still necessary considerations for assessing the long-term financial benefits. An additional ongoing cost relevant to the new technology being used is the material costs for the coagulant agent being used, though it is a very small cost for an industrial-scale operation.

Two of the major constraints outlined by Saputo in the Fall semester, the budget and space restrictions, both changed as we moved forwards into the Winter semester. With regards to the budget, because our focus shifted to a different and smaller wastewater stream, the maximum allowable initial cost of $750,000 was no longer relevant. Instead, the aim was to be well under $100,000 and achieve a short payback period. The space available for our system was also reduced. Previously we had a 10 m by 10 m area with a high roof, along with a storage tank that was going to be installed outside of the plant. However, because we switched focus on which wastewater stream we were dealing with, the external storage tank was no longer available to incorporate into our design. As a result, a small storage tank needed to be included in our design and be located within the allotted space.

With regards to the removal of pollutants in the wastewater stream, there was a significant change in which pollutant was considered the priority for removal. Previously technologies were proposed to achieve the highest-possible removal rates of TKN. However, it was changed to FOG being the most critical for high removal efficiency. Despite that, the removal of TKN was still desired to address potential future regulations, as was the removal of phosphorous, chemical oxygen demand (COD), and suspended solids because municipal regulations and fines are still applied to them. So while FOG was given the highest priority, the coagulation/flocculation system was still designed for effective removal of the broad spectrum of pollutant. The pollutant levels in the wastewater stream are shown in table 1 below. For the design, we have assumed the constant temperate of the wastewater of 40°C, based on stream characteristic data provided by Saputo. For the FOG removal, our goal was to achieve the acceptable levels set by the city, which is 0.15 g L^{-1}.

Table 1. Stream characteristics of the wastewater stream being treated.

Volume (L/day)	Total Suspended Solids (TSS) (kg)	Chemical Oxygen Demand (COD) (kg)	Phosphorus (kg)	Fat (kg)	pH
12 553	31	775	7	29	7

Finally, to determine the appropriate sizing of each component in the system, the necessary residence times for each stage determined the necessary volumetric capacity. Additionally, because successful coagulation and flocculation are dependent on proper mixing rates, the ideal turbulence was critically important for the designing of the tube systems. The required coagulant dosage and produced sludge were both dependent upon the characteristics of the wastewater stream. Lastly, with dairy processing, pollutant concentrations in wastewater streams are often quite variable (Rivas et al., 2010). By designing a balancing tank to stored the incoming wastewater for several hours, fluctuations in the pollutant concentrations should be reduced. However, because the system was a physical/chemical one, rather than a biological one, there was less sensitivity to concentration fluctuations so there was reduced concern over diminished efficiencies.

3. Literature Review

Coagulation and flocculation are a two-stage process of wastewater treatment, involving chemical and physical processes to remove fine matter present in the wastewater. Coagulation is a method of water treatment where some chemical agent is added to cause tiny suspended and colloidal particles to come together and form larger particles (Al-Najar, 2010). Colloidal matter are those that are between 1 nm and 1 µm, and these are the particles that are being primarily targeted in coagulation (Al-Najar, 2010). The suspended particles are charged, which is what prevents them from combining and precipitating out. By adding salts that easily dissolve into the wastewater, the ions are able to neutralize the particles charges and destabilize them, as is shown in figure 1. Iron or aluminum salts are most commonly used as coagulant agents because of their large ion charges which facilitate the destabilization (Crittenden et al., 2012). Once this destabilization occurs, which requires an incredibly short residence time to be completed, the destabilized particles begin to clump together and form slightly larger suspended matter (Somasundaran et al., 2005).

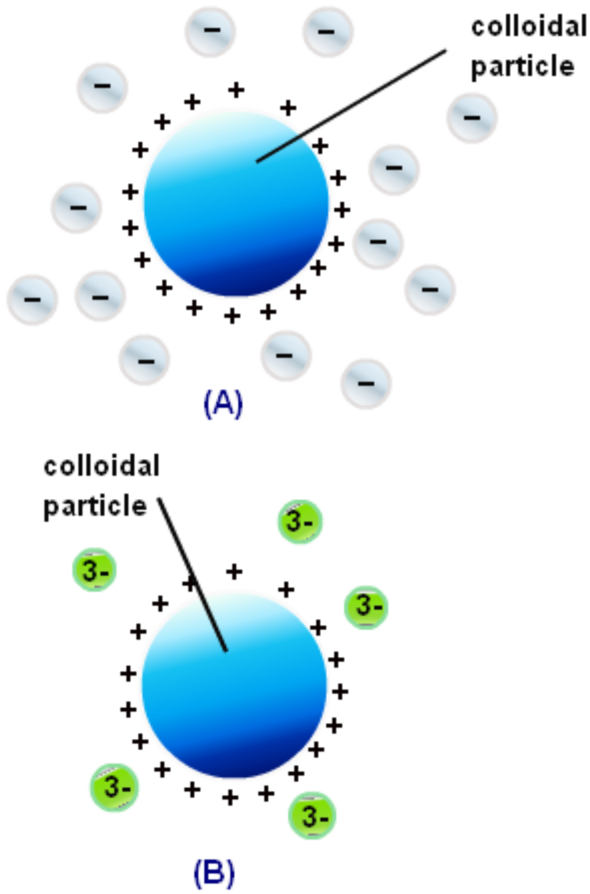

Figure 1. Depiction of interaction between suspended or colloidal particle and coagulant agent ions, resulting in the destabilization of the particles. Source: www.earthkart2011.blogspot.ca.

Coagulation is then followed by flocculation, whereby the particles brought together through coagulation are gently mixed together, resulting in them forming even larger particles called flocs (Al-Najar, 2010). Flocculation takes much longer than coagulation because it depends on the wastewater being mixed for a period of time. The mixing intensity of the wastewater is very important for the efficiency of the flocculation process (Crittenden et al., 2012). If the mixing is too gentle, then the destabilized particles will not experience the necessary collisions that cause them to form the larger flocs. However, if the mixing is too rigorous, the flocs formed will be subjected to shear forces that result in them be broken apart. There is therefore an ideal mixing intensity for the wastewater to be subjected to in order to maximize the flocculation efficiency, and that intensity depends on the specific characteristics of the wastewater and the coagulant dosage applied. Once the wastewater has experienced sufficient mixing, the flocs that have formed are large enough to be removable via gravity sedimentation (Somasundaran et al., 2005).

Figure 2 shows the stages of flocculation, with the destabilized particles being mixed to form aggregates that are then settled and removed from the wastewater. Additionally, a flocculant aid, typically an organic polymer, can also be added to further promote the formation of flocs, though it is often neglected as the mixing alone tends to be highly effective (Crittenden et al., 2012).

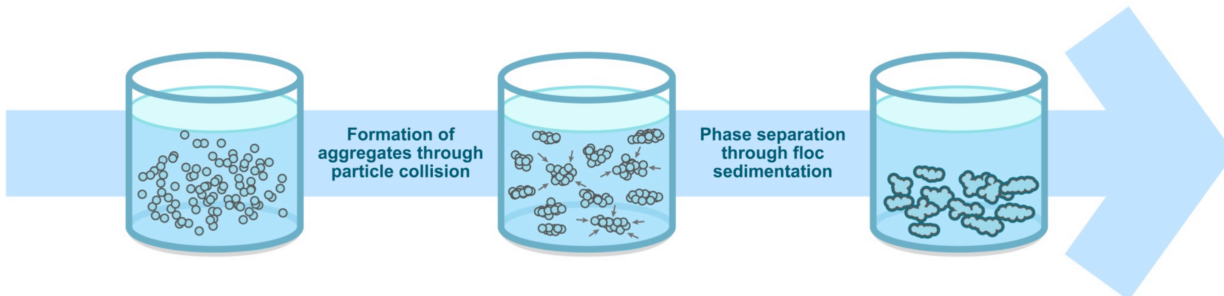

Figure 2. Flowchart showing the stages of flocculation and sedimentation, starting with destabilized particles being subjected to movement, aggregated flocs being formed, and then the settling of the flocs. Source: www.feralco.com.

4. Analysis

4.1 Design Overview

The final design consists of four main components: a balancing tank, coagulation tube, flocculation tube and a settling tank—in a system that makes use of hydraulic mixing in pipes due to the simplicity and costs effectiveness of the technology. The balancing tank was required to handle the incoming of inconsistent batch flow. The coagulation tube is characterized by a sudden pipe expansion for rapid turbulent mixing between the wastewater and coagulant chemical, aluminum sulphate. The flocculation tube is characterized by a smother mixing in a longer pipe section and finally the settling tank allows for the sedimentation to accumulate and be removed. An overview of the system is shown in figure 3 below. Each component of the system is presented more in depth in the following sections.

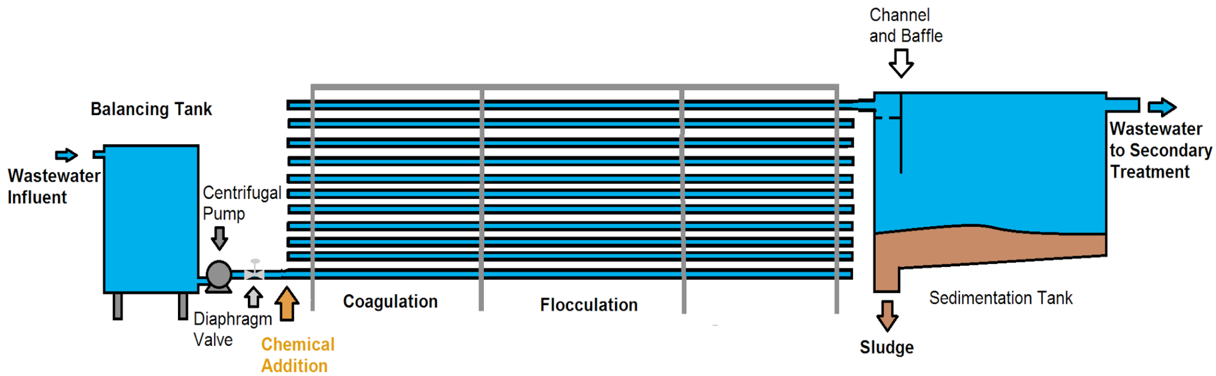

Figure 3. 2-dimensional side view of full system, with wastewater moving from left to right though the balancing tank, centrifugal pump, coagulation tube, flocculation tube, sedimentation tank, and finally separated from the sludge and removed.

4.2 Balancing Tank

The first component of the system is the balancing tank. As the system operates on continuous flow, a balancing tank is required to render the batch input flow into a continuous outflow. In sizing of the tank the key parameter was the variation in batch input which varies from batch to batch and day to day as a result of production fluctuation. Overall there is a range of 25 to 50 L, inputted every 20 minutes from six different sources, and approximately 12,500 L day^{-1} total. Another important parameter used to determine the size of the balancing tank is the desired outflow rate. This was derived from the desired velocity and diameter sizing within the flocculation pipe. It was required to have turbulent conditions for mixing in the flocculation pipe while ensuring the pipe diameter was large enough to reduce pipe length and cost. With these parameters, it was established that an outflow rate of 11.56 L min^{-1} was required (refer to the flocculation pipe section for more details on this).

An excel spreadsheet was used to test the operation of the system based on the ideal outflow rate, and determined the appropriate size of the balancing tank. Trials were run with different inflow batch rates, ranging from 25 to 50 L at 20-minute intervals for 20 hours. The outflow rate was kept constant at 11.56 L min^{-1} and drawing water continuously from the tank. Because the outflow was greater than the average inflows, trials ran with the assumption that the tank would fill up for several hours before the system would start operating. We set the goals that once water started being drawn from the balancing tank, the system would run continuously until the end of the 20-hour production day, and that the emptying of the balancing tank would coincide with that 20-hour mark. These two conditions allowed us to run the experiments and produce the results shown in table 2. The maximum capacity is the peak volume of wastewater that needs to be stored before water starts being drawn from it.

Table 2. Results of balancing tank trials for output flow of 11.56 L min^{-1}, over full range of possible inflow values, showing the maximum volume of wastewater the tank must hold as well as the total daily operational time.

	Input 20-minute Batch Flow (L)		
	25	**37.5**	**50**
Peak Volume (L)	3100	3600	3400
Operation time (h)	13	10	7

Running these two dependent parameters against each other in a spreadsheet gave the ideal final tank size of 3.6 m^3 with an operation time varying from 7 to 13 hours, depending on the varying volume from operation. The tank has a height of 2 m and inside radius of 0.76 m (with a tank wall thickness of 0.012 m). The tank size and operating conditions would ensure the tank never runs dry and never overflows under the specified inflow and outflow conditions. The tank is elevated 0.5 m off the ground by a metal frame consisting of four legs, each of radius 0.05 m, for safety reasons and to allow for maintenance, as shown in figure 4 (Design Tanks, n.d.).

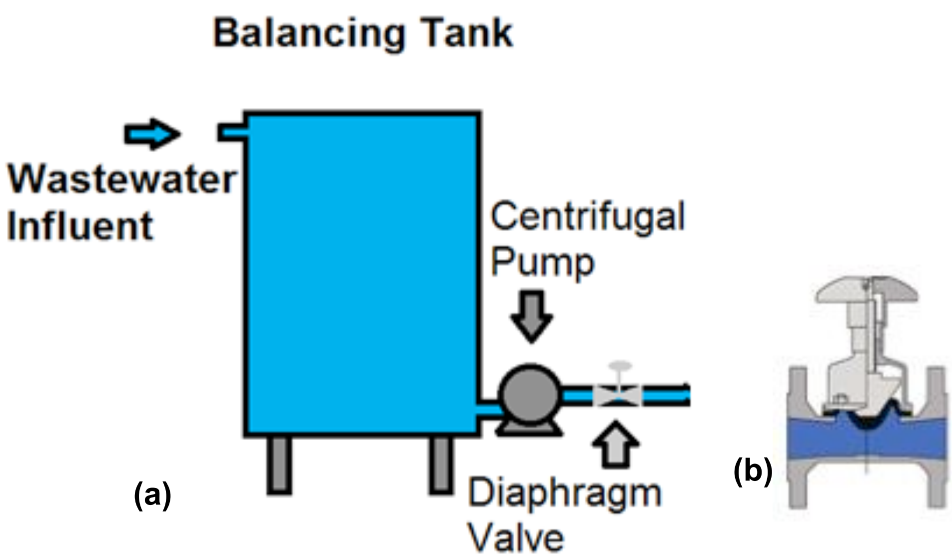

Figure 4. (a) Closer view of balancing tank, along with centrifugal pump and diaphragm value. (b) Detailed picture of the diaphragm valve while open.

At the bottom-side of the tank is the pipe leading to the coagulation section. A centrifugal pump is placed here to counter the head loss in the system, as centrifugal pumps are commonly used in the food industry (IHS GlobalSpec, 2014). In this system the pump is required to overcome a calculated head loss of 1.62 m. Following the pump is a diaphragm valve used to ensure the desired flow rate in the system. This is also important to ensure a constant flow of wastewater and consequentially adequate concentration of aluminum sulphate.

4.3 Coagulant Agent

In wastewater treatment, COD are general indicators of chemical and biological pollution. In our project, oil, fat and grease are mainly contained in cheese wastewater besides COD and biological oxygen demand (BOD). They all can be reduced through coagulation and flocculation. Coagulant chemicals has to be applied during coagulation process. There are two main types of coagulant chemicals, which are primary coagulants and flocculant aids (Ghaly et al., 2006). Coagulants are always used in the coagulation/flocculation process, though flocculant aids are not necessary and are generally only used if necessary to achieve higher removal rates (Ghaly et al., 2006). In order to achieve a more cost-effective solution, the system was designed using only a coagulant, though the design can be easily adapted to incorporate the addition of a flocculant aid.

To remove fat, oil, and grease in wastewater treatment, there are many different coagulant chemicals that can be chosen. They are usually metallic salts, and typically either aluminum sulfate, ferric chloride, or ferrous sulfate (Baskan et al., 2009). In our wastewater treatment system, we chose aluminum sulfate, $Al_2(SO4)_3$, as the coagulant chemical due its better performance with regards to efficiency and cost. Table 3 shows that with same chemical concentration at 2 g L^{-1}, aluminum sulfate has the highest average removal efficiency of 90% and the ideal pH value of aluminum sulfate ranges from 5 and 7.5 which is closest to pH value of our system. Ferric chloride is effective down to pH 4.5, and ferrous sulfate, effective only above pH 9.5, are also sometimes used. In the low initial arsenate concentrations, aluminum sulfate provides the highest arsenate removal efficiency. aluminum sulfate is also available in solid form, and it reacts with alkalinity in water to form aluminum hydroxide, which is a white precipitate and settles readily (Baskan et al., 2009).

Table 3. Comparative solids removal efficiencies for aluminum sulfate, ferrous sulfate, and ferric chloride at different chemical dosages. Source: Ghaly et al., 2006.

Chemical concentration (g/L)	Aluminum sulfate		Ferrous sulfate		Ferric chloride	
	Final total solids (mg/L)	Reduction (%)	Final total solids (mg/L)	Reduction (%)	Final total solids (mg/L)	Reduction (%)
1.0	3385	85.1	16450	27.8	2548	88.8
1.5	2650	88.4	20138	11.6	3878	83.0
2.0	2358	89.7	18875	17.1	6800	70.1
2.5	2613	88.5	20475	10.1	7933	65.2
3.0	3088	86.4	20413	10.4	8578	62.2

The FOG removal efficiency for aluminum sulfate increases steadily with increased dosage and achieves higher rates than ferric chloride or ferrous sulfate, as shown in figure 5. The presented graphs demonstrate the efficiency of the three coagulants through comparisons of their final transmittance of the treated wastewater. The initial average transmittance of these wastewater samples is 48%, with a minimum value of 42%, and a maximum value of 50% (Karamany, 2010). Figure 5(a) present the transmittance for the samples treated with aluminum sulfate. As shown, the transmittance increases in a very stable status compared with figure 5(b) and 5(c). It shows the best transmittance is 96% at concentration of 250 ppm. From figure 5, we can also see ferric chloride and ferrous sulfate also have their maximum transmittance point, but they are very unstable. As concentration increases, it is hard to control the result to reach the highest removal efficiency (Karamany, 2010). This is another factor that supported our choice of aluminum sulfate as our coagulant chemical.

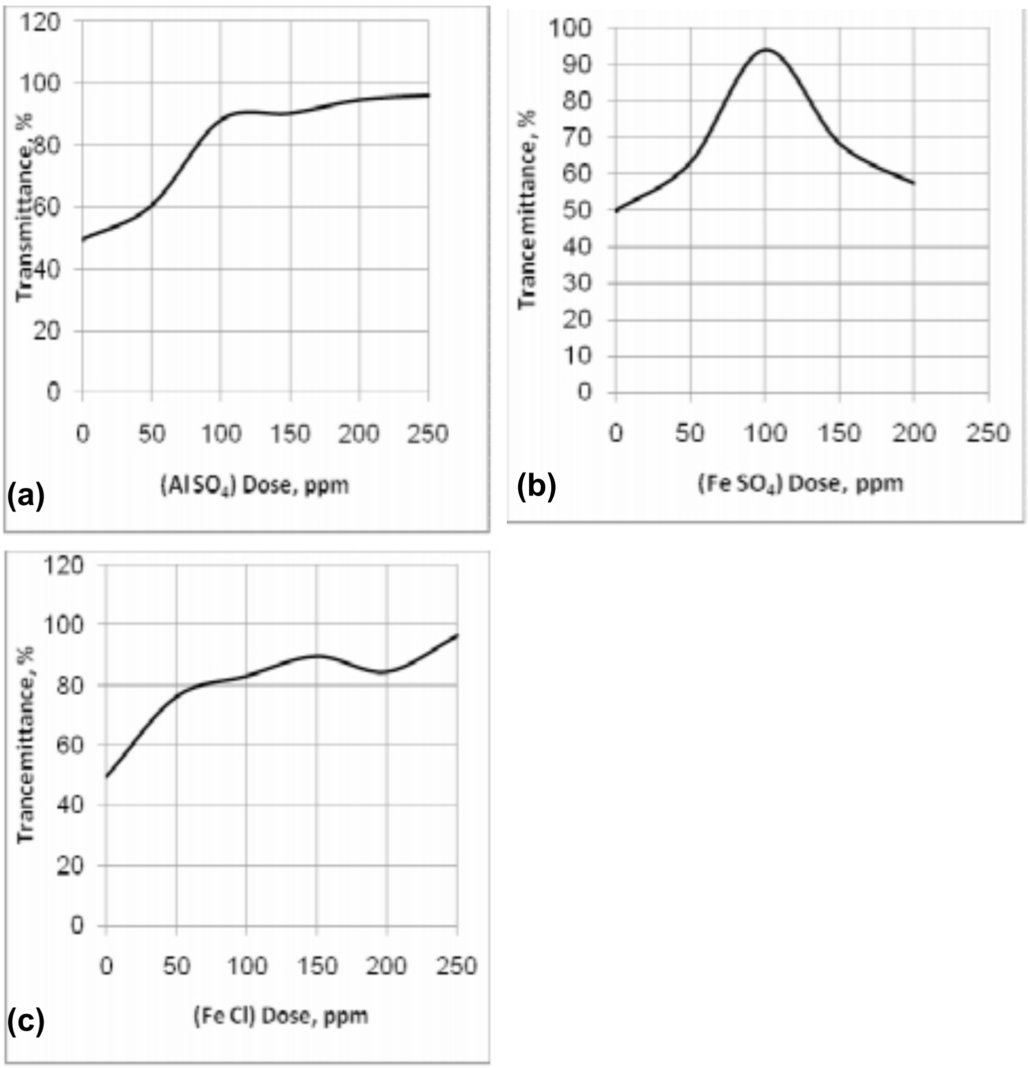

Figure 5. Transmittance efficiencies at varying dosages for coagulants (a) aluminum sulfate, (b) ferrous sulfate, and (c) ferric chloride. Source: Karamany, 2010.

4.4 Coagulation Tube

The coagulant pipe section of the design requires sudden rapid mixing to allow the aluminum sulphate to bond particles in the wastewater together and for it to be evenly distributed within the fluid. The pipe is designed to have a sudden expansion following the addition of the coagulant, which creates eddies in the corner of the larger pipe and establishes an area of rapid turbulent mixing (Crittenden et al., 2012). The set-up of this section is shown in figure 6. Regarding turbulent flow in pipes, values of Reynolds number above 4000 are generally considered turbulent (Engineering Toolbox, n.d.). Reynolds number is calculated as:

$$Re = \frac{ud_h}{v}$$

where:

$u =$ cross-sectional velocity (m/s)

$d_h =$ hydraulic diameter (m)

$v =$ kinematic viscosity (m^2/s)

It was necessary to estimate a value of kinematic viscosity for the wastewater stream. We did this by taking an adjusted value for milk at 40°C (estimate stream temperature) and the value of water at the same temperature and then averaging the two (given our stream is by product of cheese production). We assumed the rate of decrease in kinematic viscosity with regards to increasing temperature in milk would be a rate similar to that of water. While the change may be less drastic, we can assume that in reality our stream is closer to water than milk in nature which makes up for the possible error in this assumption.

$$v_{stream} = \frac{v_{milk,adjusted}(@40°C) + v_{water}(@40°C)}{2}$$

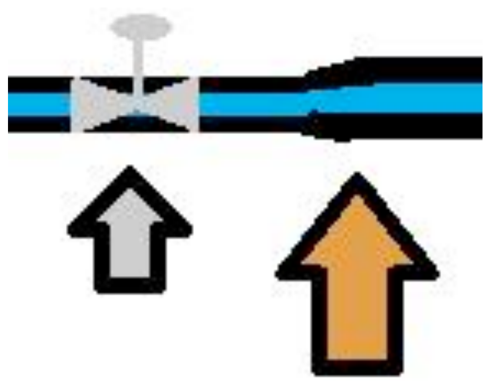

Figure 6. Simple depiction of change in pipe diameter at entrance of coagulation tube.

In both the coagulation and flocculation pipe flow conditions are considered turbulent by Reynolds numbers of 6790 and 4050 respective. It is thus clear that within the sudden expansion the conditions would be magnified and rapid mixing would occur, to ensure this would work would require building a prototype of this component. Given the desired parameters for the flocculation section and using a recommendation value ratio of 5:8 for the sudden expansion (Amirtharajah et al., 1991), the resulting pipe sizes are a 3/4" nominal pipe diameter leading into a 1 1/4” (with slight rounding for pipe convention). Velocity in the coagulation pipe given the outflow rate of 11.56 L min^{-1} and the pipe diameter is 0.56 m s^{-1}, we know this from the relationship:

$$Q = \frac{V}{A}$$

where:

$Q =$ flow rate $\left(m^3/s\right)$

$A =$ area $\left(m^2\right)$

$V =$ velocity $\left(m/s\right)$

The aluminum sulphate chemical addition must be added briefly before the sudden expansion to ensure the even distribution. The addition of coagulant 0.1 s prior to the sudden expansion is recommended (Amirtharajah et al., 1991). This resulted in the chemical addition being located 0.056 m prior to the sudden expansion. In terms of coagulant dosage, we proceeded with an estimated concentration required of 100 ppm = 99.89 mg L^{-1} based off a range estimation of 75 to 250 ppm (Al-Najar, 2010). This results in coagulant continuous outflow rate of 5.6×10^{-5} kg s^{-1}, obtained by taking the dosage and multiplying it by the wastewater velocity. Depending on daily operation time, total daily requirement will vary between 1.41 kg and 2.62 kg. A dispenser system would be required for the outflow of coagulant, in this system we would proceed with a simple nozzle for injection given the small size of our pipe system and the outflow rate of coagulant, a simple image can be seen in figure 7. Following the sudden expansion is the start of the flocculation pipe.

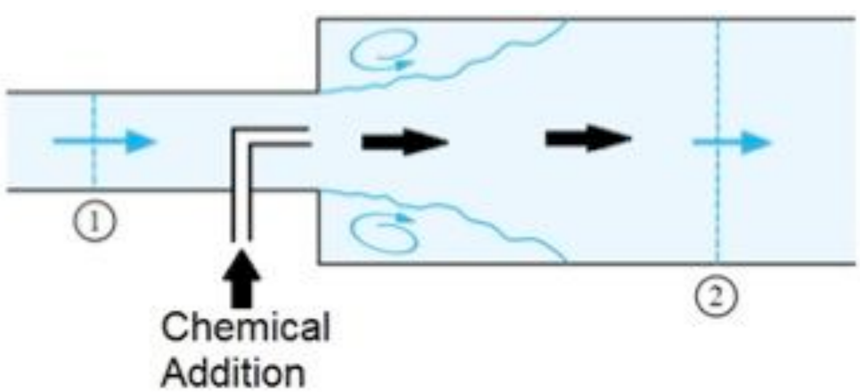

Figure 7. Detailed schematic of addition of coagulation and entrance into the coagulation tube, showing the increased turbulence from the sudden expansion that causes hydraulic mixing.

4.5 Flocculation Tube

The flocculation pipe is a location of less intense mixing as compared to the coagulation pipe, it also has a much longer duration. The mixing in the flocculation pipe occurs due to pipe friction as well as turns in the system. Water is mixed for a recommended 400 s (Gregory, 1981), at a velocity of 0.2 m s^{-1} in a pipe 1 1/4" nominal radius. The required pipe length is thus 80 m. The Reynolds number within this pipe section is slightly above 4000, which is desirable for adequate mixing though not too high to break flocs that are forming. The final structure consists of a total of twenty-two 90° turns and an elevation of 1.35 m (required to bring the wastewater to top of settling tank). This number of turns were selected as a balance between limiting head loss and the physical length of the system. The elevation and pipe turns along with pipe length were important as being the most critical contributors to head loss within the system (other minor components include the valve and sudden expansion). Figure 8 below shows the general overview of the pipe section, while the 3D drawings further on in the report provide more detail for a better representation.

Figure 8. 2-dimensional overview of the flocculation tube system, showing the pipes from the side, with the wastewater entering from the bottom left corner and exiting from the top right corner.

Having an understanding and profile of the head loss in the system is key to ensure proper operation. The length of the pipe consisted the major loss and is solved for by using the Darcey-Weisbach equation (Engineering Toolbox, n.d.), which is:

$$\Delta h = \lambda \left(\frac{l}{d_h} \right) \left(\frac{V^2}{2g} \right)$$

where:

$\Delta h =$ head loss (m)

$\lambda =$ friction coefficient $(-)$

$l =$ length of pipe (m)

g = acceleration of gravity $= 9.81 m/s^2$

The friction coefficient must be obtained by solving the Colebrook Equation (Engineering Toolbox, n.d.):

$$\frac{1}{\lambda_D^{1/2}} = -2\log\left[\frac{2.51}{\mathrm{Re}\,\lambda_D^{1/2}} + \frac{(k/d_h)}{3.72}\right]$$

where: $\lambda_D =$ Darcy-Wisbach friction coefficent $(-)$

$k =$ pipe surface roughness (m)

Given the values of the system and estimate kinematic value for the waste stream, the head loss due to pipe friction was found to be 0.1857 m.

Next we had to account for minor losses which were primarily found in the flocculation section (in bends) but also in the coagulation pipe for the valve and sudden expansion. The generic equation for minor head loss follows:

$$h_L = K_L \frac{V_1^2}{2g}$$

where: $h_L =$ head loss (m)

$K_L =$ coefficient of friction $(-)$

For our components, the values of K_L can be found to be (Engineering Toolbox, n.d.):

$$K_{bend} = 0.3$$
$$K_{valve} = 2.3$$
$$K_{expansion} = 0.3$$

The total minor head losses combined to 0.023 m which is very minor given the major loss and that due to elevation. The total combined head loss was found to be 1.6245 m.

4.6 Settling Tank

Following the flocculation pipe is the settling tank. Sedimentation is a physical water treatment process using gravity to remove suspended particles, which in our case is primarily fat, oil and grease (EPA, 2002). Sedimentation tanks are purposely built to remove suspended solids by sedimentation and are different from clarifiers. The main difference between clarifier and sedimentation tank is that clarifier uses mechanical mean to continuously remove suspended solid where sedimentation tank only use gravity (Nemerow, 2007). Settling basin are design to retain water while the solid particles settle. Our design is based on a continuous flow process which mean that the water is continuously feed inside the sedimentation tank. To ensure proper settling of the particles the settling basin is separated in four section: inlet zone, settling zone, sludge zone and outlet zone, which are shown in figure 9 (Asgharzadeh, 2011). The inlet zone is where the water comes into the sedimentation tank. To ensure that the water will not be disrupted into the settling and sludge zone, baffle can be added to reduce the velocity of the incoming wastewater. Sedimentation occurs at the settling zone as the water flow toward the outlet zone. The clarified water then flow in the outlet zone and is either going into the secondary treatment or the sewage system. The particles will settle from the settling zone to the sludge zone which is more efficient with very low current in the basin. The sludge is then collected by gravity at the bottom of the sedimentation tank to be further process (Nemerow, 2007). Since the chemical used in the coagulation and flocculation system is not harmful to the environment the sludge can then be dried and sold as fertilizer.

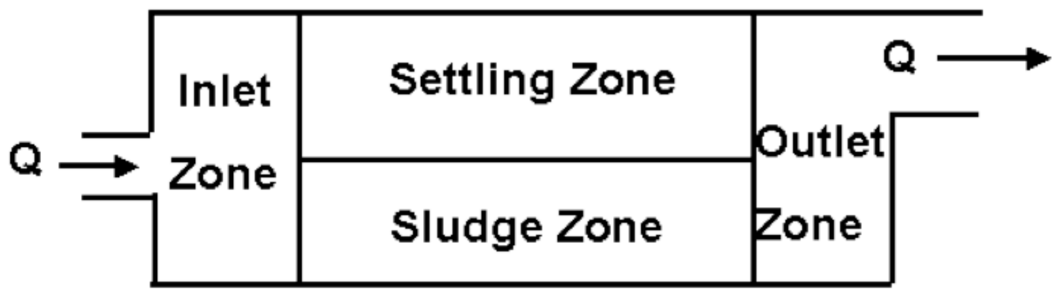

Figure 9. Schematic of the sedimentation tank with the four settling zones depicted. ***Source: http://upload.wikimedia.org/.***

The efficiency of the sedimentation basin is proportional to the efficiency of the preceding coagulation and flocculation process. It also depend on the flocs size, shape and density when they enter the basin. Flocs that are too small or too large, are irregularly shape or have a low density will not settle properly (Somasundaran et al., 2005). The flocs entering the sedimentation basin can disintegrate if the velocity is too high caused by a pump or a bend in the pipe. This is the main reason why our pump is at the beginning of the coagulation process since it is not desirable to disintegrate the flocs by putting the pump at the end of the flocculation system. In addition, the pipe of the flocculation system near the sedimentation tank is not bent to also prevent the disintegration of the flocs particles formed in the flocculation process. Another major cause of inefficiency of the sedimentation tank is short circuiting of the water which means the water bypasses the normal flow path and goes directly into the outlet of the tank (EPA, 2002). To prevent this situation baffles are installed at the end of the inlet zone. When the basin shot circuit the particles do not have enough time to settle properly which influences the efficiency, the economy of the plant and the quality of the treated wastewater. One major sign of short circuiting is when the sludge product is not even at the bottom of the basin. Adding dye in the water can determined the current flow path and help determined if short circuiting is occurring (Nemerow, 2007). Short circuiting can occur based on the shape and design of the sedimentation basin and the difference in temperature inside of the water. The difference in temperature will not be a major problem since our wastewater is first collected in a balancing tank and the water stays there long enough to cool down since our wastewater comes at around 40ºC and has an even temperature. However, cold water is not preferred since it prevents flocs from settling properly which mean longer settling time or a larger dose of coagulant (Asgharzadeh, 2011).

To design a rectangular sedimentation tank it needs to follow specification for efficient settling rate. The depth of the sedimentation basin should be between 2 to 5 m. The length needs to be four times the width of the basin (Industrial Waste Program, 2012). It needs to have baffles to reduce the incoming flow momentum. The slope at the bottom of the tank should be more than 1%. The detention time is usually between two to four hours (Industrial Waste Program, 2012). Since we have a continuous flow of 11.56 L/min and a detention time of four hours it gives a sedimentation tank volume of 2.8 m^3. The depth should be between 2 to 5 m, and for our design we chose to use 2 m. The width and the length were calculated from was it left of the volume of the tank which is 1.4 m^2. Since the length needs to be four time the width it gives a length of 2.4 m and a width of 0.6 m. A slope of 1% was chosen which gives an angle of 0.6º. It was decided to have the inlet water coming from the top of the sedimentation tank to not disturb the sludge production at the bottom of the tank. However the first time the sedimentation tank will need to fill up, causing the flocs particles in the wastewater to disintegrate from the height of the fall. To prevent this situation a channel or flume has been design, shown in figure 10. In addition, the channel or flume will also provide the baffle to slow the influent water velocity. This design allows the water to enter the basin by flowing through the evenly spaced holes at the bottom of the channel and then flow under the baffle situated at the end of the channel. The holes would be the same diameter as the flocculation pipes which is 1 1/4", so therefore there will be seven holes with 0.04 m spacing. The channel will be 0.1 m below the inlet water and 0.1 m wide. The baffle will be two thirds of the sedimentation tank's height which is equal to 1.3 m to allow better circulation of the incoming water. The fully designed sedimentation tank is shown in figure 11. The residence time chosen was four hours which is the longest residence time. It was chosen because it is alway better to reduce the cost of a design than increasing it. In addition, to efficiently optimize our system a jar test is needed to observe the size of the flocculation particles, the density and the time needed to settle properly. This will be further discussed in the optimization section of the report.

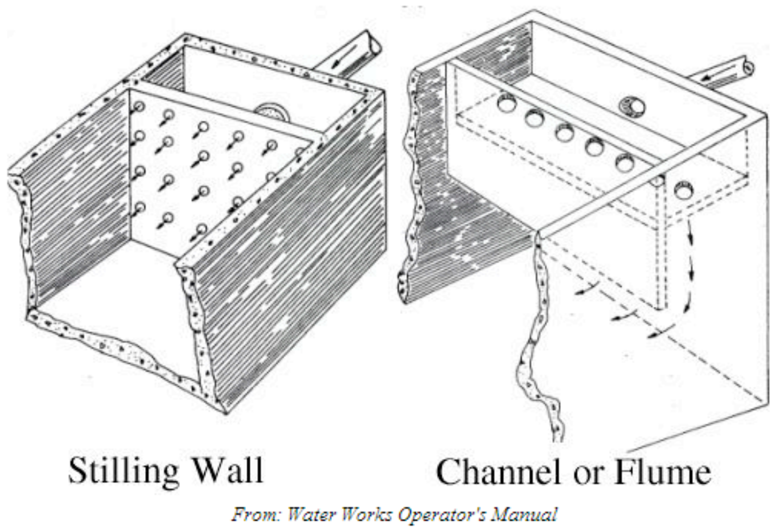

Figure 10. Representation of two different possible configurations for reducing the velocity of wastewater entering the sedimentation tank. The channel or flume, depicted on the right, was chosen for the system. Source: http://water.me.vccs.edu/concepts/sedzones.html.

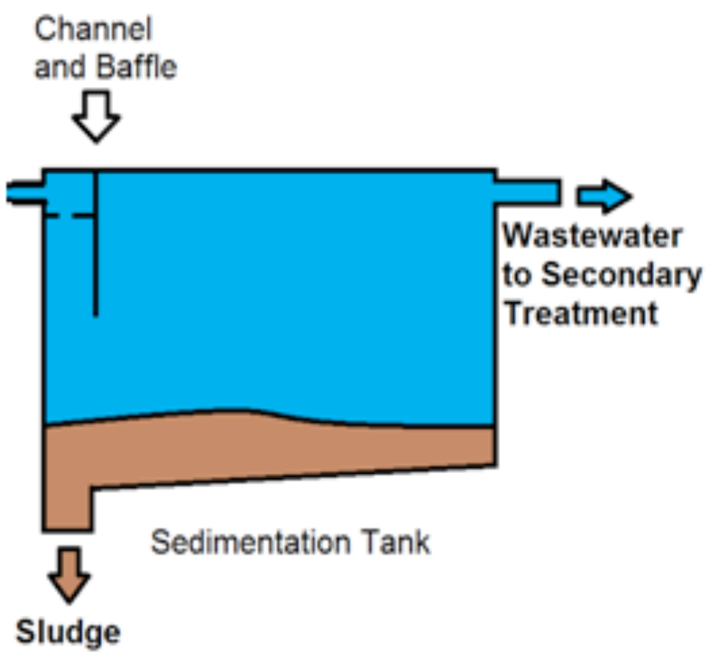

Figure 11. 2-dimensional representation of the sedimentation tank, showing the wastewater entering at the top left-hand corner from the flocculation tube, moving through the channel and baffle, and then settling in the tank for the sludge to be removed through the bottom with the treated wastewater is removed from the top right-hand corner.

5. Simulation

Our original plan for this semester was to model and optimize our design with the software Simulink. To do so, equations describing coagulation and flocculation processes were required. However, no modeling equations that reflected our design criteria (i.e. amount/rate of coagulant input, mixing rates, retention times, sludge produced and sizing of tanks) were found. Also, no modeling equations to depict the efficiency of the coagulation and flocculation system (i.e. removal rate of suspended particles as a function of time or coagulant input or mixing rate) were available in literature, only empirical results which differed from each experiment. Therefore, it was not possible for us to build a model and simulate the dynamic behavior of our design ourselves.

We then proceeded to find a software that would have such equations already built in it. We came across two prospective software, STOAT and OTTER, both made by the WRc group. The first one we tried, STOAT, turned out to have a 'chemically assisted sedimentation' component that would be of interest to us. However, we discovered that it consisted of a coagulation input stage accompanied with an upflow floc blanket clarification stage, which was not what we wanted to do. We then tried OTTER which had every component we needed to model a complete coagulation and flocculation process. The problem was that our input values for the raw water characteristics exceeded the allowed range. OTTER also did not include the evaluation of FOG as a pollutant to test. Through correspondence with the software developers to request help with these issues, they pointed us towards a third software called SimEau that they had just developed, and gave us full access keys to the software. We tried using this software too but we were limited in that it also could not account for FOG. Therefore, limited by time and resources available to us, we did not do a comprehensive simulation of our design.

Instead, anticipated removal rates were drawn from literature review (Rivas et al., 2010), and excel was used to test what the resulting pollutant removal and sludge production based on the case studies we drew from. The resulting efficiency ranges are presented below in table 4. The sludge removed from sedimentation tanks typically has a water content of 45% (Rivas et al., 2010). Based on this, the total daily sludge production was determined to be between 1280 and 1530 kg/day. These results suggest that the FOG levels in the wastewater can be reduced from 2.31 g L^{-1} to 0.46 g L^{-1}. This does not quite meet the municipal target of 0.15 g L^{-1}, though the incorporation of a flocculant aid may be sufficient for removing the rest of the necessary FOG. If a secondary treatment system is designed in the future, passing the treated wastewater through it would certainly lower the FOG concentration below 0.15 g L^{-1}.

Table 4. Daily pollutant production and removal rates, based on data provided by Saputo and literature review, including the minimum and maximum quantities of pollutants removed and the produced sludge.

	Mass (kg)	Min Removal (%)	Max Removal (%)	Min removal (kg)	Max removal (kg)
TSS	31.0	89	94	27.59	29.14
COD	775.0	65	78	503.75	604.5
Phosphorus	7.0	31	63	2.17	4.41
TKN	32.0	69	83	22.08	26.56
FOG	29.0	70	80	20.3	23.2
			Total removal (kg)	575.89	687.81
			Total sludge (kg)	1279.76	1528.47

Based on these ranges, we also used the municipal fee rates provided to us by Saputo to determine the potential savings from the reduced fines. This data is presented below in table 5. In sum, the potential savings range from $7,600 to $11,200.

Table 5. Estimates of minimum and maximum on a daily and annual basis, based on current municipal bylaws and fines.

	Fine ($/kg)	Daily Min ($)	Daily Max ($)	Annual Min ($)	Annual Max ($)
TSS	0.17	4.69	4.95	1463.37	1545.59
COD	0.022	11.08	13.30	3457.74	4149.29
Phosphorus	4.051	8.79	17.86	2742.69	5573.85
TKN	0	0	0	0	0
FOG	0	0	0	0	0
			Annual Total ($):	7663.80	11268.73

6. Testing

6.1 Failure Mode Considerations

In the field of wastewater treatment, extreme care must be taken to ensure that the whole system is operating properly, because a system failure can be catastrophic for human and environmental health. It then becomes important to identify and quantify potential risks or hazards associated with our chosen design. It is important to remember that our system is designed exclusively for Saputo's purpose to pre-treat their wastewater before it is discharged into municipal sewers. So, consequences associated with a poor removal of particles are significantly less than for municipal treatment plants because the effluent water is not meant for drinking purposes. Nevertheless, this event represents one of the most important failure modes of the system and it should be discussed.

In the event that particles are not removed properly from the raw water, several causes can be identified. The most common is an incorrect or inappropriate chemical feed rate due to a change in flow rates or raw water composition; water chemistry, temperature and pH can affect the performance of many coagulants (Somasundaran et al., 2005). Therefore, a sudden change in any of these factors may lead to overdosing or under-dosing of coagulants which in turns leads to a reduced solids removal efficiency. Automatic dosing control equipment able to respond quickly to a change in source water quality should be used to minimize its effects.

Another cause to an improper removal of particles is the hydraulics or an inadequate mixing at each stage. The coagulant must be added with rapid mixing and mixing must be slowed during flocculation to avoid breaking up the flocs. Since our design is based on hydraulic mixing rather than mechanical mixing, a complete review of the treatment plant hydraulics must be done in order to provide a solution to the failure. However, equipments such as flow control valve should also be inspected in the case of malfunction.

In addition, it can happen that chemical supplies are exhausted. To prevent this from happening, records of chemical use should be kept as a reference to the length of time the supply is likely to last. This way, a reserve supply adequate to cover the time before resupply will be maintained. If the shortage often comes from the chemical supply tank in use, an alarm on the tank to indicate when it is close to running out must be used.

Also, a situation of important power failure must be considered, in which case, a stand-by generator should be ready to operate for about 10 hours. Finally, in the case of a major equipment breakage where the system would require a complete or partial shutdown, a by-pass pipe will discharge untreated wastewater directly to municipal sewers. Preventive maintenance of the equipment can help reducing the frequency of breakdown failures and it is excessively important since we are dealing with oily wastewater high in fat.

The most important measure to make sure chemical dosing and hydraulics of the system are appropriate is visual observation of the effluent water. It is important because it is generally a good indication of overall water treatment process performance. In addition to this visual monitoring, the measurement of effluent water turbidity either by manual sampling or continuous reading with a turbidimeter will give the operator a better indication of overall installation performance. However, end-of-process quality checks are not sufficient. Since the transit time through the treatment plant is approximately four hours, the effect of a change in coagulant dosage at the start of the treatment or any other changes will not be detectable in the effluent water for a period of four hours. It is then important to monitor turbidity as well as other water quality indicators such as pH, temperature and floc quality throughout the water treatment process (Ministry of Health, 2014). Poor process performance can thus be detected quickly and corrective measures can be adopted accordingly.

6.2 Potential hazards

When designing an industrial piece of equipment that is to be used by workers, it is highly important to assess hazards or risks associated with it. First, since our design requires handling and storage of bulk quantities of aluminum sulphate, $Al_2(SO_4)_3$, the potential dangers associated with this substance must be identified. According to the New Jersey Department of Health, aluminum sulphate can cause serious damage to the eyes because it becomes corrosive when in water solution. Also, it can irritate the skin when in contact, causing a rash and burning feeling; inhaling it can irritate the nose, throat and lungs, causing coughing, wheezing and/or shortness of breath (NJ Health, 2009). Therefore, workers need appropriate personal protective equipment such as gloves, eye protection and respiratory protection. Aluminum sulphate will react with water, moisture, strong bases, ammonia and amines. It is also highly corrosive to metals in the presence of water and moisture. It must be stored in tightly closed containers in a cool, well-ventilated area (NJ Health, 2009). Aluminum sulphate itself is not a fire hazard because it does not burn. In the case of a leak or spill, properly trained and equipped employees may clean up the powered material in the most convenient and safe manner and place it into sealed containers for disposal (NJ Health, 2009). Another hazard for workers may be slippery surfaces or electric shock due to lying waters.

For an industrial food plant, handling and storing great amounts of chemicals represents a significant risk of contamination. Needless to say, if traces of aluminum sulphate were to be found in the cheese Saputo produces, it would be a disaster. Therefore, high care must be taken during delivery of the chemical and as mentioned above, it must be stored in a tightly closed container in a cool, well-ventilated area. Fortunately, Saputo already has such installations for the storage of their cleaning chemicals, so this is where bulk aluminum sulphate will be stored.

Finally, it is important to reiterate that a failure or inefficiency in the coagulation flocculation process does not result in a high danger for the community of Montreal since the treated wastewater is being discharged into municipal sewers for further treatment. This is however not desirable because high fees would be billed to Saputo if untreated wastewater were to be discharged in the city's wastewater system.

6.3 Start-up and Maintenance

Equipment items used in this design such as valves and mixers are simple on/off devices that only require adjustment for speed or position. Other items such as pumps and chemical feeders may require special procedures for priming and calibration. Detailed operating instructions on how to do so should then be given to the operators. If, at any time, there is a doubt about the performance of a piece of equipment, the operator should refer to the manufacturer's technical manual (EPA, 2002).

In order to keep an optimal functioning of the coagulation flocculation system, a routine maintenance of the equipment (tanks, pipelines, pumps, valves, etc) must be performed. Typical functions include keeping electric motors free of dirt, moisture and pests, ensuring good ventilation in the working area, maintaining proper lubrication and oil levels, checking for proper valve operation, inspecting for noise, vibration, leakage, overheating, or other signs of abnormal operation (EPA, 2002). Also, the operation of sludge removal and the nature of the sludge removed should be monitored. Finally, once a year, the balancing tank and the clarifier should be emptied to clear deposits and possible algal growths, as well as to check the condition of concrete faces against attack by chemically dosed waters (EPA, 2002).

7. Optimization

Following the conception of a design, one should test it to make sure it functions properly and after, based on the results of the test, provide changes to the original design and improve it. However, neither a full simulation nor a prototype of our design was possible for us to carry out due to resource and money constraints. Therefore, it is impossible for us to know if our design will really work as it is designed now.

Nevertheless, there are components of our design that we know could be optimized such as coagulant dosage, residence time in the sedimentation tank and geometry of the flocculation tubes. First, appropriate coagulant dosage is very important since direct costs are associated with the purchase of coagulant. So, it is required that high removal of suspended and dissolved solids is accomplished with the least amount of coagulant possible. For any water, there is an optimum pH, temperature and alkalinity range for which the process occurs at minimal time and minimal dosage of coagulant. Figure 12 shows the fairly tight optimal pH range of 5.5 to 7.5 for an aluminum coagulant.

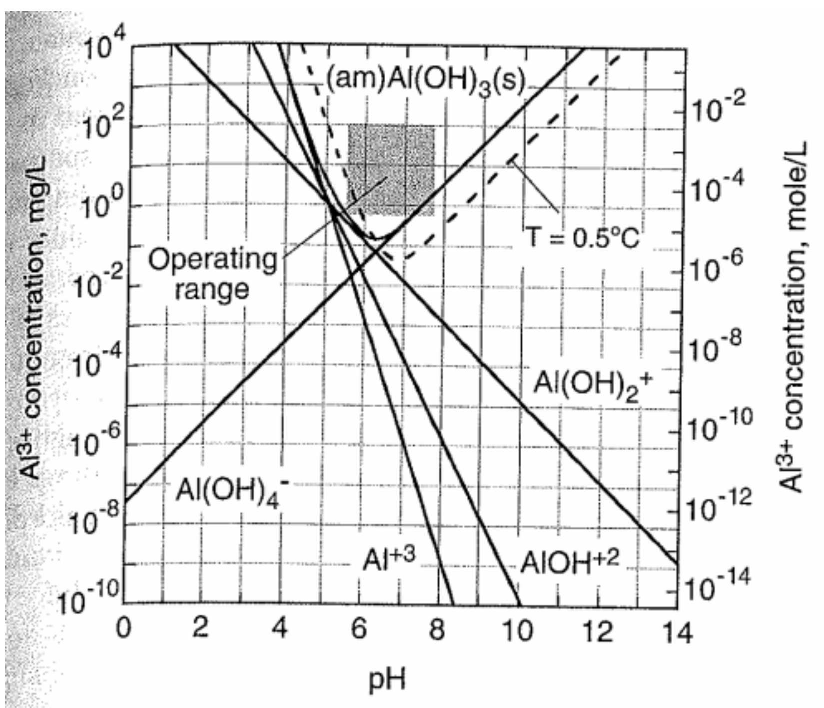

Figure 12: Graph showing the effect of pH on the solubility and precipitation of of aluminum sulfate, with an ideal operating range existing between a pH of 5.5 and 7.5. Source: https://awwoa.ab.ca.

In the field, jar tests are commonly used to determine the optimum conditions in terms of coagulant dose and pH (EPA, 2002). Usually, a series of three coagulation tests are needed to determine the optimum coagulant dose and pH based on the properties of the raw water. These tests are solely based on color and turbidity removal.

Jar tests are also used to determine the optimum residence time in the sedimentation tank. This residence time is highly dependent on the size and density of the flocs formed during the flocculation stage. In our design, we decided to choose the longest time to be conservative, which is four hours. However, the effective range for sedimentation tanks typically varies between two to four hours (Crittenden et al., 2012). Therefore, an optimal residence time somewhere between this range could be found and it would increase the efficiency of the sedimentation tank.

There is also the geometry of the flocculator that could be optimized. Although we designed it to have the smallest footprint possible, the number of turns, the slope and the length of the pipes are factors that could be modified in order to increase the efficiency of the flocculation process. In fact, one would want flocculation to be completed in the shortest time possible, resulting in fewer pipes being required. Such optimization can be achieved with highly sophisticated simulation softwares, however we didn't find this step to be relevant since our design is using very minimal space compared to the one we were allowed by Saputo.

8. Results

8.1 Final Design

To summarize the overall system, it consists of a 3.6 m^3 balancing tank that operates between 7 to 13 hours a day with an average inflow of around 12,500 L. The flow rate of 11.56 L min^{-1} within the system is provided for and monitored by a centrifugal pump and a diaphragm valve. In the coagulation section there is a sudden pipe expansion from a 3/4" to 1 1/4" nominal PVC pipe. Briefly prior to the expansion (1 s or 0.056 m) there is an input of chemical at a rate of 5.6×10^{-5} kg s^{-1} representing a total Alum sulphate requirement ranging from 1.41 to 2.62 kg depending on hours of operation. The wastewater velocity ranges in the small to big pipe from 0.56 to 0.2 m s^{-1} respectively with the condition for turbulence being meet in both sections as over 7000 in the coagulation and over 4000 in in flocculation pipe.The residence time is a few seconds in the coagulation pipe and around 400 s in the flocculation pipe. The flocculation pipe runs 80m long total with 22 turns of 90° and rises 1.35 m in elevation over that length. The total head loss including elevation, major losses (pipe length) and minor losses (valve, sudden expansion, turns) is 1.62 m. Finally the settling tank has a volume of 2.8 m^3 and a residence time of four hours. Its dimensions are a depth of 2 m, a length of 2.4 m and a width of 0.6 m.

8.2 Drawings and Dimensions

Based on the final design parameter 3D models and AutoCAD drawings have been made. Figure 13 shows different view of the 3D model of the wastewater treatment system. All the dimensions from different view of the final design are shown in Figure 14. The yellow lines represent the inside of the components.

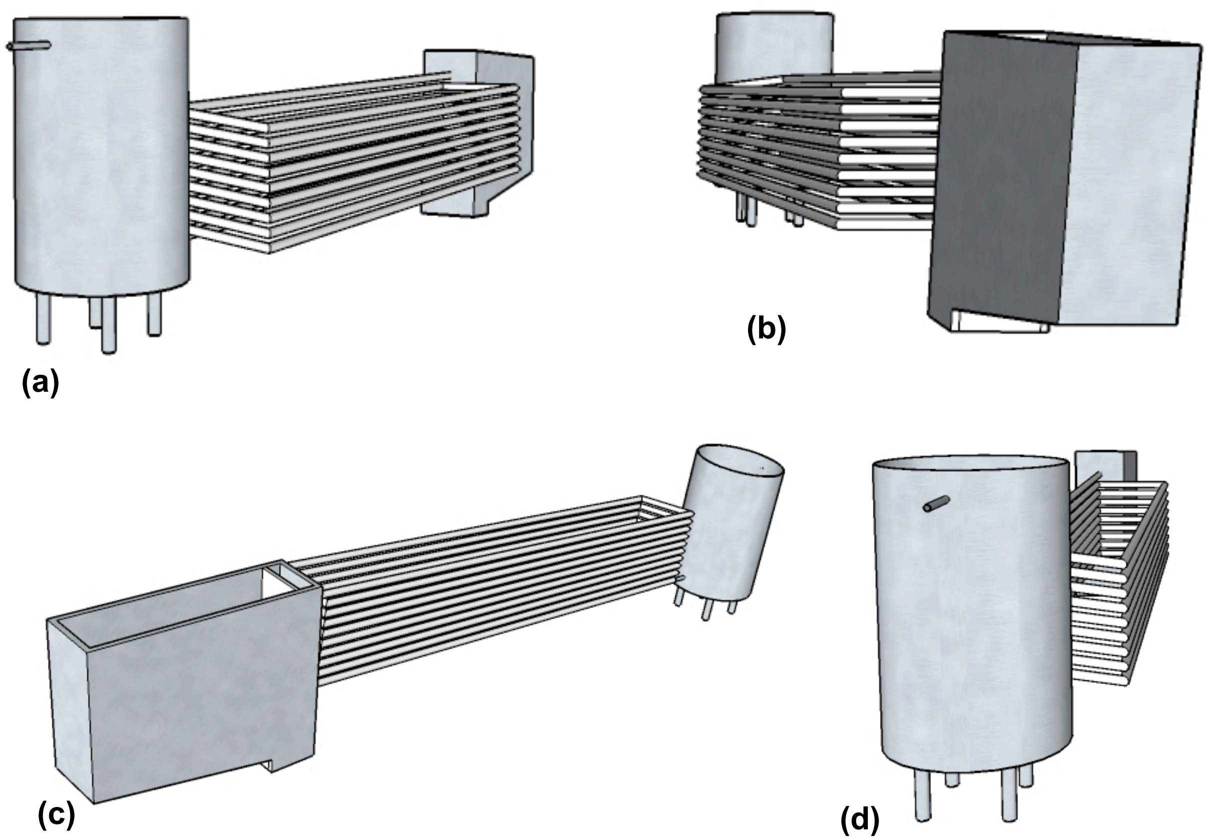

Figure 13. 3-dimension models of the full treatment system, shown at different angles in (a), (b), (c), (d). The cylindrical tank is the balancing tank, the rectangular pip coil is the flocculation tube, and then rectangular tank is the sedimentation tank. The coagulation tube is in between the balancing tank and flocculation tube and not easily visible in any of the four angles.

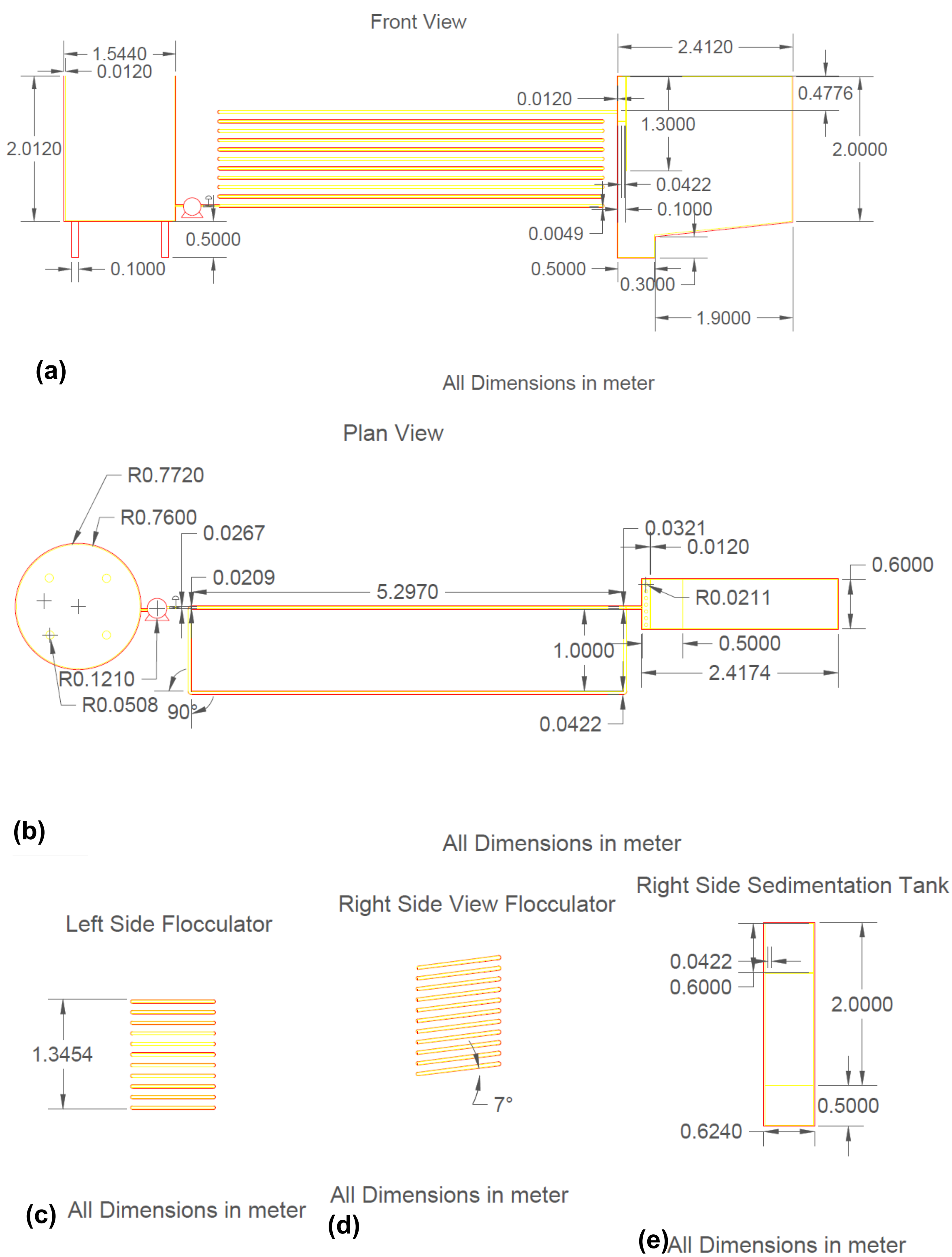

Figure 14. AutoCAD drawings from different perspectives, including the full design dimensions: (a) front view of the full system, (b) top view of full system, (c) left side of the flocculation tube, (d) right side of the flocculation tube, and (e) right (outward-facing) side of the sedimentation tank.

8.3 Location in Plant

Figure 15 is the plan of the Saputo's plant that need the wastewater treatment. The red circle shows the emplacement of the design inside the plant. The place allowed to the wastewater treatment is only half of the location shown in the red circle. We decided to separate this location lenght wise since our design is long and not wide. Figure 16 shows the design to scale with dimensions in the St-Leonard plant. As it is observed the design has enough place. There is also space to install the storage room for the chemical use during the coagulation and flocculation process. In addition, there will probably have enough space for the secondary treatment if Saputo decides to move forward with a secondary treatment system in the future. This location is near the sewage inlet which will facilitate the disposal of the treated water. Since they are a food industry, they cannot reuse the water in the production chain but they can reuse it for the cleaning in place system. However before reusing the water Saputo will need to install a secondary treatment system and most likely also a tertiary treatment to ensure there are no pathogens in the water.

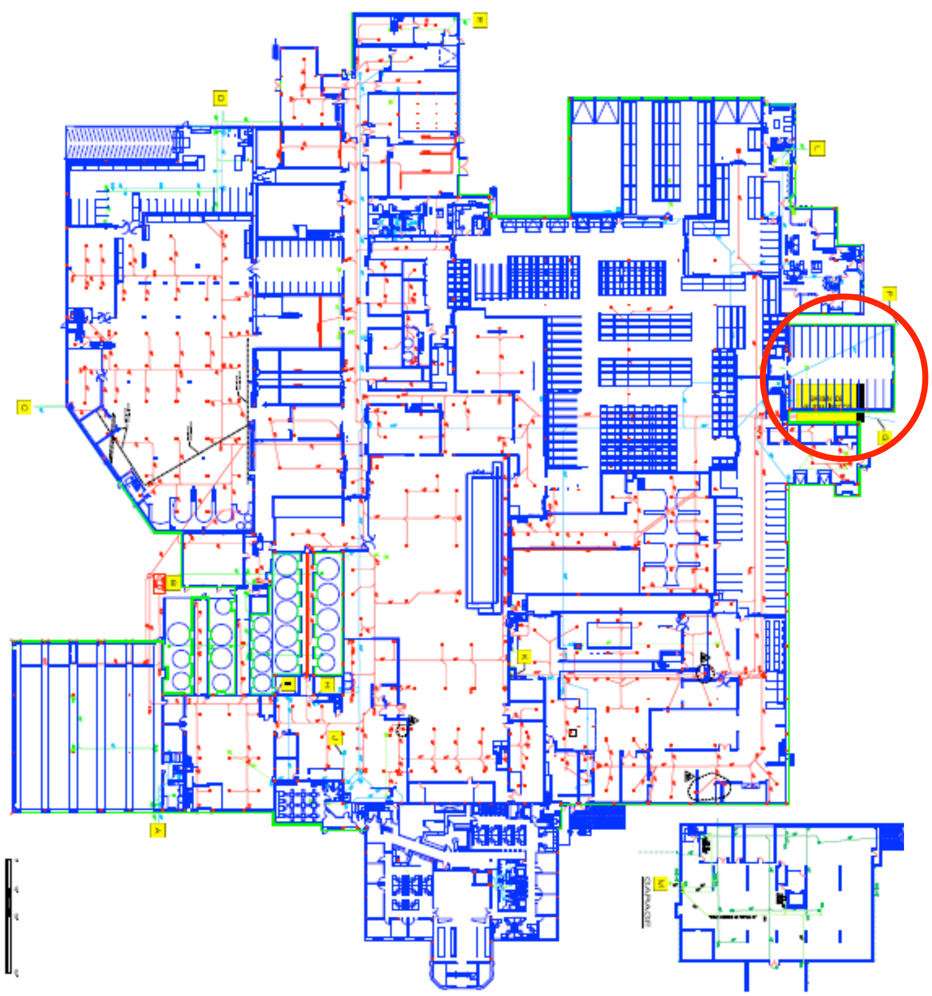

Figure 15. Full plan of the St-Leonard plant, with the location of the space allocated to the treatment system shown in a red circle.

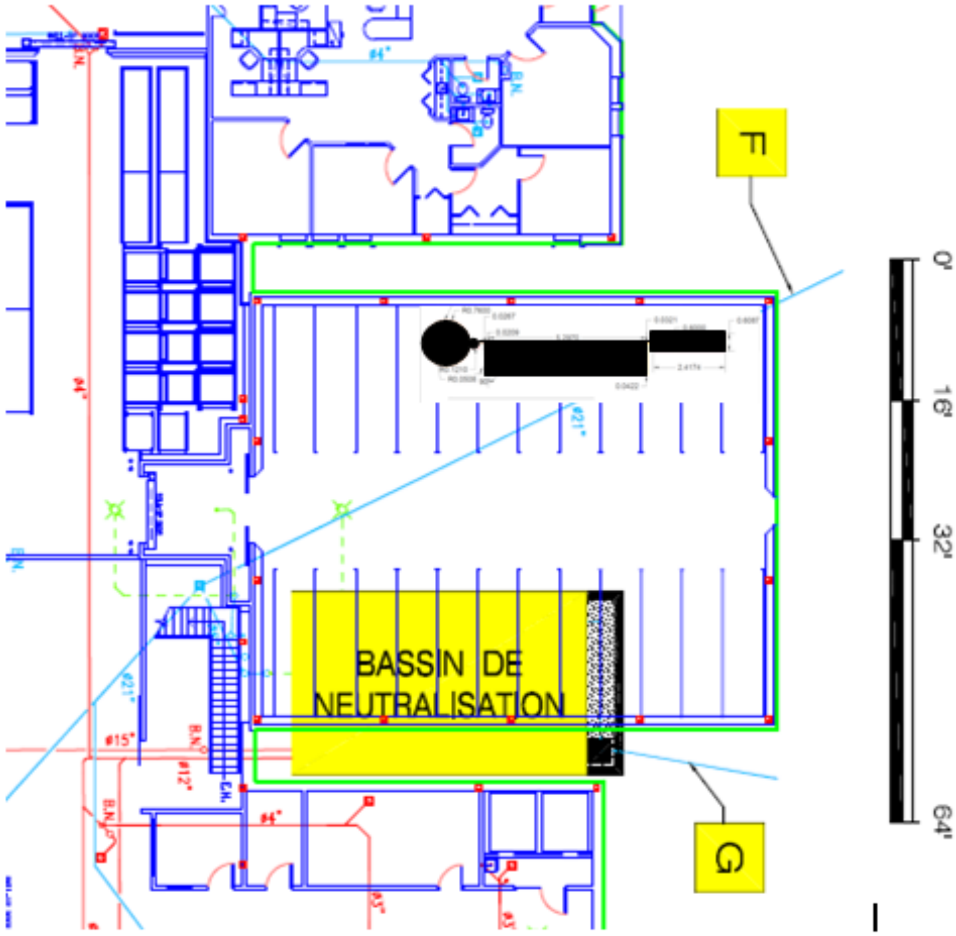

Figure 16. Closer view of space allocated for the treatment system, with designed components represented by the solid-black shapes, drawn to scale to show the space requirements of the system, as well as the remaining available space that could be used for a secondary treatment system.

8.4 Materials

The 3600 L balancing tank and 2800 L sedimentation tank are both made of fiberglass-reinforced plastic because it is a material highly resistant to corrosion. Also, since most water tank sizes are given in imperial or US gallons, our tank sizes represent respectively 951 US gallon and 660 US gallon tanks. We therefore require custom-sized tanks.

Centrifugal pumps are commonly used in wastewater systems to provide for extra head required (IHS GlobalSpec, 2014). On the other hand, diaphragm valves are not commonly used because they are quite expensive and precise (IHS GlobalSpec, 2014). Usually, gate valve are used to act as a simple on/off switch for preventive measures. However, in our design the valve plays a very important role because it must regulate and control the flow coming out of the balancing tank. This step is key since the injection rate of the coagulant is based on a continuous and stable flow. Therefore, if the flow is not controlled properly, the system's efficiency would suffer.

PVC pipes (schedule 80) are used because they are corrosion resistant and well fit to transport liquids at temperatures up to 60°C. The lengths and diameter sizes required have been calculated in the designing of the system. Also, twenty-two 90° elbows are required for the turns in the flocculation step. Two flow meters are suggested in order to determine if the flows in and out of the flocculation tubes are appropriate. The readings of these instruments will also help in the assessment of the hydraulics of the system, in the case of failure.

Finally, one can rapidly see that most of the budget cost is dedicated to buying a sludge dryer. Indeed, they are quite expensive and yet mandatory in our design due to the high production of sludge every day. We have chosen a good sludge dryer with a small footprint called Enviro-Dri™. It is efficient and easy to use (Durco Filters, 2014). The dryer is necessary to make the handling and disposal of the sludge considerably easier.

8.5 Cost Analysis

A full cost estimation for all components of the designed coagulation/flocculation system was done, based on available quotes for the materials required to build it. The materials required for the building of our design were found from online vendors. The breakdown is shown in table 6 below.

Table 6. Full component list and associated costs for the installation and implementation of treatment system, showing the total investment cost.

Item #	Parts	Vendor	Unit price	Quantity	Price
1	Balancing tank (3600 L)	Water tanks	$1000	1	$1000
2	Centrifugal pump	Global Industrial	$350	1	$350
3	Diaphragm valve	Global Industrial	$1200	1	$1200
4	Chemical feeder	Stuart	$150	1	$150
5	3/4" PVC pipe (schedule 80)	Commercial Ind. Supply	1.75$/m	0.3 m	$1
6	1-1/4" PVC pipe (schedule 80)	Commercial Ind. Supply	3.50$/m	80 m	$280
7	90° elbow PVC pipe (schedule 80)	Commercial Ind. Supply	$1.89	22	$42
8	Flow meter	Instrumart	$56	2	$112
9	Supporting structure	-	$2000	1	$2000
10	Sedimentation tank (2800 L)	Emis	$5000	1	$5000
11	Sludge dryer	Durco filters	$30000	1	$30000
				TOTAL:	**$40135**

Our design requires an initial cost of $40,135. In addition to this cost, Saputo will have to pay for the annual purchase of the coagulant which is estimated to be around $400/year. The operating costs for electricity are negligible since it is only required for the pump. It was calculated that our design has a payback period of four to seven years, depending on the efficiency and resulting reductions in fines, as well as the exact cost of the coagulant. It is important to note that delivery costs may not be included in the quotes we obtained, so the actual full cost of the system may be somewhat higher. As a result, the payback period is likely on the higher end of six to seven years.

9. Conclusion

The objective of our project was to find an optimal treatment solution of Saputo's wastewater stream for the removal of fat, oil and grease. Coagulation and flocculation system was chosen on our design. With the consideration of cost and efficiency, we choose aluminum sulfate as our coagulant agent. During the design of this primary wastewater treatment, we have tried the simulation, testing and risk analysis. Based on the testing result, coagulant dosage and residence time were optimized to improve the design. There are also some criteria that have to be balanced: meeting municipal regulations, space limitations, costs, resources, daily volume of wastewater and potential for waste by-product reuse. Cost estimation and materials for the our design system were figured out. The design is efficient and cost-effective, with a payback period of around six years. Our designed system also managed to leave a significant portion of the allotted space free, allowing for the potential of a secondary treatment system to be designed and installed should Saputo’s needs change in the future.

We will take the competition "Create the Future Design Contest 2014". We are eligible for the entry requirement, which is under Sustainable Technologies catalogue. The competition is to design products that reduce dependence on non-renewable energy resources, as well as products designed for other purposes using environmentally friendly materials or manufacturing processes. Our wastewater treatment design completely satisfies this requirement. We will submit our report to this competition before the deadline of 23:59 h on 1 July 2014.

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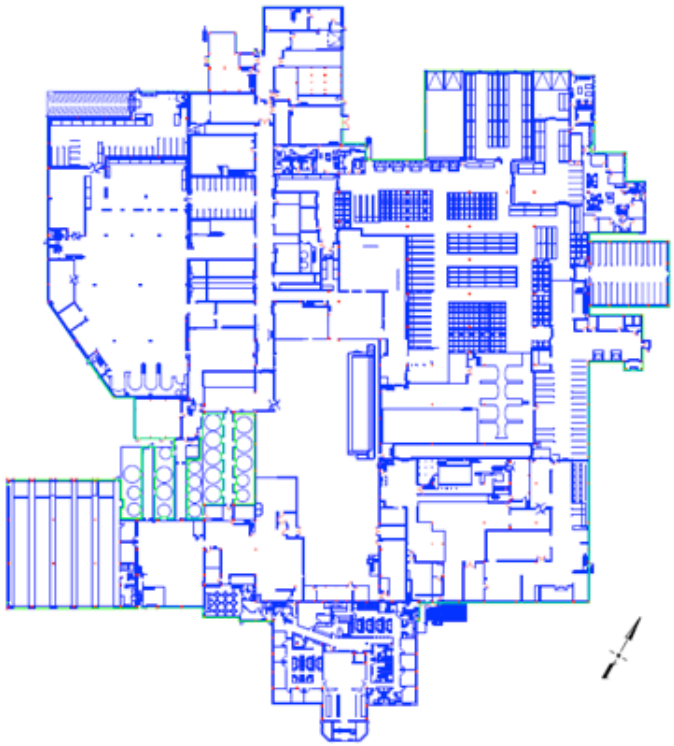
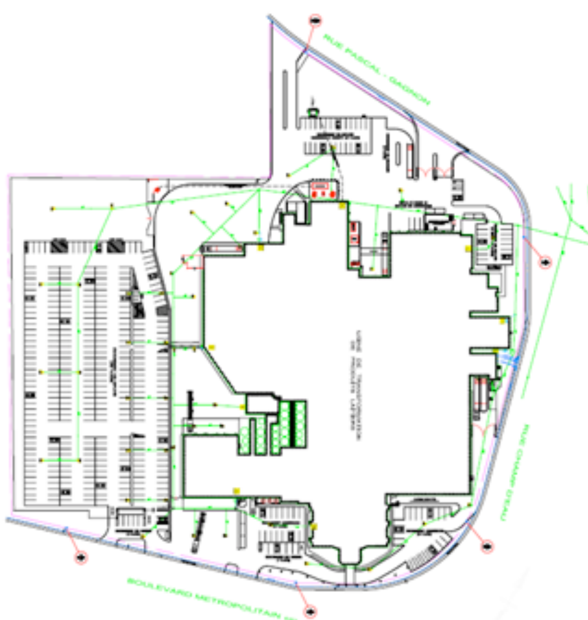
11. Appendix

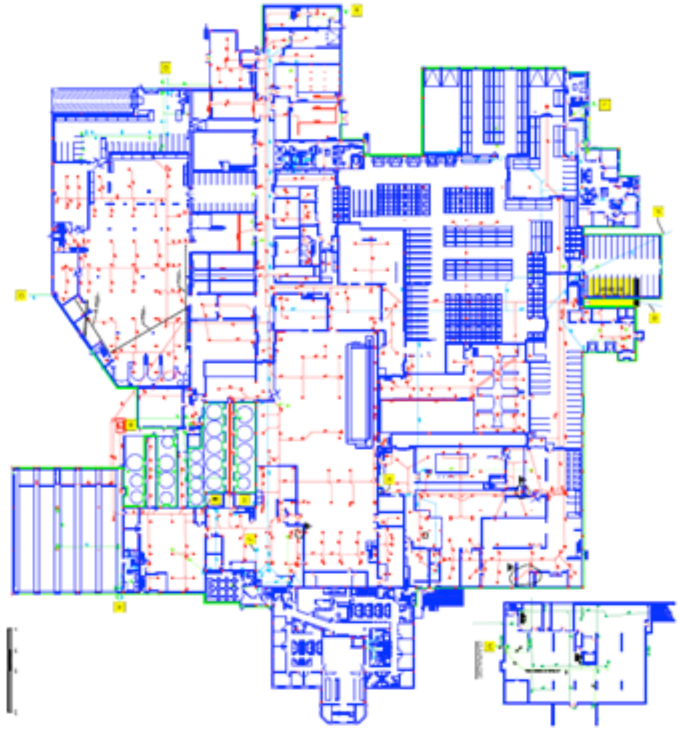
A.1 Inside plan of Saint-Leonard plant provided by Saputo



A.2 Exterior drainage system of Saint-Leonard plant provided by Saputo



A.3 Interior drainage system of Saint-Leonard plant provided by Saputo



A.4 Summary source provided by saputo

		312	j/année							
Description de la source	**Liquide Aux egouts (kg)**	**Azote TKN (kg)/j**	**% d'Azote permis**	**Proteine % (as is)**	**Azote TKN (%)**	**Azote TKN (ppm)**	**TKN (ppm /2,6MMm3 Eau)**	**Conc. % Gras**	**Gras (kg)**	**% Gras du total permis**
Lait cru (debourbages d'un separateur)	1,149	6	3.5%	3.5%	0.5%	5,486				
		182							**390**	
Seperateur Lait Specialite	1,555	7	4.0%	3.0%	0.47%	4,679	3	0.25%	3.9	1.0%
Seperateur Lait Mozz 25 07,Rinse Eau a	1,638	7	3.6%	2.6%	0.41%	4,051	3	0.10%	1.7	0.4%
Debourbages whey Sep&Clar. (11 06 12)	9,360	18	9.7%	1.2%	0.19%	1,881	7	0.25%	23.4	6.0%
	-	-								
Totales :	**12,553**	**32**	**17%**				**12**		**29**	**7%**
Conc Whey (25%) rincage lignes/silo	100	1	0.4%	5.0%	0.8%	7,837				
Restantd de fromages planchers	500	20	10.8%	25%	3.9%	39,185				
Ferment principal	200	2	0.9%	5%	0.8%	7,837				
Process Cheese	100	4	2.2%	25%	3.9%	39,185				
Fines (solids) in Desludges	94	5	2.8%	35%	5.5%	54,859				
Speciality Tables drippings Whey	??		0.0%							
Spills due to failures /foam, etc.	??		0.0%							
CIP residuals	??									
Permeat FM (2 x 14usgpmX20h)	**127,109**	**53**	**29.3%**	**0.27%**	**0.04%**	**420**	**21**	0.00%	**-**	0.0%
Eau Cuiseur	20,000	**6**	**3.4%**	**0.20%**	**0.03%**	**312**	**2**	0.00%	**-**	0.0%
		341	kg de proteine				47			
si recupere la proteine par 50% @ $1.8/kg										

A.5 Matlab code (following page)

Contents


```
%Designproject_Saputo.m

%Group 2
%Final Design Project
%March 27 2014
%Scaling of Wastewater Treament System
```

dimension of pipes

```
clc,clear

% given
Q= 1.167*10^(-4); % =7L/min [m3/s]
vel= 0.20; % velocity within flocc tube[m/s]
visc_w=0.658*10^-6; % water at 40C (asume inflow temperature of 40C)
visc_milk=2.8*10^-6; % milk at 20C is 4.3*10^-6, if we assume similar decrease rate
visc=(visc_w+visc_milk)/2; % 50-50 distribution between water and milk for kinematic

%solve for the diametere knowing: Q=vel*area. Calculating value
d_m_pre=sqrt((4*Q)/(pi*vel)); % diamete floc pipe [m] before adjust

%fixing values while maintaining velocty, increasing diameter requires an
%increase in Q flow rate. Must increase for standard pipe size.
d_m=35.052/1000; % rounding diameter (inside value) for 1 1/4 inch nomial pipe, diam
Q=(vel*(pi*(d_m^2)/4))*(1000)*(60); % increased value for Q=11.58L/min [L/min]

%Reynolds number for flocc pipe flow
Re_flocc=(vel*d_m)/visc %over 4000 for turbulent
```

```
Re_flocc =

   4.0546e+03
```

Calculations for sudden expansion

```
% recomended diameter ratio 5:8 (Dittmann, 1986)
ratio=5/8;
d_coag=ratio*d_m; %diamete of pipe where coagulant in inserted [m]
d_coag=0.0209296 % round down (from 0.0219m) for pipe size convention (3/4" pipe)
vel_coag=((d_m^2)/(d_coag^2))*(vel); % velocity in coag pipe [m/s]

% we want coagulant to be inserted .1s before sudden expansion
coag_location= vel_coag*0.1 % distance from sudden expansion where coag should be ac
```

```
%Reynolds number for coag pipe flow
Re_coag=(vel_coag*d_coag)/visc
```

```
d_coag =

    0.0209


coag_location =

    0.0561


Re_coag =

   6.7905e+03
```

Head loss in pipe

```
% MAJOR LOSS

% straight section
t=400; % [s]
L=t*vel; % [m]
g=9.81; % [m/s^2]
lamba=0.0399; % solved using online calculator (eng. toolbox)
% link: http://www.engineeringtoolbox.com/colebrook-equation-d_1031.html
%Darcey-Weisbach equation:
hL_major=lamba*(L/d_m)*((vel^2)/(2*g)) %[m]

% MINOR LOSS

%bends
k_bend=0.3; % coefficient for head loss in 90 degree flanged turn
n_turn=22; %total of 9 turns that are 180 degree split in 2.
hL_turn= k_bend*((vel^2)/(2*g))*n_turn; % minor loss due to bends [m]
%valve
k_valve= 2.3; % Diaphragm Valve, Open. link:http://www.engineeringtoolbox.com/minor-
hL_valve= k_valve*((vel^2)/(2*g));%[m]
%sudden expansion
area_ratio=(d_coag^2)/(d_m^2); %value =.39, needed to use table for k
k_exp=0.3; % from table value, university waterloo
hL_exp= k_exp*((vel_coag^2)/(2*g)); %[m]
hL_minor=hL_turn+hL_valve+hL_exp %total minor head loss [m]

%TOTAL PIPE LOSS
%total minor and major loss within pipes
hL_pipe=hL_major+hL_minor
% convert to psi link: http://www.engineeringtoolbox.com/pump-head-pressure-d_663.ht
SG=1.01; % between milk and water.
pL_pipe=0.434*hL_pipe*(3.28084)*SG; % pressure loss in pipe, 3.28084ft=1m [psi]
```

```
%ELEVATION
% Loss elevation
total_elevation = 1.43*3.28084; % loss in pipe elevation 1.5m to ft [ft]
pL_elevation=total_elevation/2.304; %[psi]

%TOTAL LOSS
pLoss_total= pL_pipe+pL_elevation; % [psi]
hLoss_total=pLoss_total/(.434*SG); %[ft] conversion
Loss_total=hLoss_total/3.28084 % [m] coversion
```

```
hL_major =

    0.1857


hL_minor =

    0.0230


hL_pipe =

    0.2086


Loss_total =

    1.6245
```

Coagulant Dosage

```
%Recommended dose varies by source and would be established from trials,
%NJIT range 75-250ppm, if we take 100ppm=99.89mg/l

coag_dose=9.989e-5;
flow_coag=coag_dose*vel_coag% [kg/s]
mass_coag_7hr=flow_coag*25200 % amount of coagulant based off 7 hour opperation
mass_coag_13hr=flow_coag*46800 % amount of coagulant based off 13 hour opperation
```

```
flow_coag =

   5.6035e-05


mass_coag_7hr =

    1.4121


mass_coag_13hr =

    2.6224
```