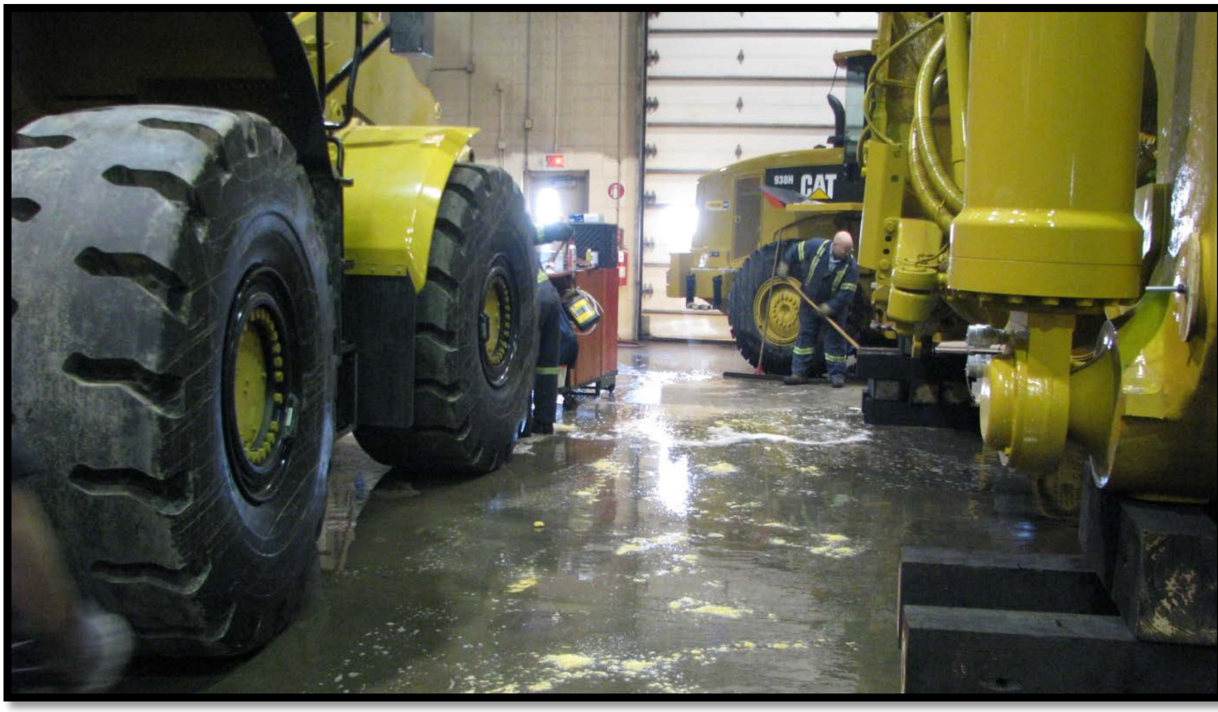

Oil-Water Separation System for Industrial Wastewater

McGill

SUMMIT TO:

BREE 495 ENGINEERING DESIGN III

FINAL REPORT

SUBMIT BY:

McGill University

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EXCUTIVE SUMMARY

Petroleum and its derived products are harmful if they are released in the environment. At Hewitt in Pointe-Claire, oil spill occurs from the maintenance of machinery and it is released as wastewater from the cleaning of the garage floors. The wastewater system was installed 40 years ago when the regulation for industrial wastewater effluent were not as severe. Therefore, a new system is required for improving the quality of the wastewater.

The chemical property of the cleaning agent is one of the important parameter affecting the efficiency and the physical and chemical design of the separator. The current degreaser renders the cleaned oil to be in a state of emulsion, which cannot be efficiently treated by conventional gravity separator. In this report, specifications for the design of a new oil-water separator will be given to meet the stringent municipal regulation of a discharge wastewater concentration of 30 mg/L or less.

Based on the Stokes's Law, the new separator will have a dimension of 6m length by 1m width to meet the required minimum area of 5.29 sq. m. and it will be divided into three chambers. Physical additions to improve the overall operation include a coalescent media, an aeration/flotation device and a control system for bioremediation. Lastly, information for additional steps of design process of prototyping and testing will be overviewed.

1. INTRODUCTION

Oil can be classified into two different categories: biological and mineral. Biological oil has their origin from plants and animal, they are hydrophobic molecules such as cholesterol. Mineral oil is composed of plants that are buried underground during millions of years. Fossil fuel is necessary due to it is easily transported and highly energy dense, furthermore its byproducts have a wide range of application. The molecular constitutions of the hydrocarbon product derived from fossil fuel are not easily biodegradation by naturally occurring organisms found in the environment. Having a specific density that is lower than water, it is susceptible to form a thin layer on the surface. This layer can be harmful to the fish, birds, and plants. Therefore, the presence of oil in the ground, in water and on living organisms is considered as pollution.

In the past decades, many well-known accidental spills have occurred during petroleum extraction in sea or during its transportation by cargo, such as the Exxon Valdez and, the recent, Gulf of Mexico. However a more common source of oil spill occurs from the release from industrial, agricultural, and domestic sources. Often these sources are released by dumping untreated operational and cleaning wastewater into rivers and lakes. This process can account for a major portion of the annual 6 million gallons (Gary L. Gerdes, December 2000).

In this project, the focus will be put mineral oil used in the transportation industry, such as lubricant and fossil fuel. During the maintenance of the oil-dependent device, the release of contaminated and oil and grease is a common occurrence. However, the cleanup process usually consists of using detergent and water hose. This primitive process will result into the release of a huge amount of toxic oil that should be collected with the help of an oil and water separator.

For environmental purpose, municipal regulation exists as set a general guideline on a concentration of contaminants disposed by wastewater. In the case of oil, it is currently set a maximum concentration of 30ppm (Ontario Ministry of Transportation, February 2007).This strict new regulation can cause old separation unit to be in need of an overhaul. The article will explore various new method of improving existent system and the design of a new one.

2. DESIGNING A FEASIBLE SEPARATOR

It is important to note that the objective of this project is to design a cost-effective system that will respect the municipal regulation. Therefore, an evaluation of the performance of the current system is required. The resultant information will help identify potential improvements.

2.1 CURRENT SYSTEM

Initial experiment was conduct from the month of January to April of 2011. It had the purpose of identifying and confirming suspected problem of the existing system. The following parameters are the limiting factor of the current system:

- The utilization of emulsifying soap, which decrease the oil particles size beyond the operational capability of the current gravitation separator;
- The influent flow rate (17 gpm) which prevents an adequate hydraulic retention time;
- The small size of the current system, which does not meet the minimum required dimensions for an effective separation.

Due to these constrains a barely noticeable decrease in oil concentration was found. An overview diagram of the current system is provided in the Appendix IV.

Table 1: oil concentration presented the wastewater before treating and after treating by the separator

	Separator Inlet (mg/L)	Separator Outlet (mg/L)
Middle of Cleaning	214	162
End of Cleaning	123	114

2.2 DESIGN CRITERIA

- The wastewater treatment system (WTS) needs to be embedded in the concrete floor;
- The separator dimension needs to optimize the physical separation by the buoyancy effect of the oil droplet. This criteria involves minimizing the depth for decrease the time of rise and maximizing the length for increasing the travelling the distance before the sewer inlet.
- The WTS is self-sufficient for receiving and treating efficiently the wastewater generated by the weekly event of the floor washing.

2.3 FEASIBLE SEPARATOR SIZE

As described before, the major component of current wastewater treatment system is a API gravity –based oil-water separator. The concept of this model is based on the difference of mass density between oil and water, based on Stokes's Law (WEF, 2008). This means that the separator, of a feasible size, must meet the minimum required resident time for an oil contained in a stream of wastewater to rise and float on the surface of water. Therefore, sizing the separator properly to ensure sufficient separation time is the key factor for a successful oil removal system.

This project conducts the feasible separator sizing calculation using Stokes' Law (WEF, 2008). This law is the major scientific theory behind API gravity separator. Many references (Kirby and Mohr.) mentions that this principal simplifies the overall process and often under-sizing might occur. Therefore incorporating enhanced components is recommended.

To calculate the size of an empty-vessel gravity separator, it is first necessary to calculate by the use of Stokes' Law the rising velocity of the oil droplets. The size of the separator is then calculated by considering the path of a droplet entering at the bottom of one end of the separator and exiting from the other end of the separator (Figure 1).

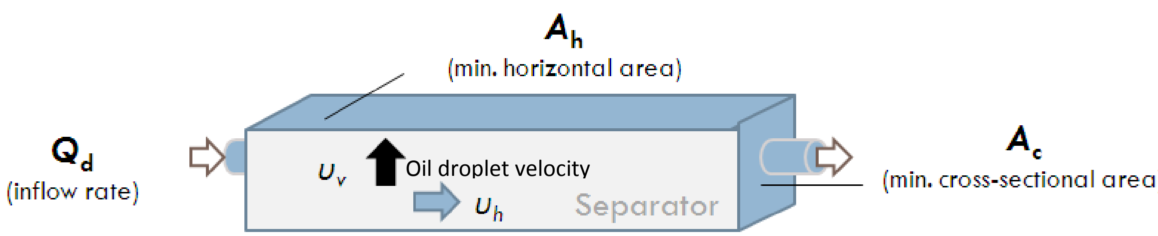

Figure 1: Illustration showing the relationship between inflow rates, minimum required area of a separator and oil droplet velocity

Defining oil rising velocity:

Stokes' Law (Equation 1) defines the rising velocity of oil droplet from the bottom of a separator to the surface of water. From this equation, the most important variables are the viscosity of the continuous liquid, specific gravity difference between the continuous liquid, and the oil droplet size. After these are known, the rising velocity and therefore the size of separator required may be calculated.

$$v_v = \frac{2}{9}\frac{(\rho_w - \rho_o)}{\mu} g R^2 \qquad \text{Eq. 1}$$

$$v_h = 15\, v_v \text{ or } v_h = 0.015 \text{ (m/s)} \qquad \text{Eq.2}$$

Where:

υ_v $[\frac{m}{s}]$: oil droplet rising velocity;
υ_h $[\frac{m}{s}]$: oil droplet rising velocity;
g $[\frac{m}{s^2}]$: gravitational acceleration
ρ_o $[\frac{kg}{m^3}]$: mass density of oil
ρ_w $[\frac{kg}{m^3}]$: mass density of water
μ $\left[N\frac{s}{m^2}\right]$: dynamic viscosity
R [m]: the radius of oil droplet

According to API, horizontal velocity υ_h is recommended to be 15 times of vertical velocity or 0.01524 (m/s) whichever the smallest one to maintain a laminar flow condition.

Determining a corresponded-feasible separator size

$$\upsilon_v = \frac{Q_d}{A_h} \qquad \text{Eq.3}$$

$$\upsilon_h = \frac{Q_d}{A_c} \qquad \text{Eq.4}$$

Where

Q_d $[\frac{m^3}{s}]$: designed flow rate
A_h $[m^2]$: Minimum separator horizontal area
A_c $[m^2]$: Minimum separator cross-sectional area

Equation 3 and 4 show that for a given flow rate, the calculated oil rising and horizontal velocity determine the minimum required horizontal and cross-sectional area of a separator. A list of parameters and values used in the design calculation are showed in Table 2.

Table 2: Parameters and values used in the design assumption

Wastewater	Value	Unit	Note	
Temperature	10	°C		
Gravitational acceleration, g	9.81	m/s^2		
Mass density of water, ρ_f	999	kg/m^3		
Mass density of oil, ρ_p	800	kg/m^3		
Dynamic viscosity, μ	0.00131	$N/m^2 \cdot s$		
Designed flow rate, Q_d	25	GPM	0.00158	m^3/s
Maximum allowable horizontal velocity, υ_h	0.01524	m/s		
Separator				
Length / Width (L/W >=5)	5			
Depth / Width (d/W = 0.3~ 0.5)	0.4			

The physical properties of water are obtained from literatures with the assumption that the designed wastewater has a temperature of 10^{o}C (the estimated lowest temperature possible in the workshop during winter time). The value of oil density is the average of common transformer oil, hydraulic oil and engine oil. The length to width ratio is set to be 5 (a minimum value according to API) in the design; the ratio of depth to width is set to be 0.4 (must between 0.3 to 0.5 according to API). The capacity of this designed separator is assumed to treat 25 gallon per minute (GPM) or 5.7 m^3/h of wastewater.

By incorporating the values from previous table into equation 1 to 4, the minimum required separator size (eq. length, width, depth) allowing sufficient separation time can be obtained (Table 3). The design calculation considers oil droplet size between 20 microns and 150 micron because: 1) oil size smaller than 20 microns is generally produced under pressure which is not our case; 2) the case site of the project involves the use of detergent breaking down free oil (larger than 150 microns) into smaller droplets. In summary: for a wastewater flow rate of 25 GPM, a separator with a dimension of 5.14*1.03*0.41 (Length*Width*Depth) provides sufficient resident time for oil size larger than 60 micron to rise to the surface of water before reaching the separator outlet for wastewater.

Table 3: Minimum required separator sizes for the separation of oil droplet from 20 to 150 microns

	Dispersed Oil Droplet Size (diameter from 20-150 microns)					
Diameter of oil droplet, D [μm]	150	100	80	60	40	20
Radius of oil droplet, R[m]	0.000075	0.000050	0.000040	0.000030	0.000020	0.000010
Oil vertical rising velocity, υ_v[m/s]	0.001863	0.000828	0.000530	0.000298	0.000132	0.000033
Oil horizontal velocity, υ_h (max. 0.015)	0.027942	0.012419	0.007948	0.004471	0.001987	0.000497
Allowed υ_h	0.015	0.012419	0.007948	0.004471	0.001987	0.000497
Minimal separator horizontal area, A_h [m^2]	0.85	1.91	2.98	5.29	11.91	47.63
Minimal separator crossing area, A_v [m^2]	0.11	0.13	0.20	0.35	0.79	3.18
Separator Minimal Length, L [m]	2.06	3.09	3.86	5.14	7.72	15.43
Separator Minimal Width, W [m]	0.41	0.62	0.77	1.03	1.54	3.09
Separator Minimal Depth, d [m]	0.16	0.25	0.31	0.41	0.62	1.23
Separator Minimal Volume, V [m^3]	0.14	0.47	0.92	2.18	7.35	58.80

An extended calculation result showing required separator sizes to treat wastewater from 17 GPM to 50 GPM is also provided in Appendix II.

3. RESULT AND CONCLUSION

3.1 PHYSICAL MODIFICATION OF SEPARATOR

Based on the previously mentioned calculations, the design of the new system can be divided into two components: the physical and chemical enhancements. In the physical redesign, it will include a bigger separation tank to meet the requirement dimensions, a baffle to regulate the contaminants location, a flow valve to regulate the influent rate, coalescent media to help the coagulation of emulsified oil particles, aeration device to decrease the oil density, create turbulence, and to increase oxygen content for bacterial growth, and finally the addition of two oil skimmers. A detail diagram can be observed in Appendix Appendix V.

3.1.1 SIZE

As a safety measure, the design will incorporate for a higher capacity (eq. maximum wastewater inflow rate allowable) and more efficiency of oil removal (eq. separating smaller oil droplet) resulted in a larger separator size. The dimension of the separator, in this project, is designed to be 6*1*0.75 m^3 (for capacity ≤ 25 GPM; oil size ≥ 60 microns; temperature ≥ 10^oC) to minimize construction cost and required space in the workshop. The control of capacity and the removal of oil size smaller than 60 microns are discussed in following sections.

3.1.2 THREE STAGE COLLECTION PIT

$V_{generated\ wastewater\ with\ cleaning\ event} = V_{tank}$

For calculating the volume of the catchment, the average volume of water spread on the floor during the washing events. Based on an average flow rate of liters per minute for a period of 45 minutes, the total amount of wastewater is $2.89m^3$. For the design purposes, a safety factor of 1.5 is added to the calculation and the total volume become is 4.34 m^3 (Appendice A1). Therefore a larger volume is required because the current volume of the catchment is $2.53m^3$.

V_{tank} depends on stokes Law

Another way of calculating the volume required is by estimating an average droplet size based with calculation based on Stokes Law. In addition to the volume, these calculation would give estimated a required length for a basic catchment. The length required based on these calculations for a treatment of oil particle of 60 µm is 6 meters. The dimension for the width and the depth are dependent on the volume of storage desired. In their optimization, the depth needs to be minimized and the width must be convenient for the purpose of maintenance. According to the previous consideration, the optimal geometry for having the required volume with a length of 6 meter is a width of 1 meter and a depth of 0.75 meter. The volume calculated from these dimensions is $4.5m^3$. Therefore, the volume requirement based on stoke law will be sufficient to store the volume of $4.3m^3$ of wastewater generated during the cleaning events.

3.1.3 DEVICES AND APPARATUS

Baffles

In addition to the different sizing of the catchment, chambers separated by baffles with a low porosity design for minimizing free oil migrating in the next chamber. The candidate material for the baffles can be recycled reinforced fiber carbon.

The baffle divides the collection pit in three distinct non hermetic chambers. The first chamber received the wastewater from the catchment; this chamber has the purpose of settling solid particles and is trapped by the first lower baffle. This extremely important, as it will prevent clogging of the coalescent media and the air diffuser, thus reducing its maintenance. Secondly, the middle chamber contains the coalescent type separator made of oleophilic material. The third tank contains the treated wastewater from the previous chamber will go into a clarification process, where the small residual contaminants will settle. The wastewater contains in the third chamber ideally should meet the criteria for Montreal effluent wastewater.

The coalescent media

The required area for the size of the coalescent block is 5 meters square of external surface area (Appendice A2). The dimension of the coalescent media to be fitted in the separator chamber has a length of 1.5 meter, a width of 1 meter and a width of 0.5 meter. Therefore, the middle chamber needs a length of 3.5 meter with the given depth of 0.5 meter and the given width of 1 meter. The design for a coalescent media has little to no straightforward calculation method. On occur small amount of information are provided by the supply, but they are often misleading (Gary L. Gerdes, December 2000).

One specific example on the calculation of the required volume from a Brentwood has yield an overall size of 2.33 cu. ft or 0.066 cu. m.. The obtained value seems a little too small to be accurate, thus as a safety factor, it has been increase to a volume of 0.6 cu. m., based on the above dimension. The exact calculation process will be shown in the appendix.

However one consistency has been the plate separation, with a fair majority recommending a 3/4". This is the ideal size to prevent clogging. In terms of efficiency, it is believe that the vertical mesh design is the most effective method based on the increase in contact surface of the design. The mesh design consists of crisscross plates that forms a mesh design, this will increase the flow path of the wastewater and, thus, the contact area.

The material of the media must be made from PVC, polypropylene, or recycled fibrous material such as kraft fibers, fibrillated lyocell fibers, glass microfibers or nanoceramic functionalized fibers (Stanfel and Cousard, 2011). According to Gerde et al (2000):"Some people in the industry believe that polypropylene is too oleophilic and does not allow oil to migrate to the water surface". The goal of a coalescent media is to get a non-laminar flow which will induce oil droplet growth on the media which promote a faster rise the particle (Gerdes et al. 2000). A series of parallel plates are juxtaposed to another series of parallel plates which form inverted V's with angles varying from 40^{o} to 60^{o} (Gerde et al., 2000). For wastewater with high loading in solid particles matter in suspension with Hewitt disposals, it is recommended using an angle of 60^{o}.

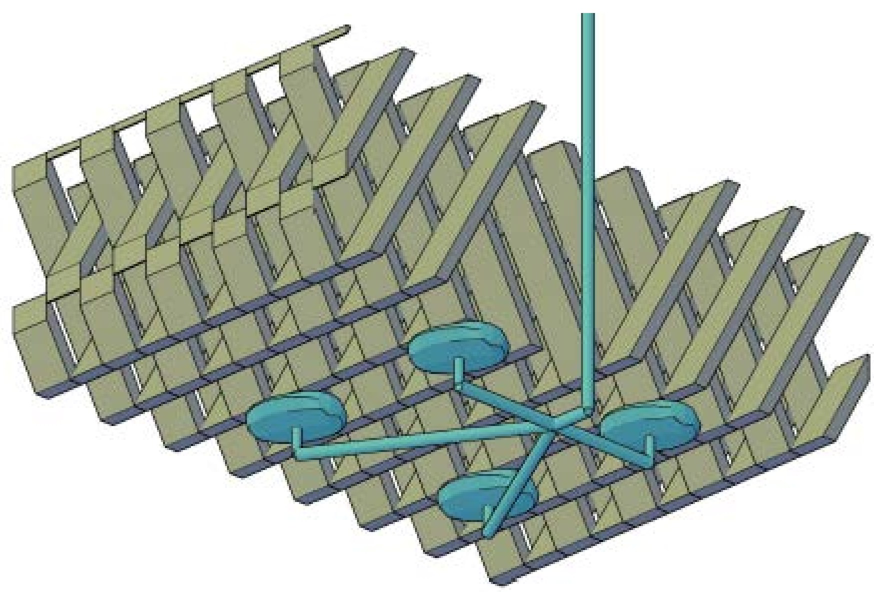

Figure 2: Coalescent media and aeration disc

Aeration system

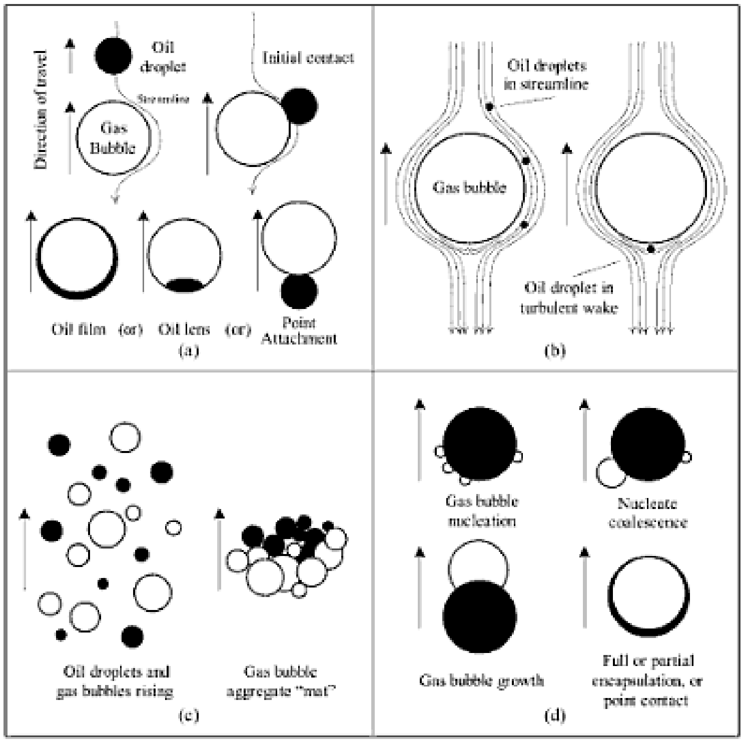

Figure 3: Principal behind the reduction of specific density (Malhotra, 2009)

An aeration unit will be added at the bottom of tank, right under the coalescent media. The addition of this devices have multiple implications. First of it is used as a tool to improve the vertical rising velocity of the oil particles by decreasing the specific weight of the molecules. This is does by the cohesive force of the oil particle and the air bubble, which reduces the overall density of the newly formed oil molecule. By injecting air bubbles into the system, the turbulence of the water flow will be increased. With an increase turbulence, a higher chance of surface contact between the oil particles and the coalescent media will occurs, thus improving the efficiency of the media. Studies has demonstrate the increase in removal rate of each of these method, where the combination of an aeration system and a coalescent media will result in a 95 percent removal rate and it will reduce a wastewater with an initial concentration of over 500ppm to under the desired amount of 30ppm.

Table 4: Reference removal efficiency

Type	Initial Concentration (ppm)	Processed Concentration (ppm)	Removal rate (%)
Conventional	550	110	80.7
With Coalescent Media	500	31	93.8
Aerated	725	70	90.6
Coalescent matrix and Aerated	500	24	95

Furthermore, the addition of an aeration system will increase the oxygen content of the wastewater. This will allow a better proliferation of the aerobic bacteria present that degrades oil. The overall design of the system will be based on the size of the coalescent media, as the increase in separation of oil the main as the purpose of this design. Thus based on FlexAir Threaded Disc, four disc shape differ with a dimension of 3 cm diameter will be installed. These will be connect to 3/4" pipes. (Hellotrade.com)

Skimmer

The skimmer is a rotating cylindrical device design to remove the surface oil layer. It consists of using cohesive force between the oil and the surface of the material to be move up. The metal part must be immerged in 1cm to 3cm of the free oil layer floating on the top of the water. The oil catches in the rotatory device drop in a conveyor which evacuates oil in a container for oil recovery.

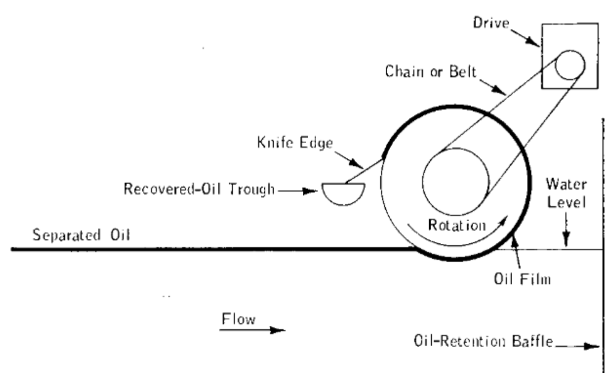

Figure 4: Oil Skimmer - American Petroleum Institute, 1969

Control Valves

The three chamber collection pit is designed to receive wastewater inflow limited to 25 gpm ($5.7m^3/h$). The control valve in the pipe linking the catchment to the catchment pit, will ensure a control of the maximum flow rate and a flow rate according to the level of water in the first chamber

Figure 5: Flow rate Valve - Alibaba Product, 2011

Centrifugal Pump

The wastewater exit the third chamber two ways: passively and by a centrifugal pump. A centrifugal pump is timed for pumping the wastewater out of the third chamber at determined period length depending upon the testing result. The active removal of the treated wastewater which meets effluent wastewater criteria is important because the outlet pipe is located at 60 cm from the floor. Therefore, the water below 60cm is retained in the three chambers. The pump will remove wastewater in chambers down to a depth of 10cm. The reason for not pumping all water is for avoiding pumping the free oil layer on the surface water. Once the content of the third chamber is pumped, the water from first and second chamber slowly flow through the porous baffles. After, a determined period of time, the pump is reactivated and the cycle start again. The currently described feature of the overall design is an essential component. It empties, by transient pumping, the three chamber collection pit design to receive the volume of generated wastewater on weekly wash prior the event. Without this system, the chambers will contains 60 cm of wastewater at any time, and the incoming inflow, although diluted wastewater contained in the chambers, will not ensure an effluent of 30 ppm of oil content. The passive effluent is designed only for emergency such as overflow occasioned by an extraordinary event.

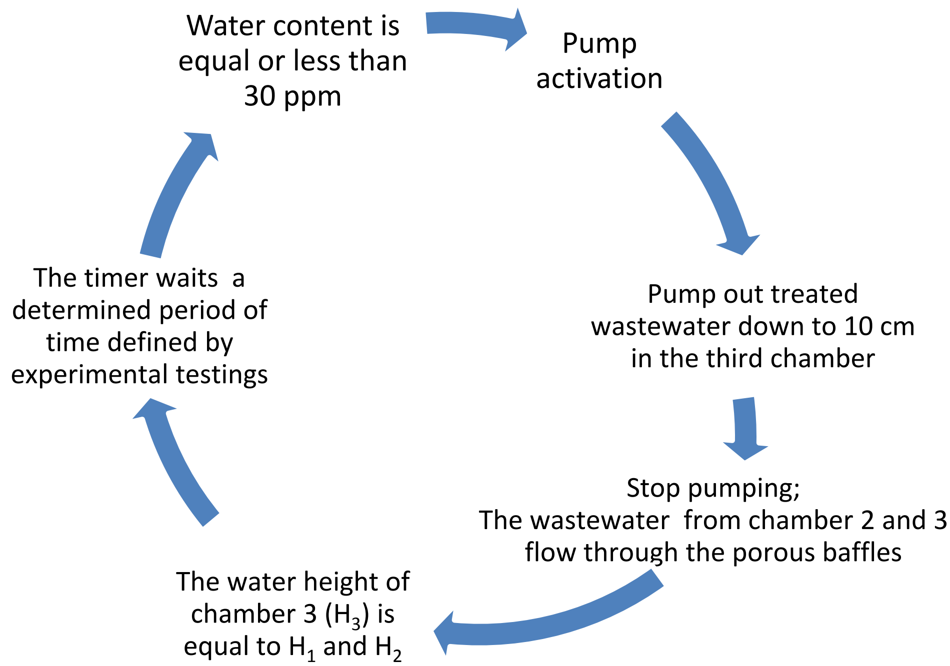

Figure 6: Wastewater Effluent Quality Control

Pipes

The pipe exit is centered horizontally and vertically on the side walls. The reason behind that design is to minimize the turbulent flow in the free oil layer on the surface and for minimizing the turbulence near the solid particles settled on the floor of the chamber. The pipe that conducts the wastewater in the sewage is centered horizontally and it is located at the 2/3 of the wall height in the third chamber. The reason that motivates the design is to increase the volume of water retained for the hydraulic retention time for the microbial degradation. Additionally, the outlet pipe has a 90 degree elbow with the outlet pointing toward the bottom for minimizing the release of the free oil layer.

3.2 BIOLOGICAL TREATMENT

In addition to physical changes to the system, an automated control panel will uses sensors to monitor the wastewater level and wastewater pH. This will also consists of measuring the microbial population, the nutrient level and other parameters described below.

Control system

The control system is performed by a program designed for injecting microbes when a low concentration of microbes is detected by a sensor in the third chamber. The same way, the sensors will adjusts the nutrient concentration, the pH level and the concentration of nutrients (Nitrogen and Phosphorus) and the dissolved oxygen. The volume of microbe injected (inoculum) is determined according to the volume of wastewater remaining in the tanks. The program includes a routine of for hourly data acquisition of the mentioned parameters. The program reports to the maintenance manager lacks of nutrients, microbial agent and enzymes contained in the containers located in the control panel. The level of wastewater and the thickness of free floating oil and/or floating debris should be recorded weekly in a data logger and reported weekly via transmission to the cell of the maintenance manager. If the wastewater level exceeds the allowance for freeboard an alarm is sent to the maintenance manager. Lastly, when the sensors detected an average concentration of 30 ppm or less of the oil content in the last chamber, the water is pumped out of the chambers.

Surface Active Agent

The surface active agents are microbes and detergents that inhibit the formation of hydrogen bond of water molecule and hydrocarbon chain. Since water is a polar molecule and hydrocarbon is a non-polar molecule. In the normal atmospheric and temperature conditions, the water, oil and concrete form three immiscible interfaces that are named the liquid-liquid-solid phase's mixture. The role of the surfactant is reducing the surface tension in the continuous phase for a homogenizing the immiscible liquid. For example, the mixture detergent-water allows the free oil to disperse in the continuous phase. In the maintenance operation, dispersion of oil in a continuous phase of water is desirable because water is a good carrying agent and its viscosity allows a good cleaning of impervious surface.

Microbes

In order to obtain maximize the microbes efficiency, parameters, such as the temperature, the pH, nutrients and the level of oxygen, should be controlled. The bacteria used in wastewater can be of type psychrophiles, mesophiles and thermophiles with stand in temperature ranges respectively from 0^0C to 15^0C, from 15^0C to 40^0C and from 40^0C to 60^0C. The supplied bacteria will grow in temperature between 0^oC and 15^0C because it is wastewater temperature. Typically, organisms better operate with a pH range from 6.0 to 9.0. However, detergents have a tendency to increase the pH beyond the desired range. The control system, provided with sensors, will inject buffers to maintain optimal avoid excessive alkalinity and acidity. However, this process will occur only on occasion, as the metabolic waste produced from microbial activity, such as nitric acid, tends to lower the pH. The inoculum is the first colony of microbes injected in the first chambers. The inoculums is applied in the first chamber of the separator. With additional experiments, we may apply microbes diluted with the washing water with a mixture device of a sanitizing pressure gun (Buckeye International, 2011).

The microbial growth has four distinct phases as shown on the figure. The hydraulic residence time may vary from 0.5 hours to 34 hours depending on the wastewater characteristic and the type of cleaning agent (Rogers and Gibon, 2009). Shortening the time of microbial growth is achieved by avoiding the lag phase. The inoculums should be taken from colonies of microbes from the mid-end of the log phase on the graph.

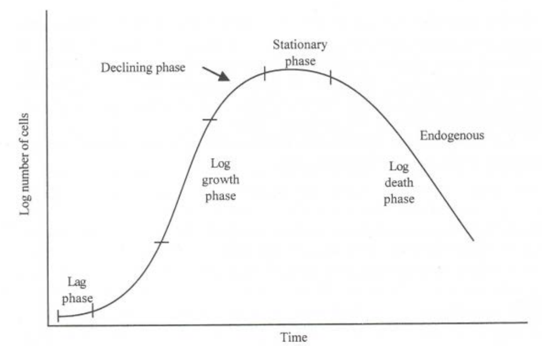

Figure 7: Microbial Growth - Rogers and Gibon (2009)

In the chambers of the collection pit, the homogenized interface of liquid-liquid which are characterized as oil in water emulsification, is an obstacle for the wastewater treatment. Quick-release detergents, which create an unstable emulsification, allow a better physical separation of the oil content. Nonetheless, conventional detergents will make a stable emulsion which will require cleaning other than by physical means.

pH Buffer

The detergent tends to increase the pH above the ideal pH range and in consequence, buffers are required for keeping an optimized alkalinity. Additionally, the metabolic waste produced from microbial activity such as nitric acid, tend to lower the pH.

3.3 OTHER PRACTICES TO BE CONSIDERED

3.3.1 REPLACING CLEANING DETERGENT

As previously mentioned, the current cleaning agent render the oil in a state of emulsion. This state will impede the efficiency of the system, thus other solutions should be look into. In the new design, the addition of the coalescent media and the bacteria degradation will help remove neutralizing these oil particles. Nevertheless, attempts should be made for using non-emulsifying soap. According to the Ontario Ministry of Transportation, three such soaps exist: Hotsy Blue Thunder, Indo 510, and Zep Split Vehicle Wash. In addition to their desired properties, they are product from Canadian companies. However the exact pricing of these soaps was determined. Thus some additional detergent will also be mentioned. (Ontario Ministry of Transportation, February 2007)

Brand	Supplier	Dilution Ratio (H_2O:soap)
Hotsy Blue Thunder	Metrovan Hotsy Equipment Ltd. Surrey, BC	110:1
Indo 510	Flexo Products Niagara Falls, ON	62.5:1
Zep Split Vehicle Wash	Zep Manufacturing Mississauga, ON	62.5:1

Note: Dilution ratio, for Hotsy Blue Thunder, means 110 parts water to 1 part of soap. (e.g. water must be added at a rate of 110 times the amount of soap). So 100 millilitres (mL) of soap requires 11,000 mL (or 11 Litres) of water.

Figure 8: Comparative product - Ministry on transportation of Ontario

In order to increase the efficiency of the coalescent media, detergent with a low phosphate content must be used. The expression “conventional detergent” designates soap without environmental virtue The expression “quick release” means that the detergent in aqueous state with the oil forms an unstable emulsification and after a short period of times the oil particle will separate from the wastewater (McLeod, 1999). The testing will allow determining the recurrent cost of the products and to select the best alternative.

3.3.2 REDUCING THE AMOUNT OF WASTEWATER

One of the major factors in determining the size of the separator is the flow rate. So in order to decrease the flow rate, pressurized water gun can be used. Furthermore, this device will allow the spread of microbial agent. A particular model called the Sockeye will produce a dilution factor from 4 up to 10 with a pressurized water gun including a mixer device. The rate of microbial mix is adjustable to 4 oz of microbe per gallon of water sprayed. The rate of microbial mix is adjustable from 4 to 10 ounces of microbe per gallon of water sprayed. The mixing head is adjustable for different rate of dilution of the substance in the sprayed water.

However it is very important to note that since the amount of water has decreased, the concentration of the oil will increase. The overall effect should be tested once the prototype is built to ensure that the system can handle a higher concentration of oil. Nevertheless, the overall dimension could potentially be reduced.

3.3.3 Maintenance of the coalescent media

The media requires a routinely cleaning (weekly, monthly) for ensuring the plates keep their oleophilic property. Also, the top section of the coalescent media will have accumulated oil scum and solid debris because of the free oil layer. The media need pressurized water wash with a detergent outside the separator chamber. In order to facilitate the process, an access gate will be place right on top of the coalescent media. The exact routine should be adjusted with time, however initially a general check up should be done once a week and the cleaning process should occur once every three month.

4. COST ANALYSIS

One of the important considerations in the cost analysis is the recurrent operational cost of the cleaning agents. An initial fixed cost involves the modification of the tanks embedded in the concrete floor with the baffles, the coalescent media, the aeration system, and the monitoring system.

Components for physical modifications:

Excavation and Embedded Concrete-Casted walls and floors

The change of configuration of the tank by re-sizing its length, width and depth will involve some cost of material and labors. Hewitt Equipment may supply the heavy equipment and labor necessary for removing the concrete slab and digging the room for the new catchments.

Employees will cut a larger area of the concrete floor than required for the desired dimensions for the new tank. They will have to remove the concrete slab and the earth down up the desired depth including the depth required for the thickness of the concrete floor.

The cost of the concrete wall casted on site of the catchments tank will be 1000$ and can be delivered by Bozanto Inc. from Pointe-Claire.

Excavation Concrete walls and floors

The change of configuration of the tank by re-sizing its length, width and depth will involve some cost of material and labors. Hewitt Equipment may supply the heavy equipment and labor necessary for removing the concrete slab and digging the room for the new catchments.

Employees will cut a larger area of the concrete floor than required for the desired dimensions for the new tank. They will have to remove the concrete slab and the earth down up the desired depth including the depth required for the thickness of the concrete floor. The cost of the concrete wall casted on site of the catchments tank will be 1000$ and can be delivered by Bozanto Inc. from Pointe-Claire. Additionally, the four fiber-glass made baffles will cost 125$/unit and therefore the four unit will cost 500$.

Components for Biological Treatment:

Detergent and Enzyme

First, an experiment need to be performed for determining if the quick release detergent is sufficient for meeting regulation of industrial wastewater without microbe. Secondly, an analysis is required for comparing “the treatment from a conventional detergent and the microbe” with “the treatment with a quick release detergent only”. After, the cost analysis may be performed with the products from table 5.

This is a short comparison of prices of cleaning detergents available in Montreal. The choice of necessary products will be more defined after the testing step described above. The choice will be based on the cheapest recurrence cost that will have the highest efficiency.

Table 5: Operational cost

Product*	Quantity	Suggested water dilution ratio (water : product)	Price
Detergent , (Quick release degreaser)	55 gallons (207.9 liters)	--	555.46$
Enzyme X	55 gallons (207.9 liters)	--	826.86$
Bacteria Bio Puck Hydrocarbon	20 pucks	1000 gallons: 1 puck	--
Detergent Floor Kleen Conventional Floor Degreaser (not quick release)	55 gallons (207.9 liters)	15:1	420.00$
Detergent Konk (not quick release)	55 gallons (207.9 liters)	20:1	---

*The name of product and suppliers are kept confidential for marketing reasons

According the price comparison chart, quick-release soaps are more expensive than conventional floor degreasers. Perhaps, a quick-release detergent is required for having an efficient cleaning of the water. The use of a conventional soap would imply a longer hydraulic residence time because the distribution of droplet of smaller size not coalesced by the media in the second unit will be greater. Therefore, the quick-release soap, despite a higher price, may be essential for having an efficient treatment and a short residence time .

Control Panel

The bioremediation system which is a pit management system cost 3495.00$. The implementation of a program for the data acquisition and automated adjustments of the parameters in the wastewater will be evaluated for cost by the consulting firm. This automated system is optional since the parameter can be adjusted manually.

Alpha-Coalescent

The alpha coalescing parts grid which form the vertical coalescing media with the dimension of 20.5" x 32.5"x 1.0" (52.07cm X 82.55cm X 2.54cm) cost 47.84$ .The total cost will be times 144 plates necessary for forming a coalescing block with the required dimension. Therefore, the total cost is 6900.00$.

pH Controller

The pH controller parts which includes a sensor cost 615.00$ additionally, the tubing of 1/4" ID x 7/16" OD (0.635cm x 1.11cm) will cost 5.66$ per foot. For eight foot, the cost of tubing is 45.00$.

Summary of the Cost:

Physical component:

Pre-Casted concrete walls and floors:	**1000$**
4 Baffles:	**500$**
Alpha Coalescent parts"	**6900$**
Butterfly Valve:	**50$ (optional automated control valve: 500$)**
Centrifugal Water Pump:	**100$**
4 Disc diffuser:	**60$**
Air diffuser Pipes:	**40$**

Biological treatment:

Control Panel:	**3495$ (optional automated system: 25 000$)**
pH Controller part:	**615$**
Tubing for sensors:	**45$**

Recurrent cost (To be determined):

Detergent

Microbe

Enzyme

Nutrient

Total of determined cost:	**12, 805$ (excluding optional choice and recurrent cost)**

4. PROTOTYPING, TESTING, OPTIMIZATION

4.1 PROTOTYPE

A scale model of the three stage collection pit can be built for testing its efficiency with the wastewater released in the garage of Hewitt Equipment. The minimum scale must be 1:40 because under this ratio, the surface tension or electro-chemical forces have an effect that impedes the inertial forces (pers. comm. Dr. Viaja Raghavan, 2011). For the testing of the dimension based on Stokes's Law , 1:10 is a reasonable scale for the testing purposes. The real dimensions are 6 meters x 1 meter x 0.75 meter, therefore the scale model will be 60cm x 10cm x 7.5cm.

The stoke number is the dimensionless measure useful for having a ratio of raising particles between the prototype and the real scale model.

$$S_k = \left(\frac{\mathrm{V}*\mathrm{d}_p^2*\rho_p}{18*l*\mu}\right) \quad \text{Eq. 5}$$

Where V = velocity (m/s)
d_p = diameter of the particle (m)
ρ_p = density of the particle (kg/m^3)
l = characteristic length (m)
μ = viscosity of the wastewater (m^2/s)

The Froude number characterize whether the state of the wastewater is sub-critical or super-critical. The first chamber is slightly turbulent induced by the inflow up to 25gpm (5.7m^3/s).The turbulence needs to be minimized for a proper settlement of the solid particles. The second chamber must have a turbulent flow in the coalescent media for optimizing the coalescing of the oil droplet. The state of fluid in the third chamber must remain as laminar as possible. The laminar state is required based on the assumption that the wastewater after the coalescent media may be treated further. The turbulence of wastewater would involve a greater mixing of the wastewater. The remaining oil droplet will raise by the difference the specific gravity of the continuous phase or degraded by the microbial activity that is accelerated with the addition of enzymes. The larger droplets may raise and the smaller droplets will be degraded. The dynamic of wastewater inside the chambers previously described, may be optimize by the height of the second and the fourth baffle which determine the entry of water respectively in the second and third compartment. The Froude number may be used for comparisons between the prototype and the real scale model.

$$Fr = \left(\frac{V}{\sqrt{g*l}}\right) \quad \text{Eq. 6}$$

Where V= velocity (m/s)
g = gravity (m/s^2)
l = characteristic length (m)

4.2 TESTING

The testing will involves a systematical approach for determining the timing and quantity of microbe input in the first chamber and for the addition of enzymes in the third chamber. The testing is primarily for simulating the extreme case such as the weekly wash event, when the separator is solicited for the given design criteria (25 gpm or 5.7m^3/h).

The testing will include comparison in wastewater effluents for different heights for the baffle 2 and 4 with constant collection pit dimensions and constant coalescent separator dimensions. The same approach may be repeated for testing different volume of the coalescent media with constant baffles height and constant collection pit dimensions.

The aerobic microbial activity transform the hydrocarbon substrate in water, carbon dioxide and waste such nitrate and sulfate. Nutrients are nitrogen and phosphorus which is already contained in wastewater and can be supplied by a maintenance operator if needed.

$$\text{Organic matter} + \text{Microbes} \xrightarrow{\text{yields}} \text{More microbes} + \text{CO}_2 + \text{H}_2\text{O} + \text{waste energy} \quad \text{Eq. 7}$$

(API- Biological Treatment, 1969)

Ex-situ testing is necessary for determining the microbe kinetic with the garage wastewater which contains a quick release detergent. The kinetic in microbiology is defined as the speed at which the reaction occurs.

$$A + E \rightleftharpoons_{k_{-1}}^{k_1} EA \xrightarrow{k_2} E + P \quad \text{Eq. 8}$$

The enzyme will reduce the activation energy for the product formation by the reactant

The Michaelis-Menten equation gives an approximation of the velocity at time t during the reaction:

$$V_t = \left(\frac{V_{max}[S]}{K_m[S]}\right) \quad \text{Eq. 9}$$

Where V = the velocity at any time (mol/s)

[S] = the substrate concentration at this time (mg/L)

V_{max} = the maximum speed (mol/s)

K_m = The Michaelis-Menten constant

The constant of association (K_m) evaluated the affinity at $V_{max/2}$ of the substrate and the enzyme for the formation of the complex substrate-enzyme. If K_m has low value, it means the association rate is greater than the dissociation rate and vice-versa. Therefore, K_m values will be used for the selection of best product from a comparative yield analysis of diverse products.

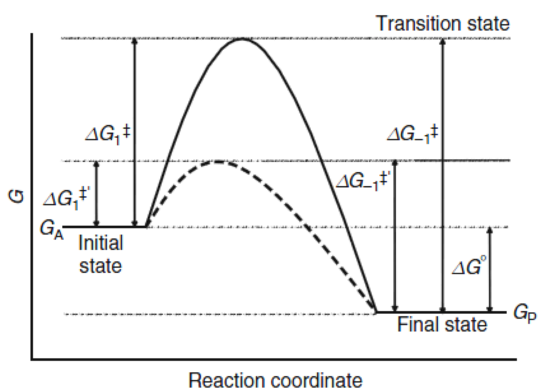

Figure 9: Constant of Dissociation (Km) - Rogers and Gibon, 2009

Conclusion

In conclusion, due to the unconventional physics behind the process, the design process was challenging. Many parameters have been overly design to ensure the compliance of the final 30 ppm oil concentration required by municipal regulations. Nevertheless, principals based on various literatures were followed. With simulation of a prototype, the overall design parameters can be improved.

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APPENDIX I

A1 Dimensions of the collection pit according to the volume of water generated on weekly wash.

Catchment tank: 72” * 58” * 37” = 1.83m * 1.47m * 0.94m = **2.53 m^3**
Tank that contain the O/W separator: 90” * 58” * 37” = 2.29m * 1.47m * 0.94m = 3.16 m^3
17 gallons per minute * 45 minutes = 765 gallons
765 gallons * 3.78 liters/gallons = 2895 liters
2895 liters * 1.5 of Safety Factor = 4344 liters or **4.34m^3**
Inflow wastewater >> retention tank capacity
4.34 m^3 >> 2.53m^3

A2 Determination of the size of the coalescent media (According to Brentwood Industries)

The surface loading rate of the coalescent medium:
Surface loading rate = $Q_m/A_H = 0.00386(S_w - S_o)/\mu$
Q_m = design flow (ft_3/min)
A_H = projected horizontal area (ft_2) for all coalescing surfaces (one side for each plate)
S_w = specific gravity of water
S_o = specific gravity of oil
μ = wastewater viscosity in poise

$Q_m/A_h = 0.00386(S_w – S_0)/\mu$
Qm = design flow (ft3/min) (25gpm or 3.34ft^2/s)
Ah = projected horizontal area for all coalescing surfaces (ft^2)
Sw = specific gravity of water (1)
So = specific gravity of oil (0.88 to 0.92)
μ= wastewater viscosity in poise (0.01)

The design is conceived for the worst case scenario and therefore the specific gravity of 0.92 is taken into account for the calculation. As discussed in the flow control section, the pipe is designed to have a maximum flow of 25 gpm (5.7 m^3/h).

$A_h = Q_m/ 0.00386(S_w – S_0)/\mu$
Ah = to determine
Qm = 3.34ft^2/s
Sw = 1
So = 0.92
μ= 0.01
A_h = 108.16 ft^2 or 10.05m^2

2[3x1]= 6m^2
2[1x0.5]= 1m^2

$\frac{2[3x0.5]= 3m^2}{10\ m^2}$

A3 Characteristics of FlexAir Threaded Disc

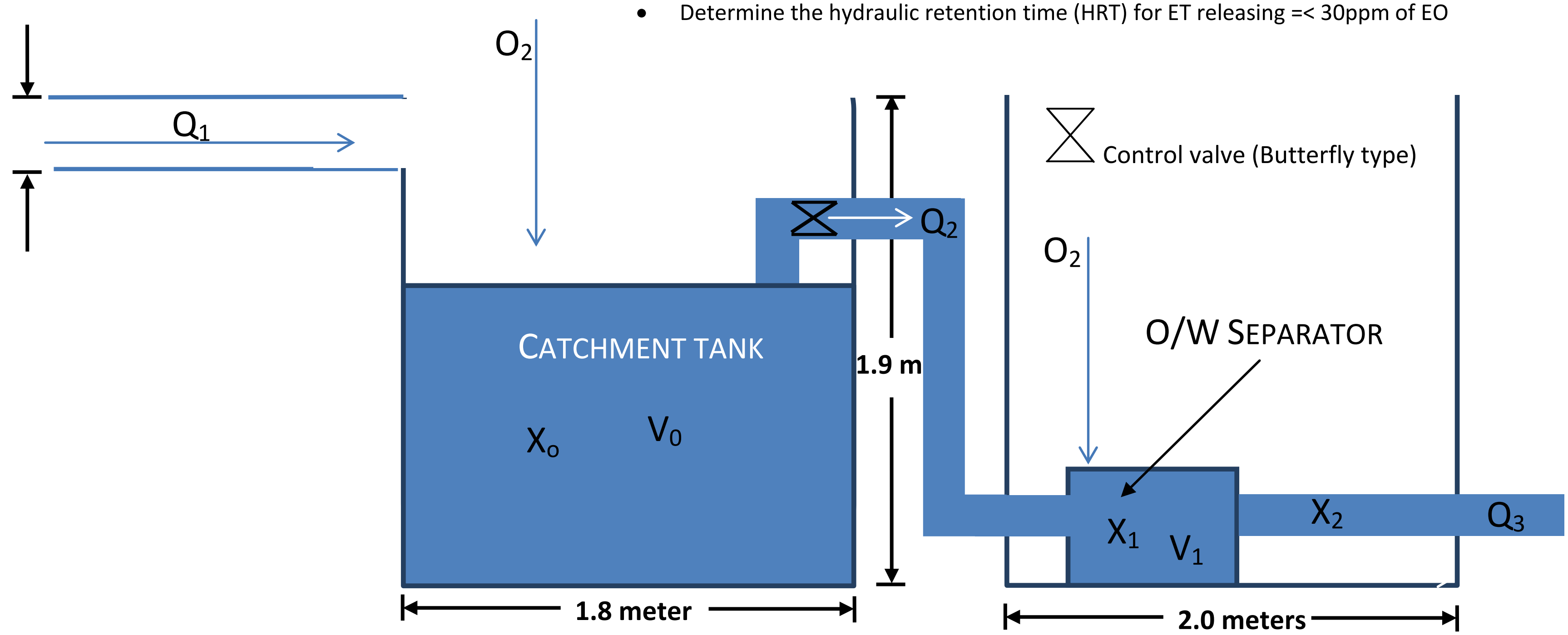
Part Number:	01691			
Model:	7" Standard			
Peak Airflow:	scfm	3.0	$m^3{}_N/h$	4.7
Design Airflow:	scfm	0.5-2.5	$m^3{}_N/h$	0.9-4.3
Diffuser Diameter:	in	9.0	mm	228.6
Active Surface Area:	ft^2	0.26	cm^2	221
Unit List Price:	$15.00			
Stocked:	No			

APPENDIX II: EXTENDED SIZING CALCULATION

	Diameter of oil droplet, D [µm]					
	150	100	80	60	40	20
Q_d =17						
Separator Minimal Length, L [m]	1.70	2.55	3.18	4.24	6.36	12.73
Separator Minimal Width, W [m]	0.34	0.51	0.64	0.85	1.27	2.55
Separator Minimal Depth, d [m]	0.14	0.20	0.25	0.34	0.51	1.02
Separator Minimal Volume, V [m3]	0.08	0.26	0.52	1.22	4.12	32.97
Q_d =25						
Separator Minimal Length, L [m]	2.06	3.09	3.86	5.14	7.72	15.43
Separator Minimal Width, W [m]	0.41	0.62	0.77	1.03	1.54	3.09
Separator Minimal Depth, d [m]	0.16	0.25	0.31	0.41	0.62	1.23
Separator Minimal Volume, V [m3]	0.14	0.47	0.92	2.18	7.35	58.80
Q_d =30						
Separator Minimal Length, L [m]	2.25	3.38	4.23	5.63	8.45	16.90
Separator Minimal Width, W [m]	0.45	0.68	0.85	1.13	1.69	3.38
Separator Minimal Depth, d [m]	0.18	0.27	0.34	0.45	0.68	1.35
Separator Minimal Volume, V [m3]	0.18	0.62	1.21	2.86	9.66	77.29
Q_d =50						
Separator Minimal Length, L [m]	2.91	4.36	5.46	7.27	10.91	21.82
Separator Minimal Width, W [m]	0.58	0.87	1.09	1.45	2.18	4.36
Separator Minimal Depth, d [m]	0.23	0.35	0.44	0.58	0.87	1.75
Separator Minimal Volume, V [m3]	0.39	1.33	2.60	6.16	20.79	166.31

APPENDIX III: SCHEMA OF ORGINAL SYSTEM

- Oil-Water Separator (O/WS): Device inefficient for treatment of wastewater containing emulsified-oil (EO)
- Change the sizing of the current O/WS + add a control valve+ enzymatic treatment (ET)
- Determine the hydraulic retention time (HRT) for ET releasing =< 30ppm of EO



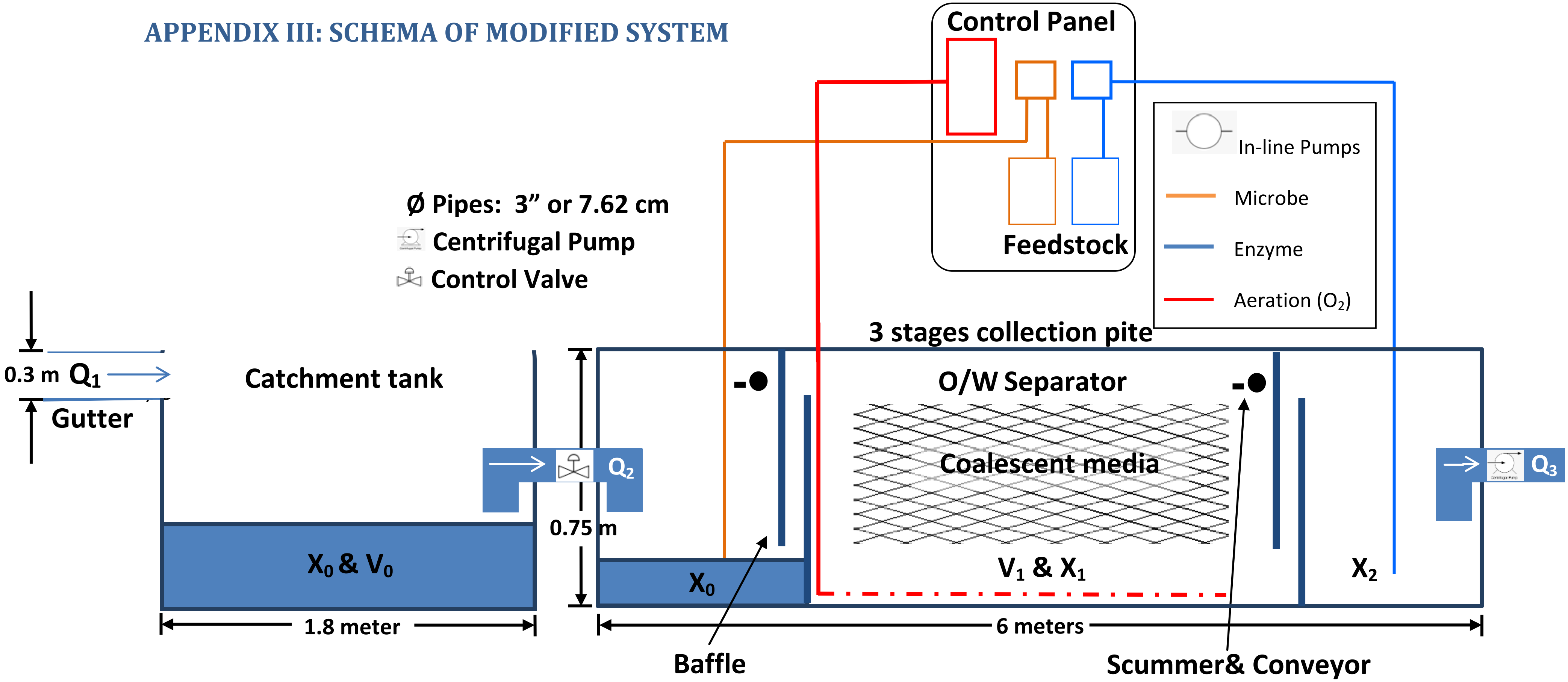
Main parameters:

X_o = > X_1

X_1 = 6 to 200 ppm (mg/L) | V_0 = 2180 L (2.78 m^3) | Q_1 = 17 gpm (3.86 m^3/h)

X_2 = Required =>30 ppm (mg/L) | V_1 = 60 L (6.0 X 10^{-2} m^3) | Q_2 = To be determined according to HRT

APPENDIX III: SCHEMA OF MODIFIED SYSTEM



Main parameters:

X_o = > X_1

X_1 = 6 to 200 ppm (mg/L)

X_2 = required =>30 ppm (mg/L)

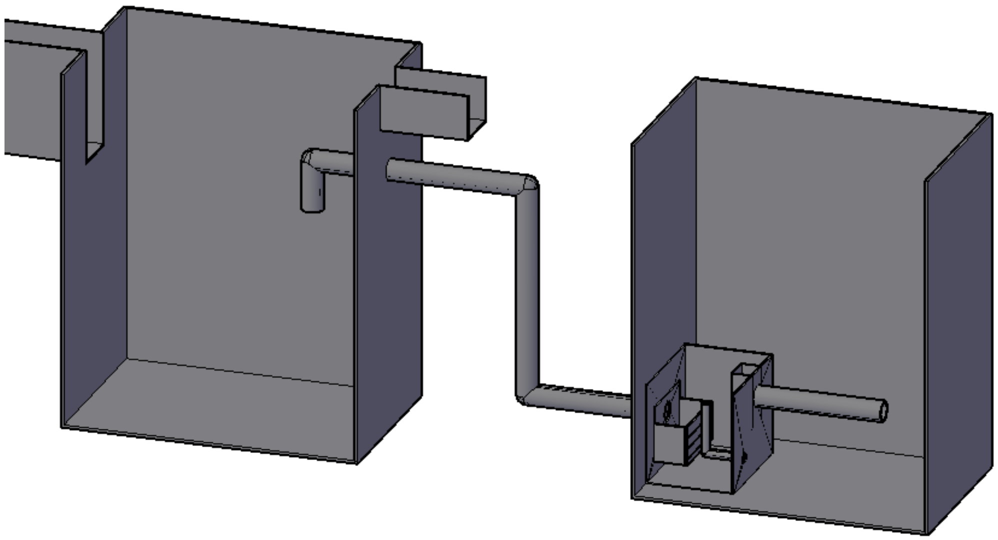
V_o = 1350 L (1.35 m^3)

V_1 = 5830 L (5.83 m^3)

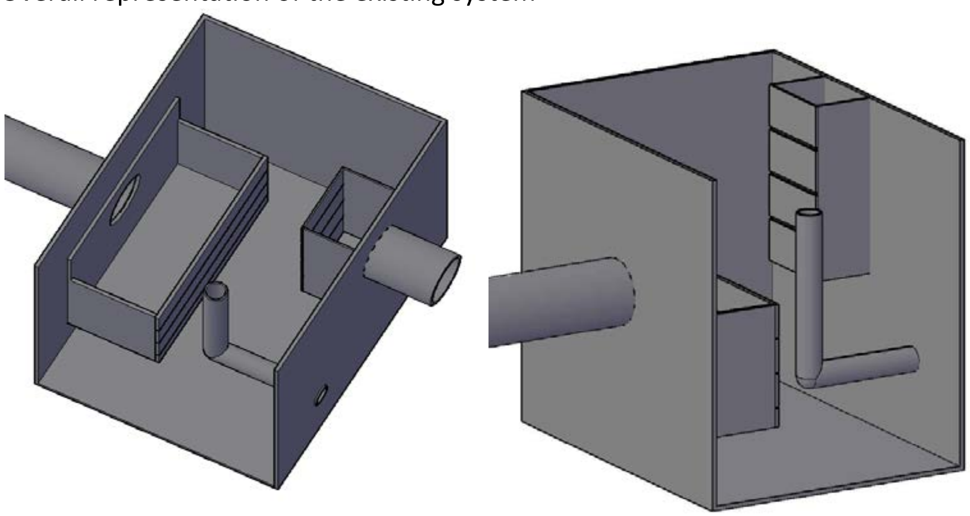
Q_1 = 17 gpm (3.86 m^3/h)

Q_2 = 25gpm (5.67m^3)

APPENDIX IV: OVERVIEW OF THE CURRENT SYSTEM



Overall representation of the existing system



Close up view of the existing separator

APPEEDIX V: NEWLY DEVELOPED SYSTEM