Engineering Design 3
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Methodological Treatment of Cigarette Butts by Anaerobic Biological Decomposition

BREE 495

Alberic Fournier
Mohamed Debbagh
Sinuo Wang

AF: 260502560
MD: 260565443
SW: 260515073

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ABSTRACT

Every year, thousands of cigarette filters are tossed away into the environment. This accumulation of litter can travel to natural environments. Cigarette butts trap over 400 non-degradable toxins, after being smoked, and present a threat to the environment and its ecosystem [1]. Filters of most cigarettes are made of cellulose acetate. Research has found that cigarette filters left on the ground and in the sun alone will degrade in 18 months to 10 years (Wilson, 2010). The goal of this project is to find an innovative solution to decompose these cigarette filters. Our team has designed a cigarette filter collection system along with a cigarette degradation bioreactor that is capable of anaerobic degradation of cellulose acetate. Our operation will focus on small scale implementation with the help of the groundskeepers at Macdonald campus of McGill University. The bioreactor will expedite the degradation process to 1 month and produce a biogas that could be used as fuel. A prototype was built to test on a small scale using mason jars and piping. Further toxicity and gas quality testing will need to be performed for analysis of our system

INTRODUCTION

About 5.6 trillion cigarettes are smoked globally every year, 4.5 trillion of which are improperly discarded (Berger, 2010). Cigarette filters are now considered one of the most commonly discarded pieces of litter. A rough calculation can be made, to show that the total amount of butts tossed add up to 765,000 tons of non-degradable litter to the environment per year (Appendix A1). Most standard cigarette filters are made of artificial and synthetic cellulose polymers, which are resistant to natural degradation processes. In ideal conditions, each cigarette butt may take up go two years to break down (Wilson, 2010). Based on calculations in Appendix A2, cigarette filter waste will double on a global scale within 16 years. It is evident that a problem is emerging from this sector of municipal solid waste. This project goes in further depth of the treatment of this problem and the possible solutions of the problem definition and design goal mentioned below.

Problem Definition

The environmental impact of municipal cigarette filter waste is a critical issue. More often than not, cigarette butts are tossed improperly without a second thought. Municipal and private facilities often provide designated cigarette disposal collection systems, but are frequently overlooked or completely ignored. The fate of cigarette filters that are properly collected by these facilities do not offer a better alternative. These filters are thrown into landfills alongside other waste products. Though landfills are the primary route of most waste disposal, they are associated with the problems of space availability, greenhouse gas emissions, discharge of toxic leachate into ground water, and loss of potential resources to the environment. The ultimate fate of cigarette filters is an issue that needs to be dealt with for the future of a cleaner environment.

Design Goal

Thus the objective of this project is to design a system that could minimize the amount of cigarette filter waste and its effect on the environment. The potential solutions encountered during the process of scientific research are based on the idea of breaking down the filter waste to natural and less harmful components.

The possible options for a design solution of this issue had been previously discussed in this project. The mentioned possible solutions included, biodegradable cigarettes, UV degradation and others. These methods all included the aspect of biological decomposition at an accelerated rate to relieve the environmental stress burdened by the cigarette filters. This Idea was incorporated to determine the final design solution of an anaerobic degradation reactor. The design of a biological degradation reactor is an option that can greatly reduce the amount of municipal solid waste (MSW) in landfills. Once a steady supply of cigarette filters has been established, from a collection system that will be discussed later, it can be processed into a granular feed for a bioreactor. Cigarette waste along with any trapped toxins within the filter can be digested to produce a degradable material and other useful byproduct giving a consumer a reason to dispose of cigarette butts. Figure Xa in appendix B shows early design sketches of what a solution may look like.

MATERIALS AND METHODOLOGIES

Literature Review

Bioreactor System Design According to the International Union of Pure and Applied Chemistry (IUPAC), a bioreactor is defined as an 'An apparatus used to carry out any kind of bioprocess' [4]. The engineered device should be able to sustain an active microbial environment in which specific microorganisms can biochemically alter feed to produce a biologically active substance depending on the system. Many aspects of the reactor will need to be considered to synthesize an ideal environment for the degradation of cigarette filter (Cellulose Acetate). Figure 1 below shows a flow diagram of the design process of a bioreactor system. Considerations for our thermal and biological degradation reactor were based on this model (IUPAC, 2014).

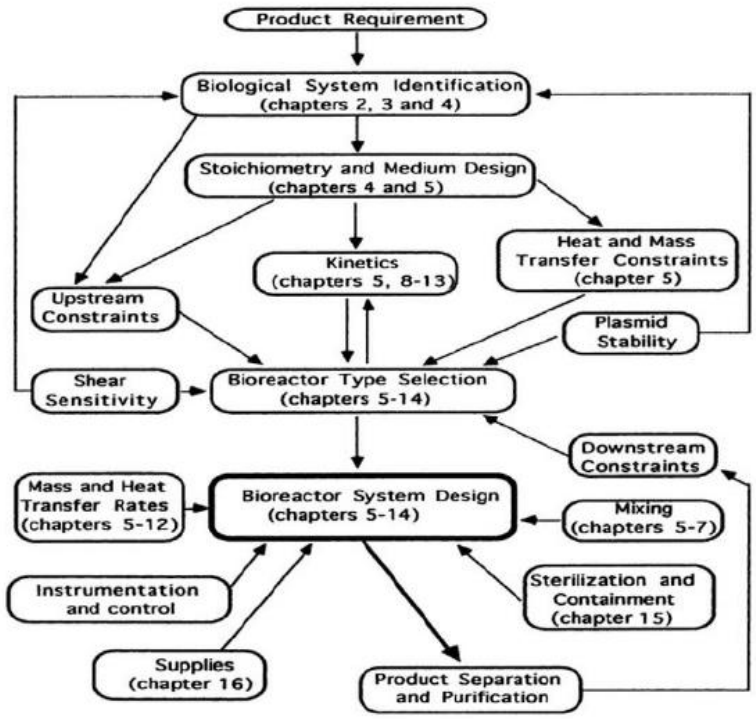

Figure 1. Schematic representation of the process of bioreactor system design (Asenjo, 1994)

Based on Ji-dong Gu's experiment on the effectiveness of aerobic composting degradation and anaerobic bioreactor degradation, a final design will feature an anaerobic biological process. Both anaerobic and aerobic methods are feasible and have shown to completely break down the cellulose acetate fibers with an accelerated rate (8 - 60 days) in the bioreactors. An anaerobic system will produce biogas, such as methane, as its terminal product which can be used for other purposes.

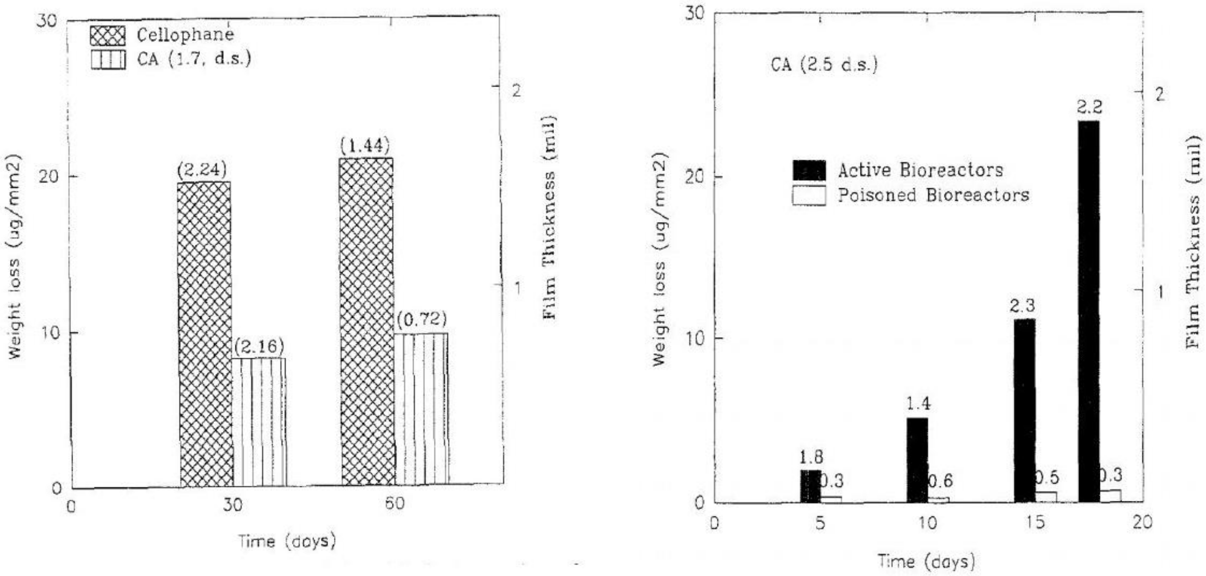

Figure 2: a) Weight loss of CA and Cellophane in an anaerobic bioreactor over time of incubation (Gu et al. 1993) b) Weight loss of CA and Cellophane in an aerobic composting bioreactor over time of incubation (Gu et al. 1993)

Microbial Medium Selection The biodegradation of Cellulose Acetate (CA) and other polysaccharide esters vary based on its degree of substitution (d.s.). In general, higher d.s. CAs are harder to degrade since there are only a few species of microorganisms that thrive on these water insoluble polymers (Samios, 1995). These microorganisms produce esterase that breakdown the cellulose acetate making it degradable.

Cigarette filters contain cellulose acetate with a high d.s. in the range of 1.7 to 2.5, making it a very good barrier against microbial penetration. It was believed that most microorganisms could not perform an enzymatic process along with cellulase that could break down the high d.s. of cellulose acetate found in these cigarette filters. Recently it was discovered that a combination of deacetylation followed by cellulase activity can lead to the biodegradation of CA associated with the high d.s. found in cigarette filters. Acetylxylan esterase was found to be produced along with xylanase by the species *Butyrivibrio fibrisolvens*. This combination of enzyme activity seems to enhance the degradation of natural polymers with high d.s. (Gu et al., 1993). *Butyrivibrio fibrisolvens* can be found in the lining of the gastrointestinal tract of all mammals. Sewage would be a good medium to find and host this bacterium for the use of our bioreactor design. Optimal salt medium conditions could also be controlled to facilitate the biological activity to occur.

Thermal Aspect The degradation of most polymers is optimal at specific temperatures. At extreme temperatures cellulose acetate will degrade at an accelerated rate. The optimal temperature in which CA will degrade at the highest rate is 60C. The bioreactor should operate at this temperature. It is not known whether *Butyrivibrio fibrisolvens* is a thermophile, but they are found in conditions of warm to hot temperatures. If it is not possible for *Butyrivibrio fibrisolvens* to thrive in this condition, then other similar microorganisms can be researched. The temperature may also be adjusted accordingly if required (Gu et al., 1993).

Limitations Though there are many advantages of designing a bioreactor system to solve the problem of cigarette filter waste, there are some potential limitations. One limitation that this design may face is creating a bioreactor that is used for large scale operations. Since trillions of cigarettes are thrown out every year, this would require a significant amount of equipment to handle this waste. It is also hard to focus on only cigarette filters when dealing with waste degradation. A possible solution to this limitation that is currently being focused on is the creation of a bioreactor landfill. Another limitation to this system is that it is completely dependent on the supply of cigarette filters acquired from the collection system. Though the system can greatly reduce the MSW in landfills, it cannot reduce cigarette waste that is not collected and is just tossed into the environment. Due to limitations and other resource restrictions, our design project will also focus on a small scale operation and the use of only cigarette filter waste

Chosen Design Method and Considerations

Using the knowledge and information from the literature above, the decision was made within the team to build a system of small scale bioreactors along with a redesigned collection system to achieve the set design goals. This design path must involve the collection of cigarette filters when considering the whole process since the ultimate goal is to reduce the waste product found in nature. The use of the bioreactor is to treat the filters that are collected to minimize the effects that it would have if it were found in nature or thrown into a landfill.

Redesigned Collection System While designing the collection system some considerations had to be taken into account. The main concern was the issue of governmental backup. Policies for a barcode system on cigarette filters and laws for recycling cigarettes could be beneficial toward a solution. Without the support of governmental regulations, a collection system could not be functional. Implementation of scanning system to analyze barcodes on cigarette is also necessary for the system and will be discussed in the collection tray section. Another key consideration of the collection system is the preparation for degradation. Features of this include a grinding and humidification process that could facilitate biological conditions before the transfer of the filters to the anaerobic bioreactor. Adequate supplement such as a water reservoir or a motor to run these features will also need to be considered. These considerations are mentioned in the flow chart shown below. It represents the lifecycle of a cigarette from manufacturing to collection to degradation with and without governmental backup. In the manufacturing process, the cigarette is ideally labelled with a barcode system and is later thrown away by the consumer. In another case, if there is no government subsidies, cigarettes without any barcodes are thrown away by the consumer. The next process is collection of the cigarettes. In the case of the labelled cigarettes, a barcode recognizing collection tray would gather many of the cigarette filters. Without barcodes, another system to recognize cigarettes need to be developed, such as a material recognizing collection tray. No cigarette recognition system would result in either conventional collection method: community collection system or as uncollected cigarette waste. Degradation of cigarettes is solely carried on if the filters are collected through the barcode or material recognizing collection tray.

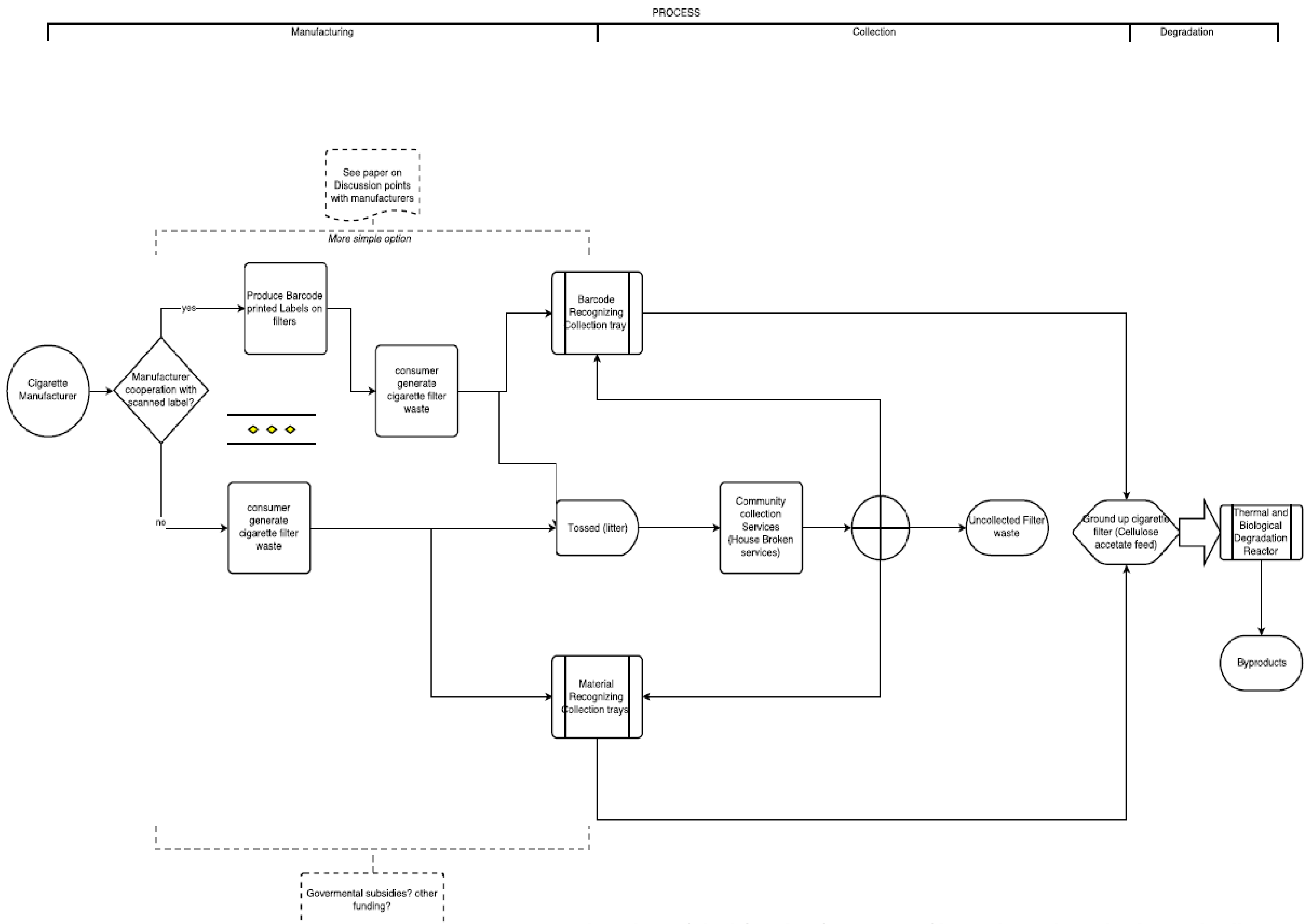

Figure 3: Flow chart of the lifecycle of a cigarette filter and its role in the designed collection

Anaerobic Bioreactor Treatment When considering the anaerobic bioreactor, some essential considerations had to be examined before any prototyping. For any bioreactor system, the environment is key to support the growth of microorganisms. The first considerations were thus related to the environment necessary for the microorganism to strive: pH, temperature, humidity, inoculation/incubation period and substrate. Since this project is dealing with toxic products, making sure that the end product is less toxic than input is a significant consideration for the success of this experiment. A toxicity testing for the biomass will be conducted to test the end product at the end of the experiment. A gas quality testing using gas chromatography will also be carry on in order to analyze the biogas collected. The last consideration is the mode of operation for this anaerobic bioreactor: batch, semi-batch or continuous. For the purpose of this project, semi-batch operation will be use because the medium can be recycled. Each parameter will be described in details in the anaerobic bioreactor section.

Sampling

To test the ability of the mentioned design, samples of cigarette filters were needed. In order to understand the full effects on the anaerobic bioreactor, cigarette filters of different condition should be tested. Figure 4 below shows the cigarette samples that were collected from the collection stations around Macdonald Campus of McGill University. These cigarette filters are used by the population at the campus and have toxins trapped within them. It should be noted that when collecting the cigarettes, the head of facilities management (Peter Knox), had mentioned that the collectors maintained anaerobic conditions when containing the filters. This may be the reason why the filters had been partially degraded when retrieved for testing. There may be other reasons for this such as the combustion of the filters themselves if they were not properly put out after smoking.

Figure 4: Samples of used cigarette filters collected for testing from the collection stations at Macdonald Campus of McGill University

Samples of unused cigarette filters were also obtained for testing. These samples were used to compare the degradation rates alongside the used filters. They also serve as a control for the toxicity testing of the final products of the bioreactor mentioned in the testing section of this paper. A key objective of the bioreactor is to produce a product that is less harmful than the inputs. By comparing used filters filled with toxins to ones that are toxin free we could determine whether it is producing harmful compounds.

The samples were ground up using a food processor and used as a granular feed for the bioreactor. In theory, the conversion of the samples to granular feed and its preparation for the bioreactor should be taken care of in the redesigned collection tray. The Redesigned collection tray will be further analyzed in following section of the paper.

<u>REDESIGNED COLLECTION TRAY</u>

Parameters

Throughout this project, there was a significant focus on a collection system that would be included along with a decomposition solution in order to gather the cigarettes for degradation. A bioreactor capable of degrading cigarette filters would not be efficient if a collection system is not designed alongside. One of the main issues of this project was to offset the waste found in the environment due to the littering of cigarettes. As mentioned previously, one of the major criteria for this project is public awareness and education when it comes to littering. Thus in order to incite the public to throw their cigarette filters in a disposal container, some sort of incentive based system needs to be included. One of the main issue that needs to be taken into account for the purpose of this project distinguishing cigarettes from other garbage collected. The system needs to include a parameter that allows it to identify the trash as a cigarette and for the client to receive his or her reimbursment. One possible solution to this problem is to include a coding system on each cigarette.

Literature Review In recent times, a numerous amount of cigarettes are traded illegally around the world. This phenomenon provokes large companies such as Philip Morris International (PMI) as their products are counterfeited and sold at a lower cost. According to some statistics, about 11% of the world's consumption of cigarettes are illegally traded annually *(PMI, 2014).* With the increasing contraband and illicit trade of cigarettes around the world, the Framework Convention on Tobacco Control is seeking new ideas to regulate the trade of cigarettes. The World Health Organization (WHO) alliance has already come up with alternative solutions including coding and marking of tobacco. Such methods include barcodes, invisible ink, radio frequency identification (RFID). These technologies are merely used for the identification and monitoring of cigarettes. For the purpose of this project, a barcode could be used to track and identify a cigarette filter. The barcode system commonly known and are present on all consumer products for the purpose of tracking. Barcodes have also been used on cigarettes packs since 2007 after the European Union reached an agreement with PMI and Japan Tobacco International in order to minimize illicit trade. An example of barcode usage in current practice is happening in Singapore. Singaporean authorities established a new regulation against cigarette illicit trading in which every cigarette will be inscribed with a "SDPC" (Singapore Duty Paid Cigarette) mark in addition with vertical lines. In application since March 2013, this law is applying to every cigarette sold in Singapore in order to differentiate between the unpaid and paid duty free cigarettes on the territory. Any cigarettes found without the SDPC mark will be considered illegal. This information was used when design a collection system for this project.

Design

The essence of having barcodes on each cigarette is to track the cigarettes to avoid littering. The collection system will thus include a scanning system in order to recognize the object as being a real cigarette. This basis is similar to the reverse vending machines that exists in countries with mandatory recycling policies. This machine incites customers to recycle empty cans or bottles for the reward of $0.05 or $0.10 respectively. Even if some consumers find it time consuming to bring back their empty cans/bottles, homeless people are always pleased to go instead and to collect a few dollars. As a consequence of this regulations, cans/ bottles are never littered on the streets. The fate of cigarette filters could be similar with some new policies and regulations.

This collection system offers a new way of dealing with cigarette filters. However, as mentioned previously in the consideration section, some governmental backup would be required in order to install barcodes on each cigarette. Recycling regulations on cigarettes also need to be implemented by the government.

For this project, a prototype of the collection system was done. Figure 5 below shows an AutoCAD drawing of the collection system of the front and side views.

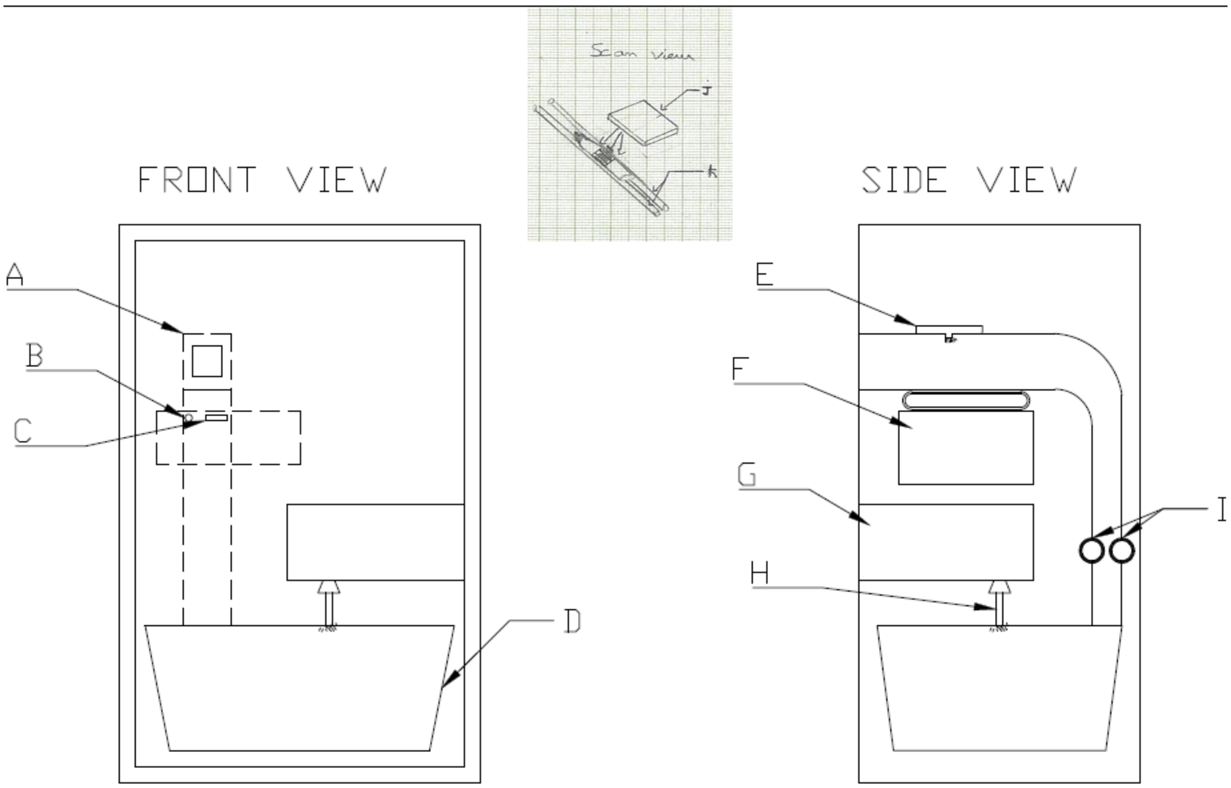

Fig 5: AutoCAD drawing of the collection system from the front, side and scanner view.

Each letter represents a critical component of the design. Some features are originally from the reverse vending machine (RVM). The size of the collection system is similar to RVM, 1-meter-wide by 1.8 meter high.

A: The user interface: allows the consumer to interact with the machine in order to know details about the procedure. For example, if he wants to know how much money he collected before asking for the receipt.

B: The receipt button: permits the customer to receive his receipt when desired. The customer then gives it to the cashier in order to receive his money.

C: Receipt dispenser: gives the customer his receipt.

D: Collection bucket: refers to the large container that stores all the cigarettes in the collection system. The latter has a capacity to hold on average two thousand cigarette filters. It can be removed from the collection system from the back.

E: Scanning system: scans the barcodes from the entering cigarette filters. If it recognizes the object as being a "True" cigarette, a message is send to the rotating bars to keep the cigarette. If the barcode does not exist or is too damaged, a message is send to open the rotating bars to allow the trash to fall into the garbage bucket. If it recognizes the object as being a "True" cigarette

F: Garbage bucket: is where all the "false" cigarettes are collected. The capacity of the garbage bucket is 10 liters.

G: Water reservoir: conserves the water used for cigarette humidification.

H: Water spray: is used to humidify the cigarettes to facilitate the degradation.

I: Grinder: allows to grind and crush the cigarette filters into smaller pieces. This process facilitates the degradation of cigarettes.

J/K: close-up components of E

Regular maintenance of the collection system is required to remove the humidified cigarettes as well as the garbage.

Cost Analysis

Recommended Return Since the collection system is incentive based, a deposit fee legislation needs to be installed on cigarette packs. The price per cigarette recycled needs to be determined. For the purpose of this project, the recycling deposit is based on water bottles according to the site *Business Insiders*. In this research it is known that the average price of a water bottle is $1.97 per liter. The recycling deposit is 10%, which gives a recycling fee of $0.04. Regarding cigarettes, the research was based on the average cost of a cigarette pack in Canada. Normally, a pack of 25 cigarette costs $12 in Canadian stores. If the 10% deposit is applied for cigarettes, it will result in a cost of $1.25 per pack of cigarette (See Appendix A.3 for calculation). In this case, no recycling fees is recommended because consumers would not consider recycling for a lower refund price. Even if some consumers would not bother recycling their cigarettes for some extra money, others could benefit from this system. Scavengers and homeless people could be incorporated in the collection process. Benefits include profit for the homeless from the cigarette collection system while cleaning the streets of cigarette filters and providing filters to the collection trays.

Ideal Tray Cost The price of a reverse vending machine should also be analyzed to estimate the cost of the collection system. After some research, the bracket of price for RVS is between $1000 and $3000 depending on the type and efficiency of the reverse machine. Since the process is the same but with some different features, the price of a collection system should fall into the same range of price.

ANAEROBIC BIOREACTOR (Prototype)

Small Scale Treatment

The primary focus of this project was on the biological treatment of the cigarette filter samples. The design that was chosen for this project consisted of a system of small scale bioreactors or "serum bottles" that are connected with purge tubes to simulate semi-batch conditions of a bioreactor. The system would have to consist of; a vessel that contains the biological activity in anaerobic conditions; a gas collection and extraction system; and a medium that would facilitate the degradation process as well as maintain the selected bioreactor conditions.

Components

"Serum Bottle" The vessel of the designed prototype, also known as the "serum bottle" because of the small scale nature of the operation, contains the biological medium and maintains an anaerobic environment. Based on this information a system of mason jars and sealed rubber lids was selected as the vessel due to its ability to be vacuum sealed. 2 protruding openings on the lid of the vessel can be observed from the figure below. The lids were modified to include a gas valve and sample extracting opening. The left opening in figure 6 a. is the gas valve that will allow biogas produced by the biological medium to be transported to a gas collector. The right opening from figure 6 a. is an opening that is usually sealed with a cap that could be opened for sample extraction and testing.

Figure 6: a) aerial view of the Vessel or "serum bottle" of the prototype b) side view of the vessel of the prototype

Gas Collection Figure 6 below shows the AutoCAD rendering of the prototype. Indicated by a red circle is the schematic of the gas collector prototype. The gas collector consists of a system of 2 PVC pipes and a tube running through the middle. One PVC pipe is slightly smaller than the other and fits over the tube. The sides are then filled with water and allows the smaller pipe to rise due to buoyant force. Once biogas starts traveling through the tube into the collector, it will be trapped between the water table and the PVC container. This will cause the container to further rise. Increments were placed on the side of container to indicate the volume of gas collected. The gas could then be extracted using a syringe for further testing or other practical uses.

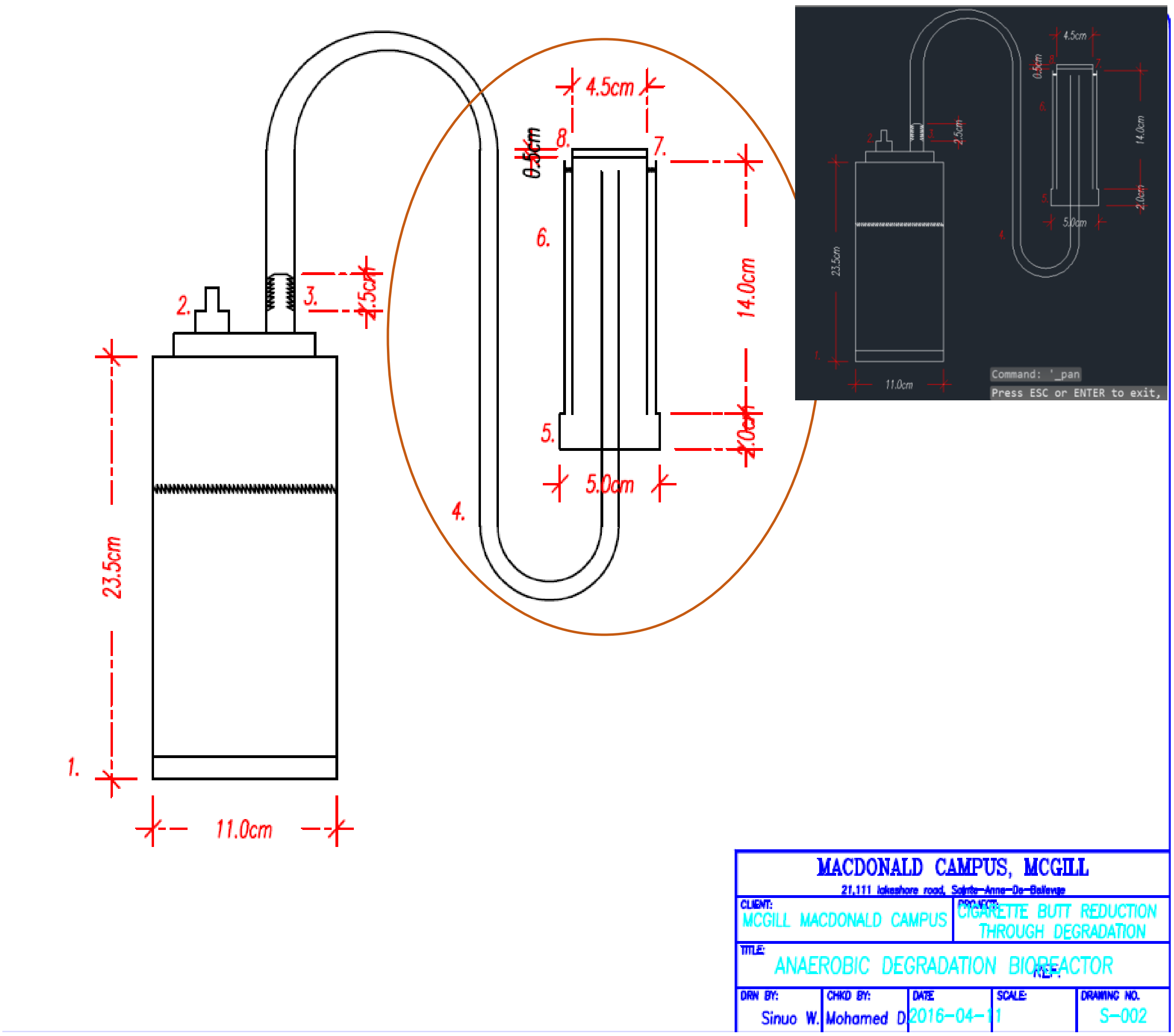

Fig 7: AutoCAD drawing of the anaerobic bioreactor with the gas collector.

The collectors are limited in volume. If the gas is not extracted in time the collector my tip over and release the gas. Frequent monitoring and extraction will need to be done once the test has started running. Another limitation of the design is the manual extraction of gas for further use. The design has to be remodeled in the future to accommodate a complete semi batch system. For the purpose of the project the prototype will be configured manually.

Set up Figure 8 below shows the setup of the designed prototype. The vessel and the gas collector are connected together with a tube with one end attached to the gas valve and the other attached through the gas collector. All sections are sealed using silicone to prevent any liquid or gas from escaping.

Figure 8: set up of the full prototype. Vessel connected to the gas collector along with six other vessels and gas collectors in the back.

Proposed Bioreactor configuration

The biological medium that will be contained in the vessel consists of 4 main components; the substrate; the anaerobic salt medium; the carbon source; and the optimal temperature that it will be operating at. The bioreactor will base its biological medium on Ji-Dong Gu's paper on "*Cellulose acetate biodegradability upon exposure to simulated aerobic composting and anaerobic bioreactor environments.*" configuration for the anaerobic conditions.

Substrate Cellulose Acetate with varying mass based on the each of the vessel configuration.

Anaerobic Salt Medium 0.138 g KH2PO4, 0.176 g K2HPO4, 0.0200 g (NH4)2HPO4, 0.2000 g NH4Cl, 0.600 g MgCl2 • 6H20, 0.2000 g FeCI2 • 4H20, 0.1000 g KCl, 0.1000 g CaCl2, 0.0100 g KI, 0.0040 g MnCl2 • 4H20, 0.0040 g CoCL2 6H20, 0.0005 g NiCl2 • 6H20, 0.0005 g CuCl2, 0.0005 g ZnCl2, 0.0005 g H3BO3, 0.0005 g Na2MoO4 • H20, 0.0005 g N4VO3, 0.0001 g Na2SeO3 and 1 ml of 0.1% (w/v) resazurin per liter was autoclaved for 15 min and put under a continuous flow of nitrogen, which was previously passed through hot copper filings (300°C) to remove traces of oxygen. When cooled, 4.2 g of $NaHCO_3$ and 0.25 g $Na_2S \cdot 9H_20$ were added to the medium and the pH of the medium was adjusted to 7.2 with HCL. (Gu et al, 1993)

Simulated Municipal Solid Waste Mixture 24.0% shredded maple and oak leaves(1:1 ratio), 46% shredded news and computer paper(1:1 ratio), 15% meat(dog and cat food) and food waste, 9% sawdust, 5% plastics (Gu et al. 1993)

Thermal Conditions Incubated at mesophilic temperatures (0 – 70°C)

~ 40°C

Final Product

The biological medium is predicted to produce three main components. The main product is biogas. Biogas can be defined as ‘a gas that is formed by anaerobic microorganisms. These microbes feed off carbohydrates and fats, producing methane and carbon dioxides as metabolic waste products’ [9]. The biogas could be used as a sustainable source of energy. Further gas quality testing on the produced biogas should be performed to test the accuracy of the definition for the design.

Activated biomass is another output produced from the biological treatment process. It is not known what the content of the activated biomass and its harmful effects until further toxicity testing is performed. In most anaerobic reactor system leachate is also produced along with the biomass. In the small scale operation there is no use for it and may also be toxic. On a large scale such as a landfill, it could possibly be recirculated to prevent more greenhouse gases from being produced. Further toxicity testing should be done for this component as well and will be further discussed in the testing section of this paper.

Cost Analysis

The components of the bioreactor prototype consist of mason jars, tubing, PVC pipes, valves, and other plumbing tools. The price of each component is located in the Appendix. The cost of a single vessel was added up to be $51.57. The project consisted of 6 vessels, meaning the total theoretical price of the project should be $198.02. The prototype was made for small scale operation and the price may need to be scaled up of vast quantity use.

TESTING

Testing of the final product is necessary in order to examine the quality of the output. Two tests will need to be performed: Toxicity of biomass and gas quality testing. While the first one will examine the quality of the biomass collected, the second test will test the content of the biogas collected in the gas collector. For the purpose of this paper, both tests will be explained in details.

Toxicity of Biomass

It is a test that uses bioassays to examine the toxicity of the left product. Bioassays are used to inspect the effects of matter on the biological activity of living organisms. For this paper, the effects of cigarette filters on the biological activity of the microorganisms will be examined. Contact with laboratories downtown Montreal to carry on this experiment was established. Nevertheless, this test is time consuming and hard to perform. Other methods were thus examined but often considered too expensive. Bioassay is still considered the best option for testing.

Gas Quality testing

The gas quality testing is used to analyze biogas using Gas Chromatography (GC). The latter is used to examine the content of the biogas such as the presence of methane, carbon dioxide or hydrogen sulfide. For this project, research assistant Hicham Benslim was contacted at the MacDonald to perform the test. The biogas collected in the gas collector would be obtain using a syringe (See gas collection section for more information) and send to the laboratory for analysis.

Efficiency

Efficiency is always an important criterion to consider when comparing alternatives. It can be calculated using the experimental data and examined further to determine the optimality of the experimental design. In this project, the efficiency of the design is directly related to the time used to degrade the cigarette butt. Thus, it is crucial to measure the time to decomposition of the cellulose acetate. The experimental test will be compare to a control test. In this test, the parameters of the sample set and control set are the same, expect that one set of sample goes through an anaerobic reaction, while the other is simply put in the serum bottle. If possible, measurements should be taken and used to record the weight change of each serum bottle with the respect to the time. A decomposition rate of cellulose acetate can be calculated from the decomposition time and decomposed weight, with unit of g/day. Decomposition rate under the normal condition is assumed to be the reference rate, while that rate calculated from anaerobic bioreactor refers to the advanced decomposition rate. Efficiency of the design is calculated based on the formula below:

$$Efficiency = \frac{Advanced\ decomposition\ rate - reference\ rate}{reference\ rate}$$

Experimental set A sketch of the experimental set setup is shown by figure Xb in the appendix. Multiple serum bottle will be prepared under the anaerobic medium conditions. The experimental set could be adjusted for different parameter, such as the amount of substrate added, the quality of filter added (new or used filter) and more. As mentioned before the experimental set will be compared to a control set. The control set will either be kept in aerobic conditions or purged so that no biological activity could occur. This would give us a comparison to determine whether in fact the degradation is due to the biological activity that is occurring in the experimental set.

OPTIMIZATION

Large Scale

The ideal collection system is based on rewarding the population to throw their cigarette filters in a disposal container. To popularize this project, support from the government is necessary, along with the proper explanation. Specific policy should be formulated and public infrastructures are necessary in order to fully cooperate with the plans. After collecting large amount of cigarette filters, the corresponding bioreactor center should be constructed as well.

Risk analysis

The risks of the biogas system are also very undeniable. Fermentation and anaerobic processes of the waste require strict maintenance at all times. Even with comprehensive regulations, explosions from the combustion of biogas happen unexpectedly every year due to the exceeded temperature and pH level (Schroeder, 2014). Moreover, the toxicity of the biogas during the experimental procedure cannot be easily estimated, thus a long-term disposal of residue is mandatory. Maintenance and detection of the system would generally increase the total cost to operate the system especially in a large scale operation.

Further use

Biogas is a significant source of renewable and sustainable energy that has emerged in recent decades. As previously mentioned, the biogas that is extracted from the degradation process of the cigarette butt, is mainly composed of methane and carbon dioxide. The composition of the biogas range from 50% to 75%, and 25% to 50% of the total respectively (Aaktech, 2005). Because methane concentrations are relatively high compared to CO_2, biogas is a high quality fuel that releases large amount of energy when combusted with oxygen. The energy can be further used to drive a generator, produce electricity and be recycled back into the system by burning as a fuel for heat.

Similar to the way natural gas is compressed, biogas can also be compressed to be used in vehicles as a source of fuel (Andrews, 2008). Unlike conventional fossil fuels, biogas generates less emission and other pollution to the environment. As a consequence, processing biogas not only solves the problems of exceeded waste, but also converts the wastes into consumable energy. It conforms to the idea of ecological disposal of wastes, while incorporating other significant benefits.

CONCLUSION

The effort to find a solution to the ever growing problem of cigarette filter waste faces many challenges. The answer lies in the biological degradation of the Cellulose Acetate compound and was explored in depth within this project. After producing a design solution, that was then further prototyped and built after careful consideration of strict guidelines, experimentation and testing seem to be the next step. Due to time constraints, and the long nature of the preparation and safety protocol, the testing was delayed until summer 2016. No define conclusion on the effectiveness of the prototype can thus be provided yet. The team is dedicated to the project and will continue its progress. Results from the testing will therefore allow for a full analysis of the design prototype. However, based on similar studies (Gu et al. 1993), the accelerated degradation of cellulose acetate in an anaerobic system seems promising.

CLIENT PROFILE

Facility Management at McGill University Macdonald Campus

Client position: administration and regulation of Macdonald community

Organization: McGill University Macdonald Campus

Telephone: 514-398-7773

Email: administrator.fmd@mcgill.ca

Mailing address: MacDonald Stewart Building, 21111 Lakeshore Road Ste Anne de Bellevue, QC, Canada, H9X 3V9

We dedicate our project to the collection of cigarette filters at Macdonald Campus. We contacted the facility manager on campus, Peter Knox and discussed with him the design solutions.

ACKNOWLEDGMENT

Mentor: Dr. Marie-Josée Dumont

Mentor position: Assistant Professor in the Department of Bioresource Engineering CoDirector, Integrated Food and Bioprocessing Master Program

Organization: McGill University

Telephone: 5143987776 Email: mariejosee.dumont@mcgill.ca

Mailing address: Room MS1025, MacdonaldStewart Building, 21111 Lakeshore Road St Anne de Bellevue, QC, Canada, H9X 3V9

Dr. Dumont provided us the idea to use UV light degradation as an option and inspired our team come up with other degradation options. She also introduced us to her lab team and offered assistance

Supervisor: Grant Clark; guided us through the project and gave us the idea for the gas collection system

Facility Manager: Peter Knox; allowed us access to the collectors around Macdonald Campus

Workshop: Scott Manktelow; helped us construct the prototype of the bioreactor

COMPETITION

Enrolled in the **Sustainable Projects Fund: McGill Office of Sustainability.**

APPENDIX

Appendix A: Calculation

A1. Estimation of the annual cigarette filter waste

1 pack (25 filters) weights for 4.25g

Weight of each filter= $\frac{4.25\text{ g}}{25\text{ filters}} = \frac{17\text{g}}{\text{filter}}$

Estimated cigarette filter waste = $\frac{17\text{g}}{\text{filter}} *$ 4.5 trillion = 765,000 tons

A2. Time to double the existing waste

Doubling time: $Td = \frac{70}{\text{r}}$ in which r is the growth rate r%

Growth rate of cigarette filters: 4.5% yearly (London: Action on Smoking and Health, 2015)

Doubling time= $Td = \frac{70}{4.5} = 15.56\text{years}$

A3. Refunding fee for one pack of cigarette

Average price of a water bottle: $Price = \frac{\$1.97}{\text{liter bottle}}$

Recycling deposit is 10% with a return of 8%, which leads

$$Deposte\ refund\ fee = \frac{\$1.97}{liter\ bottle} * 10\% = \frac{\$0.197}{liter\ bottle}$$

$$Retrun\ fee = \frac{\$1.97}{liter\ bottle} * 8\% = \frac{\$0.1576}{liter\ bottle}$$

$$Recycling\ fee = \frac{\$0.197}{liter\ bottle} - \frac{\$0.1576}{liter\ bottle} = \frac{\$0.04}{liter\ bottle}$$

Regarding cigarettes:

$$Cigarette\ costing = \frac{\$12}{25\ cigarettes} = \frac{50\text{ cents}}{cigarette}$$

10% deposit applied for each cigarette:

$$Deposit\ refund\ fee = \frac{50\text{ cents}}{cigarette} * 10\% = \frac{5\text{ cents}}{cigarette}$$

, which results in

$$Deposit\ refund\ fee\ for\ one\ pack\ = \frac{5\text{ cents}}{cigarette} * 25 = \frac{\$1.25}{cigarette}$$

A4. Cost of bioreactor prototype

(Canadian tire)Wide Mouth Mason Jars, 250 ml: $12.99 /12 = $1.08 per jar

(Amazon) Python 10PAL 10-Feet Airline Tubing: $2.99

(rona)Brass union: $4.99

(rona)Brass hose end: $5.79

(rona)O-ring Kit: $4.39 per pack

(rona) Silicone Sealant: $5.89 per pack

(rona) FLAT WASHER: $12.00 per pack

(rona) Industrial PVC Pipe Plug - 3/4" – White: 1.45

(rona) PVC Pipe for Vacuum: $12.99 for 2

Total cost of one vessel: sum of all components = $51.57

Cost for 6 sets: 5.89 + 4.39 +12.00 + 6(1.08+ 2.99 + 4.99 +5.79 +1.45+12.99) = $198.02

Appendix B: Figures

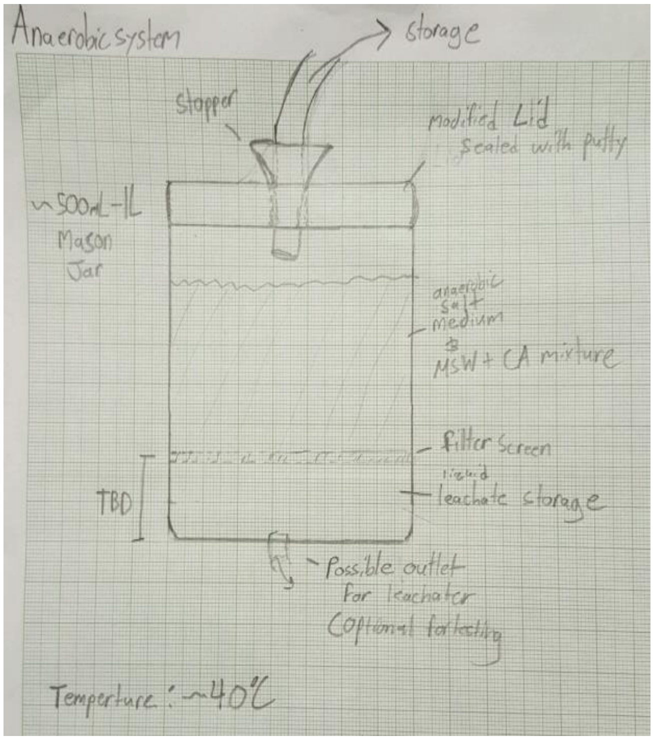

Figure X a) early sketch of what the anaerobic reactor had envisioned

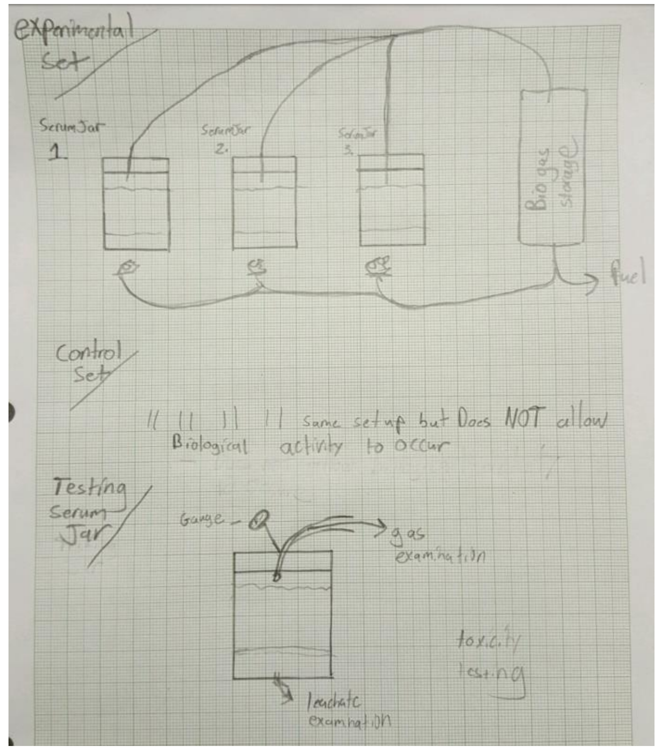

Figure X b) a Sketch of the experimental and control set

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