SUSTAIN-A-DRAIN:
AN ADVANCED STORM DRAIN MAINTENANCE
PROCESS FOR MUNICIPALITIES AND INDUSTRIES

By

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Abstract

California roads are constructed to divert incoming rainwater into the ocean through flood control systems known as storm drains – similar to how most developed regions design their roads, particularly those subjected to severe rainfall to prevent roads from flooding and obstructing traffic. Chemical-ridden rainwater that enters storm drains is not effectively filtered for contaminants and directly pollutes the ocean and negatively affects marine wildlife. Millions of gallons of potentially reclaimable water are rendered invaluable and eventually leads to contamination of oceans annually. Rainwater accumulates petroleum hydrocarbons that separate from the ground due to the density of water being greater than that of oils so they separate from the ground and wash into storm drains, in addition to other pollutants including oxygen-demanding substances, nitrogen and phosphorous, and heavy metals. Some of these contaminants promote the growth of algal blooms and causes mass marine die-offs from the diminished dissolved oxygen (DO) levels. Areas with depleted DO levels become dead zones known as hypoxic areas that can no longer support most marine life. In an effort to rebuild deteriorating ecosystems and combat threatening environmental hazards, such as cultural eutrophication, the Environmental Protection Agency (EPA) has developed regulations for groundwater discharge. The Sustain-a-Drain solution to this detrimental issue proposes a filtration design combined with a waste management process to provide a sustainable and affordable model, consisting of a filter insert, indicator, and bioremediation process. The filter fabric is made of 100% recyclable materials that can be reused up to seven times, and has an efficiency of 99.2%.

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Introduction

Pollutants that wash away with incoming rainwater lead to a degradation of water quality, which affect ecosystems such as estuaries, lakes, canals, and other ocean outlets and watersheds. Pollutants mainly associated with urban area runoff include petroleum hydrocarbons, oxygen-demanding substances like nitrogen and phosphorus, and heavy metals.[1] Heavy metals that serve as a threat to aquatic ecosystems due to their ability to stay in a soluble form include, lead (Pb^{2+}), zinc (Zn^{2+}), and copper (Cu^{2+}).[1] Furthermore, as the degree of development of urban areas increases so does the amount of pollutants per unit area delivered which leads to a detrimental process known as cultural eutrophication. Cultural eutrophication is a type of pollution that occurs mostly from excess runoff from land where it stimulates the growth of algae and leads to massive fish kills due to a lack of available oxygen. Eventually, these areas progress to become hypoxic areas, also known as dead zones, where the oxygen levels are so depleted that these zones can no longer sustain most marine life.[2] The Environmental Protection Agency (EPA) has developed regulations known as the effluent limitations, which establishes the acceptable levels of contaminants for groundwater discharge in order to regulate the amount of pollutants flowing to large bodies of water.

In order to meet EPA standards, storm drain inserts are currently available to capture potentially hazardous contaminants. These filter inserts are disposable, often comprising of a non-washable, high-density polyethylene fiber that chemically absorbs contaminants. Additionally, due to current systems lacking an indicator to notify maintenance technicians that the filter is fully saturated and requiring replacement, most drains are equipped with these filters that have a high chance of containing a spent filter that has not been replaced. This allows harmful contaminants to enter storm drains freely. Such inserts procure some results in treating rainwater but have an unreliable replacement schedule. Furthermore, the filters would be rendered useless due to the chemical binding ability of contaminants to the filter fabric.[4] Since spent filters that have no indication of saturation, cannot be reused, and have a higher chance of dumping waste into storm drains, an alternative waste management system was created to incorporate recyclability of the filter. This would potentially lead to a violation of implemented regulations such as the Clean Water Act, section 402: National Pollutant Discharge Elimination System (NPDES), which monitors the amount of untreated discharge that enters drainage systems.[5]

Over the course of five years, Sustain-A-Drain has designed a washable, reusable and eco-friendly storm drain insert with a novelty indicator that facilitates proper maintenance of the filter and potentially allows for water reclamation. Our system is composed of an Adsorb–It® filter fabric that is composed of 100% recycled textiles and can be washed and reused up to seven times. After a rain event, the saturated filter fabric undergoes a torsional cleaning method using a biodegradable cleaning agent, Simple Green. The novelty indicator uses Enviro-Bond 403 polymer, which has the capacity to absorb oil and turns from a white powder to a rubbery solid; serving as a physical indication that the filter is saturated. The cleaning effluent will then go through a bioremediation process using mycelium pellets from *Pleurotus ostreatus* or oyster mushrooms.[6] After the bioremediation period which is comprised of the phytoextraction process,the separator filters the used pellets from the liquid, allowing for collection and safe disposal. The spent pellets could also be sold and burned for the absorbed heavy metals.[6] The liquid waste from this process would then be used as greywater providing an overall sustainable process.

A bird's-eye view of Fleets Services Facilities at the University of California, Riverside is shown in Figure A.1 where the Sustain-A-Drain prototype is installed at the central drain. Continual data collection from this prototype allows for further optimization of the design and analysis of the storm water that is collected in order to maximize the efficiency of the insert. The current team's objective has been to calibrate and optimize the design of the filter and indicator through further testing as well as pursue bioremediation testing after designing and constructing a unique bioreactor depicted in Figure A.2.

In addition, analyzing the input and output components in the overall system that was designed will allow the formation of balanced component masses flowing into, out of, and through certain steps in the system on a standardized basis. A flow chart of our three-step system shown in Figure 1 beginning with the filtration process which consists mainly of the water treatment, the cleaning method which comprises of the filter regeneration, and finally the mycelia bioreactor, which is a part of the Sustain-A-Drain cleaning service. Using the general process flow diagram shown below (Figure 1), specific amounts of each component at any given point of the system can be tracked. A mass balance on each of the different steps is provided in Figure A.3, with calculations provided for each of the following system steps.

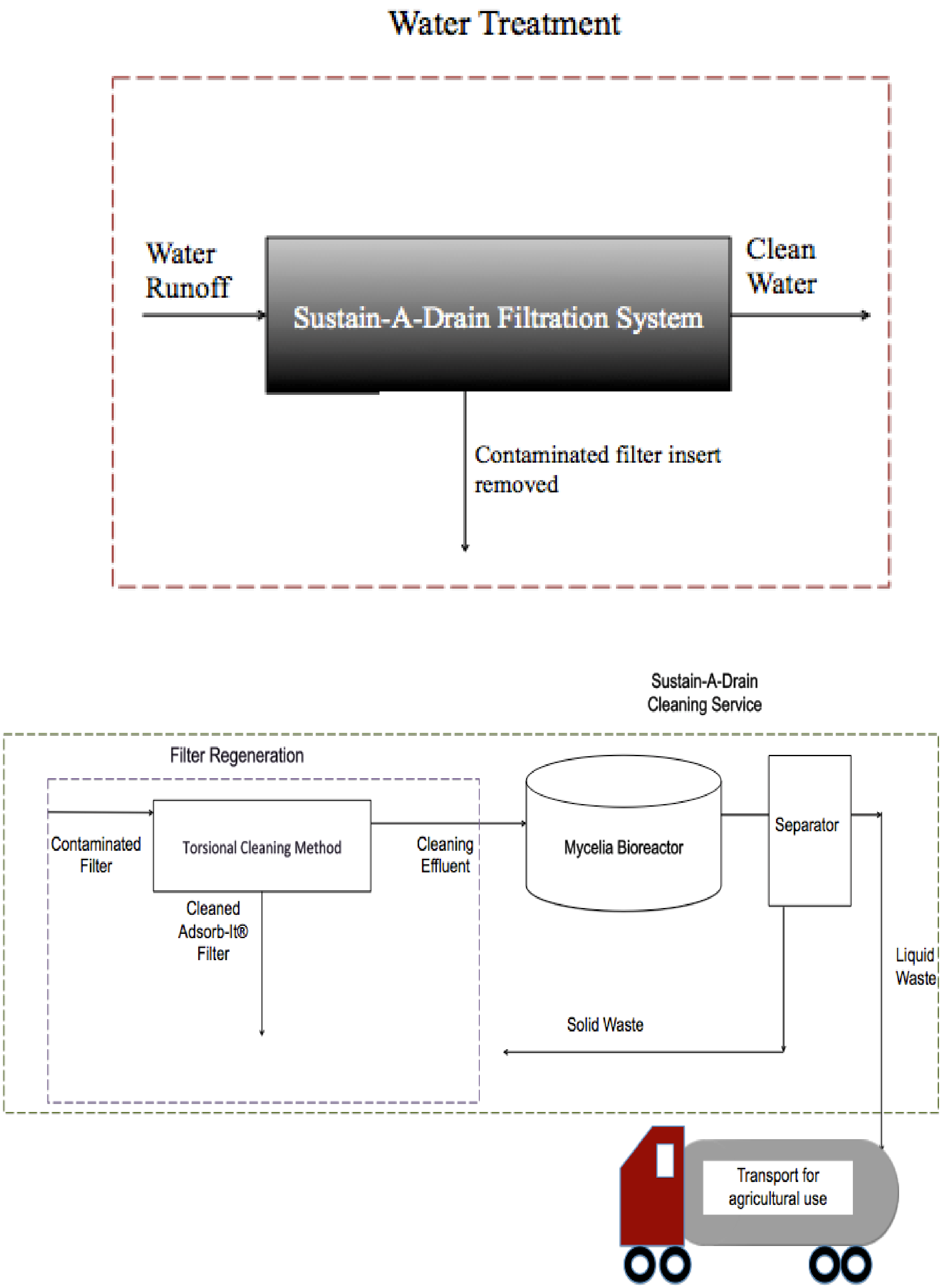

Figure 1: *Process Flow Diagram of Sustain-A-Drain Waste Management*

Literature Review

Established in 2012, Sustain-A-Drain (SAD) has been an ongoing team effort under the mentorship of Dr. Kawai Tam consisting of a different senior design team each year. Numerous designs for the filter, indicator, cleaning, and bioremediation steps have been tested and improved to formulate a comprehensive and efficient business model, modifiable to any storm drain. The results from these designs have helped develop the system that is currently being tested and improved.[7] The expansion of the filtration design shown in Figure A.4 in the appendix, is the prototype of which was proposed and developed by the 2012 Sustain-A-Drain team as well as the 2013 Riverside Infrastructure Sustainable Campus (RISC) management team.

The filter media for the previous team's filtration design consisted of three layers of Adsorb-It® fabric material, provided by Eco-Tec, Inc., sewn together and shut with a zipper. Due to the filter material's capacity to adsorb oil, its dimensions of the filter have been reduced from the first design. Marvel Mystery Oil™ was used– red oil made from several petroleum distillates consisting of crude gasoline and other types of oils – in our laboratory experiments to observe the concentrations of hydrocarbons released. It primarily consists of mineral oils and has a similar density to that of crude oil, according to its Safety Data Sheet (SDS); however, its flashpoint is higher than that of crude oil, so it is safe to handle. Therefore, Marvel Mystery Oil™ was used in all the experiments that required an oil source. As depicted by the calibration curve represented by Figure A.5 in the appendix, the Adsorb-It® material was found to be able to adsorb nearly 5 times its own weight in oil, with the slope of the graph indicating the ratio of the mass of oil adsorbed per unit mass of filter material. The novel component of this design is the indicator as it plays a crucial role in the filtration system, differentiating it from all other storm water filtration systems. The indicator contains a calibrated amount of Adsorb-It® filter and Enviro–Bond 403, a non-toxic polymer that is safe to handle and has the ability to turn from powder to a gelatinous form after coming in contact with hydrocarbons. A 3D printer was utilized to design the indicator system with a 100% biodegradable and transparent plastic within the indicator. This allows for a quick observation of the polymer to detect if it is undergoing any phase changes – making maintenance simple for technicians. The plastic unit making up the indicator is expected to be functional for the duration of the indicator life without compromise, which is currently being tested in the model installed at UCR Fleet Services. A cartridge-style design shown in figure A.7 in the appendix, with a square influent source and a pipe design was first utilized for the indicator. The square indicator design allowed for various flows of emulsified oil solutions to enter the indicator as shown in figure A.7, while the pipe-shaped indicator was constructed to permit sediment–laden water to flow through the indicator where a metal mesh could capture oil contaminants as shown in figures A.8 and A.9. The circular designs of the indicator allowed for full contact of the flow to the filter material, but had a few drawbacks after the full-scale implantation at Fleet Services, as observed by Team 1. The design did not allow a high enough flow-rate of sample water to be accepted into the indicator to take an accurate sampling size of the total inflow of contaminants. It also became consistently clogged by debris, sometimes making the indicator material difficult to observe for phase changes with sludge accumulating against the inside walls of the tube. It was observed during the rain events that the runoff water trickled against the edges when entering the storm drain. All indicator designs hung from the storm grate were unable to effectively capture any of the runoff water, leading the 2015 team to propose a ramp design for the indicator, where testing for the efficiency of the design is being done for adjustments.

To assess the reusability of the Adsorb-It® filter material, as well as the most efficient cleaning method to remove contaminants from the filter, the material was tested using a non-toxic and biodegradable detergent called Simple Green. A number of Simple Green solutions at low, medium and high dilution ratios of detergent to water were placed in a 2-liter beaker to soak 3 by 3 in^2 swatches of oil-saturated filter material. The low detergent to water ratios ranged from 1:1 to 1:10, medium dilutions ranged from 1:10 to 1:30, and high dilution ratios were greater than 1:30. The solution with a 1:10 ratio of Simple Green to water was determined to be the most efficient for cleaning the fabric.

For the bioremediation step, the previous team began to investigate the uses of *Pleurotus ostreatus*. Varying literature have shown promising results for degradation of oil and accumulation of heavy metals with *Pleurotus ostreatus* (oyster mushrooms), also known as the white-rot fungus.[9] This fungus will be used to treat the cleaning waste as it has the ability to degrade different long chain and aromatic hydrocarbons . Specifically, it is able to degrade more than 95% of many of the polycyclic aromatic hydrocarbons to non-toxic components in the mycelial-inoculated plots after more than 4 weeks.[9] Fungal mycelia are the vegetative structures of the fungus where the degradation occurs. The fungus can be grown in soil with the aid of lignocellulosic substrates. Mycelium penetrates oil and increases the biodegradation surface area.[10] Citrus peels were considered in the process to aid heavy metal recovery for resale. Accumulation of heavy metals using the fungus and orange peels ranges depending on the metal ion but generally is 0.04 to 0.50 mg/kg.[11,12] The discoveries from the literature review were incorporated into the design of the project, placing more emphasis on the *Pleurotus ostreatus* and its uses in the bioremediation step of the Sustain-A-Drain waste management system.

Methodology and Theoretical Paradigms

Material balances of the system allow for a standardized basis for the quantity of each component flowing through the streams to ensure the inputs are balanced with the outputs. Mass balances indicate the conservation of mass across a system and can be utilized to optimize flow rates and other system attributes. This helps to assess the amount of runoff entering and what is existing from our system. Varying assumptions had to be made in order to complete the mass balances, starting with the rain. The rain is assumed to be pure water flow and the area of rainfall was assumed to be UCR's fleet services, which is around 5129 m^2. Furthermore, to calculate the oil concentration present in the runoff, an average chemical oxygen demand (COD) reading for mixed commercial-residential locations was calculated to be $65\frac{mg}{L}$ using the assumed average oxygen demand coefficient of 1.[17] In calculating the recycle stream fed to the filter, the important assumption of all three layers adsorbing equally, as well as, the filter being completely cleaned had to be established even though 80% removal is stated in the filter patent.In addition, for the saturated filter stream, the key assumption of the entire filter exiting the stream along with the oil and metals adsorbed had to be established for proper calculations of that stream. For the cleaning step in the waste management system, we calculated the volume of the cleaning effluent from one filter to be around 11.4L but due to the apparatus having 6 x 2L jar testers, the mycelia mass calculations were done with the assumption that 12L entered rather than 11.4L. Finally, for the bioremediation step, the efficiency of the mycelia was estimated from literature to be around 97%, which allowed for the calculation of the mass of mycelia. In addition, for simplicity, the assumption that the mycelia will not have propagated during separation was established by literature studies explaining that the mushrooms do not grow well in a exceedingly wet environment when the mass of mycelia proceeding to the exposure to the cleaning effluent was calculated.

Filter Mass Balance:

- Annual treatment values provided but sample calculations for only one quarter presented

1. ***Rain***

Table 1: Rainfall Data from Riverside Municipal Airport for 2011–2016[19]

Quarter (averaged over 5 years)	**Average Precipitation (in/qu)**
Quarter 1 (Q1)	1.92
Quarter 2 (Q2)	0.34
Quarter 3 (Q3)	0.68
Quarter 4 (Q4)	1.53

(Q1: Jan-Mar, Q2: Apr-Jun, Q3: Jul-Sep, Q4: Oct-Dec)

2. **Area**

- Assumed rainfall area was UCR's fleet services, measured by Google Maps

  $Area = 63.06 \text{ m} \times 81.33 \text{ m} = 5129 \text{ m}^2$

3. ***Water Flow Rate for 4 quarters***

$$Q1 = \frac{1.92\frac{in}{qu} \times 0.0254\frac{m}{in} \times 5129\ m^2}{2190\ \frac{hr}{qu}\ x1000\ \frac{L}{m^3}} = 114\ \frac{L}{hr}$$

$Q2 = 20\ \frac{L}{hr}$

$Q3 = 40\ \frac{L}{hr}$

$Q4 = 91.0\ \frac{L}{hr}$

4. ***Oil Concentration in Runoff***

- EPA's Nationwide Urban Runoff Program (NURP) conducted runoff analyses from 1978 – 1983.[17]
- Consists of 28 separate projects, and 81 site locations for more than 2300 storm events
- Assuming UCR Fleet Services is best represented as a well-mixed commercial-residential location
- Findings indicate the average COD readings for mixed commercial-residential locations are 65 mg/L
- 65 mg/L assumed to be an approximate concentration of oil using an assumed average oxygen demand coefficient of 1. [17]

5. ***Metal Concentration in Runoff***

- The data used for this calculation was derived from NURP [17]
- Concentration of Lead = 114 µg/L
- Concentration of copper = 27 µg/L
- Concentration of Zinc = 154 µg/L

- These values were taken from mixed commercial-residential locations

6. ***Feed stream (F_1)***

- Corresponds to tables B.1-B.5
- Wolfram Alpha's system of equations solver was utilized to calculate the mass flow rates of oil, lead, copper, and zinc. The following system of equations was what was solved:

$$F_{oil} = \frac{(F_{H2O}+F_{oil}+F_{Pb}+F_{Cu}+F_{Zi}) \times 65\frac{mg}{L} \times \frac{1\,kg}{100000\,mg}}{0.91\frac{kg}{L}}$$

$$F_{Pb} = \frac{(F_{H2O}+F_{oil}+F_{Pb}+F_{Cu}+F_{Zi}) \times 114\,\frac{\mu g}{L} \times \frac{1\,kg}{100000000\mu g}}{11.34\,\frac{kg}{L}}$$

$$F_{Cu} = \frac{(F_{H2O}+F_{oil}+F_{Pb}+F_{Cu}+F_{Zi}) \times 27\,\frac{\mu g}{L} \times \frac{1\,kg}{100000000\mu g}}{8.92\,\frac{kg}{L}}$$

$$F_{Zi} = \frac{(F_{H2O}+F_{oil}+F_{Pb}+F_{Cu}+F_{Zi}) \times 154\,\frac{\mu g}{L} \times \frac{1\,kg}{100000000\mu g}}{7.14\,\frac{kg}{L}}$$

- Where flow rates (F_{H2O}, F_{oil}, F_{Pb}, F_{Cu}, F_{ZI}) are in L/hr
- Using F_{H2O} values from each quarter calculated earlier, the results are listed in Table B.1

7. ***Feed Stream (F_1) Flow Rate Conversions***

- All values from the Table B.1 multiplied by the components' respective densities (kg/L).

Table 7: Runoff Density

Contaminated Runoff Density	
Component	**Density (kg/L)**
Water	1[20]
Oil	0.91[20]
Lead	11.34 [22]
Copper	8.92 [22]
Zinc	7.14 [22]

- The density of oil was calculated by taking the average density of automobile oil [22]

8. ***Feed Stream (F_1) Mass Fraction Calculations***

- Each mass flow rate was divided by the total mass flow rate to get each mass fraction shown in Table B.5

9. ***Cleaned Adsorb-It® Filter (S_R)***

- Assume all three layers adsorb equally
- One 3-layered 17 in x 17 in Adsorb-It® filter is used, the same as the size of the prototype filter used at UCR fleet services.
- The company that produces the Adsorb-It® fabric, Eco-Tec, Inc. analyzed the mass per unit area using ASTM 5261:[21]

$$12.8\ \frac{\text{oz}}{yd^2} \times \frac{0.0283495\ \text{kg}}{\text{oz}} \times 1\frac{\text{yd}^2}{1296\ in^2} \times \frac{1000\ g}{1\ kg} = \ 0.2799\frac{\text{g}}{in^2}$$

$$0.2799\ \frac{\text{g}}{in^2} \times\ (17\ in\ \times\ 17\ in)\ \times\ 3\ layers = 242.7\ g\ \text{filter}$$

10. ***Filtered Stream (S_2) Exiting Filter***

- From previous work done by the Sustain-A-Drain team, the average efficiency of the filter was found to be 99.2%, shown in Figure A.10
- This efficiency was then used to calculate the total mass of oil that needs to flow through the filter before it becomes saturated
- Mass of oil at filter saturation/filter efficiency = mass of oil entering system

$$1099\ g\ \times \frac{100}{99.2}\ =\ 1110\ g$$

- This is divided by the mass flow rate of oil to achieve the time required to saturate the filter:
- Four times calculated to provide different saturation times and rainfall amounts for each quarter

$$t_1 = \frac{\frac{1110 g}{1000 \frac{g}{kg}}}{7.41 \times 10^{-3} \frac{kg}{hr}} = 150 \text{ hrs}$$

t_2 = 870 hrs

t_3 = 420 hrs

t_4 = 187 hrs

- The 0.8% of oil that did not get filtered divided by these saturation times equals the mass flow rate of oil exiting the filter:

$$F_1 = \frac{0.8\% \text{ of incoming oil}(1110 \text{ g})}{150\ hr}\ =\ 5.92\ \times\ 10^{-3}\ \frac{kg}{hr}$$

$$F_2 = 1.0 \times 10^{-5} \frac{kg}{hr}$$

$$F_3 = 2.1 \times 10^{-5} \frac{kg}{hr}$$

F_4 = 4.73 x $10^{-5}\,\frac{kg}{hr}$

- The mass flow rate of water entering the filter is equal to the mass flow rate of water exiting the filter:
    - $F_{H20,1}$ = 114 $\frac{kg}{hr}$
    - $F_{H20,2}$ = 20 $\frac{kg}{hr}$
    - $F_{H20,3}$ = 41 $\frac{kg}{hr}$
    - $F_{H20,4}$ = 91.0 $\frac{kg}{hr}$

11. ***Saturated Filter Stream (S_3)***

- Assume the entire filter exits the stream along with the oil and metals that are adsorbed
- The mass of oil per unit mass of filter was recorded from the slope of the previous team's Adsorb-It® calibration curve referenced as *Figure A.5*
- The 242.7 g of filter was multiplied by the mass ratio of oil to filter, 4.5271, which yields a mass of oil exiting the filter:
- $\frac{242.7\ g\ of\ filter}{4.5271} = mass\ of\ exiting\ oil$

    Mass of oil in filter = 1099 g

- The mass of the metals is equal to each respective mass flow rate times the saturation time:
- Saturation times provided in section 10 for S_2 calculation
- $saturation\ times\ \times\ mass\ flow\ rates\ = mass\ of\ the\ metals$

M_1 *lead* = 150 hr $\times$ 1.30 $\times\ 10^{-2}\,\frac{\text{g}}{\text{hr}}$ = 1.95 g

M_1 *copper* = $150 \text{ hr} \times 3.08 \times 10^{-3} \frac{\text{g}}{\text{hr}} = 0.462 \text{ g}$

M_1 *zinc* = $150 \text{ hr} \times 1.76 \times 10^{-2} \frac{\text{g}}{\text{hr}} = 2.64 \text{ g}$

M_2 *lead* = 1.97 g

M_2 *copper* = 0.473 g

M_2 *zinc* = 2.67

M_3 *lead* = 1.95 g

M_3 *copper* = 0.449 g

M_3 *zinc* = 2.64 g

M_4 *lead* = 1.94 g

M_4 *copper* = 0.459 g

M_4 *zinc* = 2.62g

- After this point, all results use Quarter 1 (*Q1*) values only, but all answers are included in tables B.6-B.12

B. Cleaner Mass Balance:

1. ***Saturated Filter Stream (S_3) Entering Cleaner***

- This stream is from the filter mass balance

  Mass of filter = 242.7 g

  Mass of oil = 1099 g

  Mass of lead = 1.95 g

  Mass of copper = 0.460 g

  Mass of zinc = 2.63 g

2. ***Cleaning Solution Feed Stream (F_4) Entering Cleaner***

- Data collected by previous teams showed that 10.2 L of cleaning solution was needed to clean the 3 layers of 17" x 17" filter
- 1:10 simple green solution is the ideal mix of Simple Green and water, so:

$$10.2\ L \times \frac{1}{11} = 0.927\ L\ of\ simple\ green$$

$$10.2\ L \times \frac{10}{11} = 9.27\ L\ of\ water$$

- These were then multiplied by their densities to get the mass of each component

The density of Simple Green came from the MSDS[18]

Mass of Simple Green $= 0.92727\ L \times 1004.165 \frac{g}{L} = 931.1\ g$

Mass of water = $9.2727\ L \times 1 \frac{kg}{L} \times 1000 \frac{g}{kg} = 9272.7\ g$

- These masses were then converted to mass fractions:

Mass fraction of Simple Green = $\frac{931\ g}{931\ g +\ g}$ = 0.0913

Mass fraction of water = $\frac{9270\ g}{9270\ g + 931\ g}$ = 0.909

3. ***Cleaned Adsorb-It® Filter (S_R) Exiting Cleaner***

- For simplicity, it is assumed in the mass balance that the filter is completely cleaned after each rinsing process
- However, note that the data collected suggests filters get about ~80% clean
- This means that this stream is the same mass as the filter entering the filtration system
- Therefore the mass of the filter in this stream is 242.7 g

4. ***Cleaning Effluent Stream (S_5) Exiting Cleaner***

- All of the cleaning solutions plus all of the contaminants from the filter exit the cleaning step through this stream

Mass of Simple Green = 931.1 g

Mass of water = 9,272.7 g

Mass of oil = 1,099 g

Mass of lead = 1.95 g

Mass of copper = 0.460 g

Mass of zinc = 2.63 g

<u>C. Bioreactor Mass Balance:</u>

1. ***Cleaning Effluent Stream (S_5) Entering Bioreactor***

Mass of Simple Green = 931.1 g

Mass of water = 9,272.7 g

Mass of oil = 1,099 g

Mass of lead = 1.95 g

Mass of copper = 0.460 g

Mass of zinc = 2.63 g

2. ***Pleurotus Ostreatus Mycelia Stream (S_6) Entering Bioreactor***

- From previous work and literature research, a rough relationship between reactor size and mycelia mass was determined and used to estimate the mass of mycelia needed for our bioreactor, graphed in Figure A.11 [23]
- The volume of the cleaning effluent from one filter was calculated in order to utilize this relationship:

$$(\frac{1099\ g\ oil}{910\ \frac{g}{L}})\ +\ (\frac{1.95\ g\ lead}{11340\ \frac{g}{L}})\ +\ (\frac{0.460\ g\ copper}{8920\ \frac{g}{L}})\ +\ (\frac{2.63\ g\ zinc}{7140\frac{g}{L}}\ )\ +$$

$$(\frac{9270\ g\ water}{1000\ \frac{g}{L}})\ +\ (\frac{931\ g}{1004.165\ \frac{g}{L}}) = 11.4\text{ L}$$

- Since the volume of the experimental setup (6 x 2 L) is a little bit larger than the volume of effluent, mycelia was used for the mass estimation
- Using the relationship from Figure A.11, the mycelia mass was calculated
- Mass of mycelia = $12\ L\ \times\ 0.264\frac{gal}{L}\ \times\ 0.1001\frac{kg\ mycelia}{L\ reactor}\ +\ \frac{0.0008kg}{1000\frac{g}{kg}}$ = 318 g of mycelia

3. ***Waste Stream (S_7) Exiting Bioreactor***

- The efficiency of the mycelia's ability to breakdown oil was estimated based on values from literature, which indicated an efficiency of 97% purification of crude oil
- This efficiency was used to calculate how much oil there would be left leaving the bioreactor:

  Mass of oil remaining in bioreactor = $1099\ g\ \times\ 0.03\ =\ 32.97\ g$

- The mass of the water and Simple Green leaving the bioreactor is equal to what enters the bioreactor:
  - Water = 9272.7 g
  - Simple Green = 931.1 g

4. ***Mycelia Waste Stream (S_8) Exiting Bioreactor***

- The mycelia mass leaving the bioreactor is assumed to be equal to that of the absorbed oil and metals:

$$318\ g\ mycelia\ +\ (0.97\ \times\ 1099\ g\ oil)\ +\ 1.95\ g\ lead +\ 0.460\ g\ copper\ +\ 2.63\ g\ zinc\ =\ 1388.809\ g$$

Results

The Sustain-A-Drain filtration system prototype installed in a storm drain at the UC Riverside Fleet Services Department contains a catchment basin where storm water sample was collected. A top layer subsample containing only water from the top of the basin and a bottom layer subsample where the basin is well-mixed so heavier particles that have settled become suspended were taken. The sampling procedure is executed in this manner as a means of collecting oil that has floated to the top of the basin as well as a complete sample that includes heavier components collected in the storm water. These samples are in the process of undergoing COD testing and Gas Chromatography (GC) testing. The sample was analyzed but the resulting data is still inconclusive until more testing is performed on the sample. The raw data is organized in Table B.13. Tested samples had “under range” COD readings, indicating that there could be little to no oil in the collected storm water – a positive sign highlighting the effectiveness of the filter in adsorbing oil. These results can be confirmed once the samples are further tested.

Calibration Curves

To determine if the concentration of oil is reduced as it passes through the Sustain-A-Drain filtration system, a calibration curve was developed to determine the levels of oil in storm water runoff. Solutions contained in 25 mL flasks of Marvel

Mystery Oil™ in deionized water ranging from concentrations of 0.1% to 1% by volume with 10 drops of Tween 80® were created, as well as a blank solution comprising of deionized water and Tween 80®. The solutions were put in a vortex for approximately five minutes at 3000 rpm to ensure that the oil was fully emulsified for accurate readings. Samples were then transferred into cuvettes to conduct absorption readings in a UV-VIS spectrophotometer at a fixed wavelength of 650 nm (provided by previous data). Readings were made starting with the blank followed by the lowest concentration to the highest concentrations. The absorption was plotted with respect to concentration, as shown in Figure A.6.

Analytical Discussion

Filtration System Design

Figure A.4 depicts the basic layout of the filtration system design, comprising of seven parts. In descending order with respect to depth in the storm drain, the system parts are as follows: grate, metal diverter, indicator, sediment catcher, Adsorb-It® filter, mesh basket and drain structure with catchment basin. Depending on the dimensions of the storm drain, the size of the filter insert can be adjusted to fit any drain, although the order of parts will always remain the same. The catchment basin is another vital component for testing the filtration system prototype, since the basin holds about 25 L of storm water, of which samples were collected after rain events for compositional analysis to determine the efficiency of our filter fabric and indicator. For example, depending on when the samples are collected, if a sample has a significantly higher percentage of oil than the indicator has, the design will be reconsidered; or if our indicator tells us that the fabric needs to be changed, but samples and the fabric show low percent volume of oil, then the system will be redesigned accordingly to calibrate for the filter and indicator oil adsorption. However, samples collected from the basin can get diluted, so it is necessary to note that a lower oil concentration in the sample compared to the indicator is expected until saturation occurs.

Water Reclamation

In addition to helping decrease contaminant flow to oceans and other watersheds, the scope of the Sustain-A-Drain solution includes reclamation of treated storm water for greywater uses. Water reclamation will come from two sources: the storm water captured in the basin after going through the filter as well as the cleaning effluent from the bioremediation process after treatment. One of the design aspects specific to this thesis was to focus on improving a hand pump that the team designed from PVC piping that can manually siphon the collected water from the basin. In addition to the PVC pipe, the general assembly of the hand pump includes slip caps, slip couplings, slip tees, bushings, O-rings, close risers, and plugs. Figure A.12 displays the skeleton of the assembly in which extensions of PVC piping were added based on the dimensions of the basin, ensuring water could be pumped out. After siphoning the water into a holding tank, the consumer can access the reservoir and utilize the reclaimed water.

Indicator Test

The novelty indicator is one of the most vital facets of the Sustain-a-Drain filtration system. Unlike previous teams who tested the pipe and cartridge design, the 2017 team tested a ramp design, shown in Figure A.13 that displays a detailed setup of the indicator layers. The ramp design allows the storm water to pass through the indicator and the oil will adsorb onto the fabric at the same rate as the fabric in the filter system, while preventing debris buildup and keeping the polymer visible to the user. Once the fabric is saturated in the indicator, it will seep through the ramp surface and come in contact with the polymer powder. The powder changes to a gelatinous form when fully saturated, indicating that it is time to change the filter. Currently, the team is constructing improved designs to optimize the slope of each ramp to ensure that it is at the most efficient angle for water to pass through slowly enough for oil to be adsorbed, yet calibrated to the speed at which the filter below will saturate. A brickbox has been designed and 3D printed to insert accurate amounts of the polymer powder into the indicator during construction. To prevent against leaks, the indicator will be held together with epoxy glue, which has shown no leakage in our most recent build.

Bioremediation Design

The current Sustain-A-Drain team has developed a new bioreactor design for the bioremediation process, comprising of a PHIPPS & BIRDS six jar testing apparatus as shown in Figure A.14. Each jar holds approximately two liters of the cleaning effluent that comes out of the initial step of the Sustain-A-Drain waste management process. Each jar is fitted with a sparger to purge nitrogen through the bioreactor in order to reduce dissolved oxygen and limit its concentration to optimize suppression of bacterial growth on the oyster mushroom pellets.[10] Since many factors affect the decay rates of the pellets, the pH, dissolved oxygen, and temperature will be measured with probes throughout the bioremediation period.[10] All jars will be agitated with a mixer at constant mixing speeds of less than 600 rpm to ensure no dead spots occur in the bioreactor and to maintain good pellet sizes. The entire bioreactor apparatus will be placed in a dark box since the decay rate of the oyster mushrooms is heavily impacted by the intensity of light.[10] Once the bioremediation period is over, the treated storm water would then be used as greywater and the saturated pellets would go through a phytoextraction process to remove the metals from the pellets. The period duration and oxygen concentration is yet to be determined by experimentation.

Potential Sources of Error

Sustain-a-Drain's proposed design consists of multiple testing methods, which overall could contribute to inaccuracies in our results. UV-visible spectrophotometers, Chemical Oxygen Demand machines, gas chromatography, and uncalibrated pipettes could affect the precision of our results. Proper lab protocol should be followed to avoid contamination, degradation, and inaccurate calibration. Since the amount of oil that passes through the filtration system should be close to zero, sampling variations and subsampling problems may occur. The small amount of oil that is immiscible in water may or may not be collected if a sample is drawn from a specific area of the basin, leaving it unnoticed. Handling and transporting samples from Fleet Services to the cold room and/or from the cold room to the different labs could create errors in measurement if not sealed properly.

Health, safety, and hazards assessments

Correct personal protective equipment (PPE) including heavy duty gloves, proper laboratory coat, and safety glasses or splash goggles are required when utilizing the Sustain-a-Drain filtration system. Storm drain maintenance technicians must follow PPE guidelines when performing tasks related to hazardous waste and toxic chemicals, per Occupational Safety and Health Administration (OSHA) guidelines. When the filter fabric is cleaned, 49 CFR 171.8 outlines packaging requirements for transport of the expected waste quantities of used oil, which are not to exceed 1,000 liters.[13] The waste in the filter fabric will contain oil and potentially other hazardous contaminants and the cleaning effluent will then be handled by Sustain-a-Drain to transport into tanks where bioremediation occurs.

Sustain-a-Drain clients can choose to dispose of the filter insert waste on their own, but must comply with regulations and have formal documentation of waste disposal plans on file. The used indicator will be disposed of by Sustain-a-Drain either by pick up by a Sustain-a-Drain employee or be returned by the client. The client would need to replace the indicator after it is spent. The small quantity of waste that will be acquired from refurbishing the indicator filter fabric must be handled in accordance with the packaging requirements of the 49 CFR 173.4.[14] Adherence to OSHA worker safety, which outlines that workers must be wearing gloves and goggles when performing maintenance to prevent hazardous chemical exposure (OSHA , 1910.132 and 1910. 134), and the 49 CFR packaging guidelines discussed above will ensure safety while handling the Sustain-a-Drain filter insert.[15]

The reactor is agitated at less than 600 revolutions per minute for the mycelium/hyphae to form appropriate sized pellets. Shutdown of the bioreactor will include the shutdown of nitrogen tanks and the PHIPPS & BIRDS apparatus. From here, each reactor is drained completely into labeled waste bottles (approximately 12 liters of liquid waste in total). A hazard and operability study will be used to evaluate the potential risks to personnel or equipment. The handling of the mycelia will be carried out by hazard operability analysis (HAZOP) protocol 29 CFR 1910.141 under bio-hazardous waste management. [15] Table B.14 presents a HAZOP study done for bioreactors. In addition, a HAZOP study was done for the cleaning process, as well as, when collecting samples, seen in Table B.15 and B.16, respectively.

Global, Social, Political, and Environmental Impacts of the Engineering Solution

Sustain-a-Drain Filtration System

The primary scope of Sustain-a-Drain has been to improve the quality of water discharged from storm drains from local industries and municipalities, to reduce violations of regulation limits for contaminants entering storm drains, and to increase the social awareness of investing into engineering solutions for a greener future. The Sustain-a-Drain solution is a low-maintenance alternative that can potentially replace current filtration systems in the market due to its ability to be reused and meet National Pollutant Discharge Elimination System regulations.[16] Current competitors such as the Flexstorm inlet filters have a complex geometry used in their filters which makes it quite costly. Without an indicator in the Flexstorm system, saturation cannot be detected and thus storm drains may not be fully protected. The SAD filtration system is almost entirely biodegradable or recyclable, so it has a low impact on the environment during its time of use and disposal, leaving a small eco-footprint. The global impact of the solution is positive, as it reduces the amount of contaminants that would end up in our watersheds from runoff water, which helps marine life by improving the quality of discharge into these bodies of water. Through this, social awareness can be focused on how greener solutions are impacting communities. In a political sense, many governments could implement stricter regulations on having filtration systems installed to all storm water ducts. Municipalities would not have to deal with regulation violations throughout the year, saving time and money. Implementing our filtration system to all storm drains would be relatively inexpensive and save money over time while simultaneously helping the environment. Jobs may also be created for technicians to monitor indicators and replace filters as necessary.

Bioremediation Process

Sustain-A-Drain has developed a bioremediation reactor design for a sustainable waste management process for storm water to pass through for treatment. Competing filtration systems for the most part are not reusable and have to be thrown away, which requires a fee that can become expensive. Although the contaminants might not end up in the water, they could potentially end up in a landfill where they seep into the surrounding soils and contaminate groundwater. Since our bioremediation process uses a cleaning solution that is environmentally-friendly, it is able to reduce the possibility of runoff contaminating large bodies of water, which further contributes to the overall sustainability factor of the design. The bioremediation process uses oyster mushrooms that break down the incoming hydrocarbons and accumulate heavy metals, providing a method that does not accrue any dangerous waste. The knowledge gained from looking into fungi for treatment of contaminated water would promote the idea of straying away from dangerous chemicals and investing more time into researching the potential of many natural biomaterials. The treated water could then be reused for many purposes such as greywater, which is mainly used for subterranean landscaping. For the local governments, reducing the amount of clean water used would reduce the need for regulations on water consumption during droughts. Through this simple and environmentally friendly process, an initiative for the public may be incited to be more involved in pushing industries to be more eco-friendly.

Conclusion

The mission of Sustain-A-Drain is to reduce harmful hydrocarbons from entering storm drains where they are then diverted into river, lakes, streams, and coastlines. Ideally, this will be accomplished by utilizing the Sustain-a-Drain system, which consists of three parts; the filtration system, the cleaning of a saturated filter, and the bioremediation step. In the first step, runoff water enters a storm drain through our filtration system where approximately 99.2% of oil is adsorbed by the filter and its saturation is indicated to the user via the novel indicator. Once the filter is saturated it is removed and transported to the cleaner where a cleaning solution of 1:10 Simple Green in water is used to wash the filter with a torsional wringing method to remove approximately 80% of the oil from the filter. The cleaning effluent then enters the bioreactor along with the mycelia from the oyster mushrooms, which breaks down the oils and the cleaned wastewater is then used for greywater or irrigation. This system can aid municipalities and industries meet standards set by The Clean Water Act (CWA) .

The strategy outlined for Sustain-a-Drain is to continue data collection to improve the three steps of the waste management system, as well as, continue to analyze and retrieve data from the full-size prototype at UCR's fleet services. Another focus is to learn and utilize a GC-FID method for analyzing hydrocarbon content in wastewater for testing sample storm water as well as what is adsorbed by our filter. The GC testing method, specifically the ISO 9377-2:2000, was established for evaluating the contamination occurring in water runoff. The method provides an index, which is the sum of compounds with retention times between n-decane and n-tetracontane.[24] The team will use the method to evaluate the contamination and although it does not provide quantitative information, using the basis of the peak pattern of the gas chromatogram, certain qualitative information on the composition of the oil contamination can be derived. Extensive testing of our bioreactor is planned so that accurate values are obtained for the mass of mycelia needed for the bioreactor and the mycelia's ability to break down hydrocarbons and accumulate heavy metals. Lastly, alternative testing methods for extracting the heavy metals absorbed by the mycelia will be pursued.

Appendix A: Figures

Figure A.1*: Aerial image of Fleet Services Department (Central drain identified in box)*

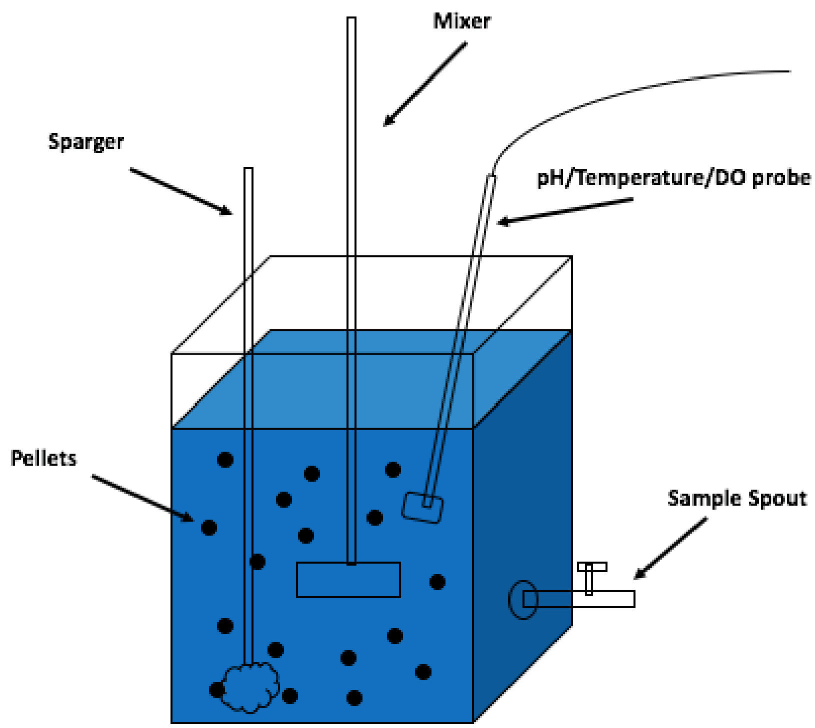

Figure A.2. *Bioreactor Setup (Batch)*

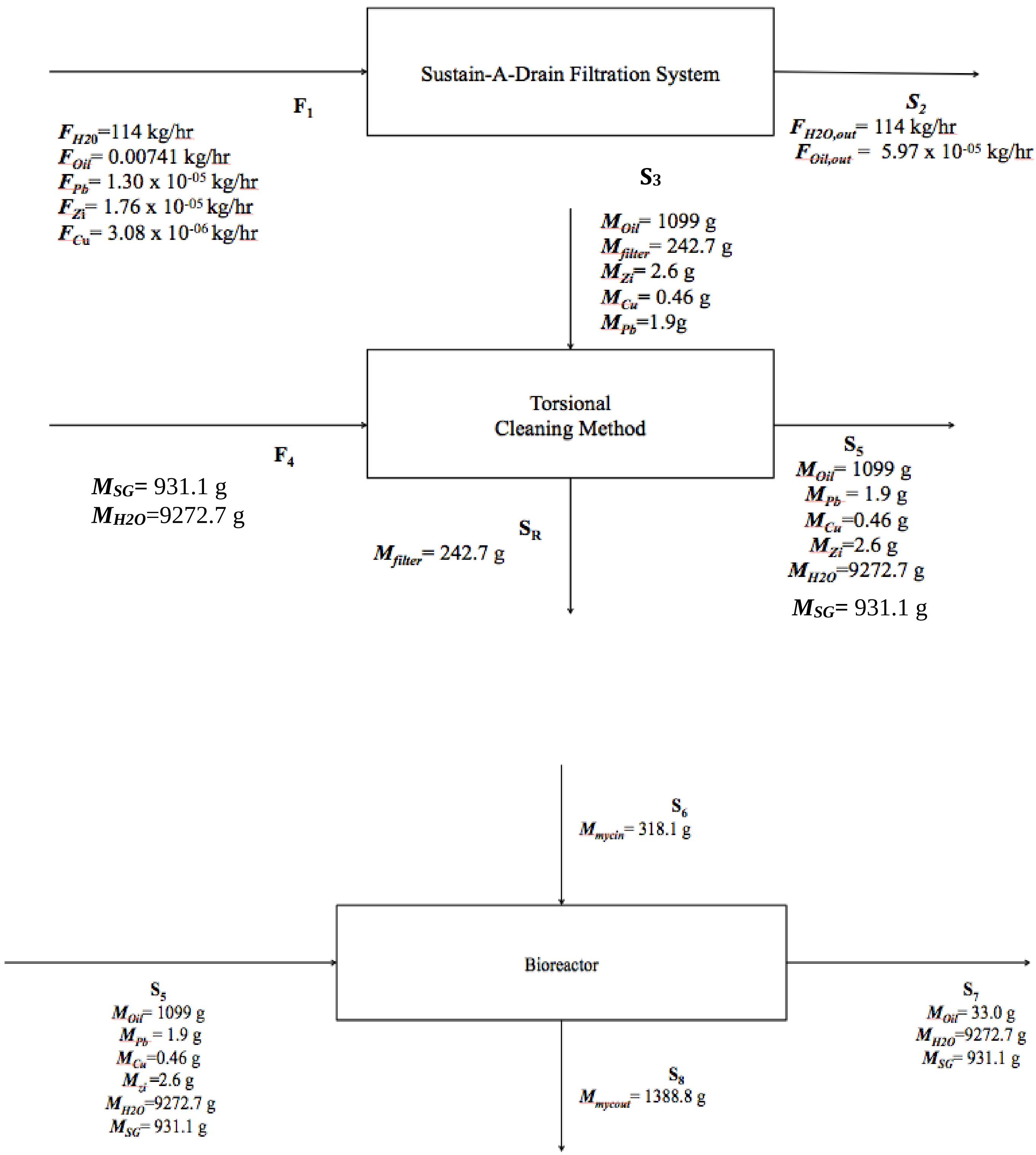

Figure A.3: *Sustain-a-Drain System Mass Balance for Rainfall in Quarter 1*

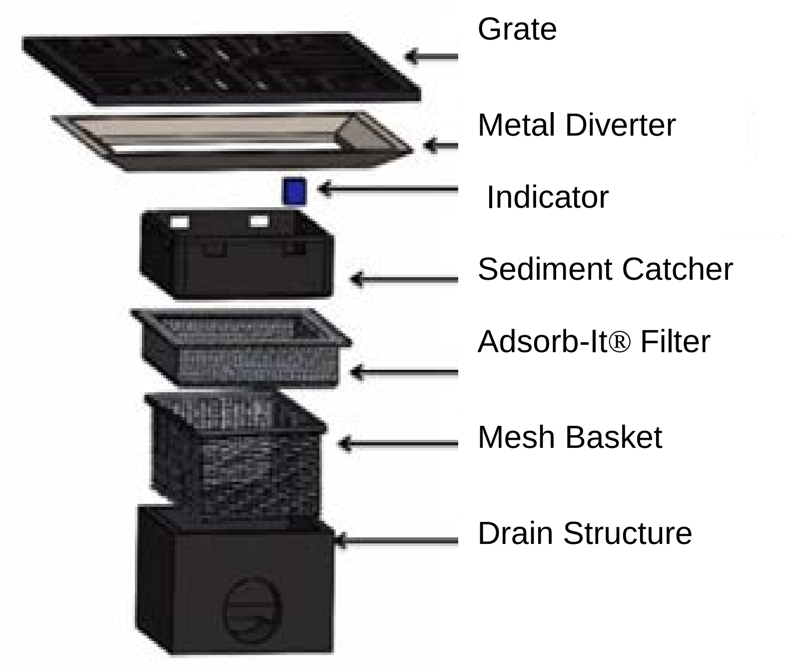

Figure A.4: *Sustain-a-Drain Storm Drain Filtration System*

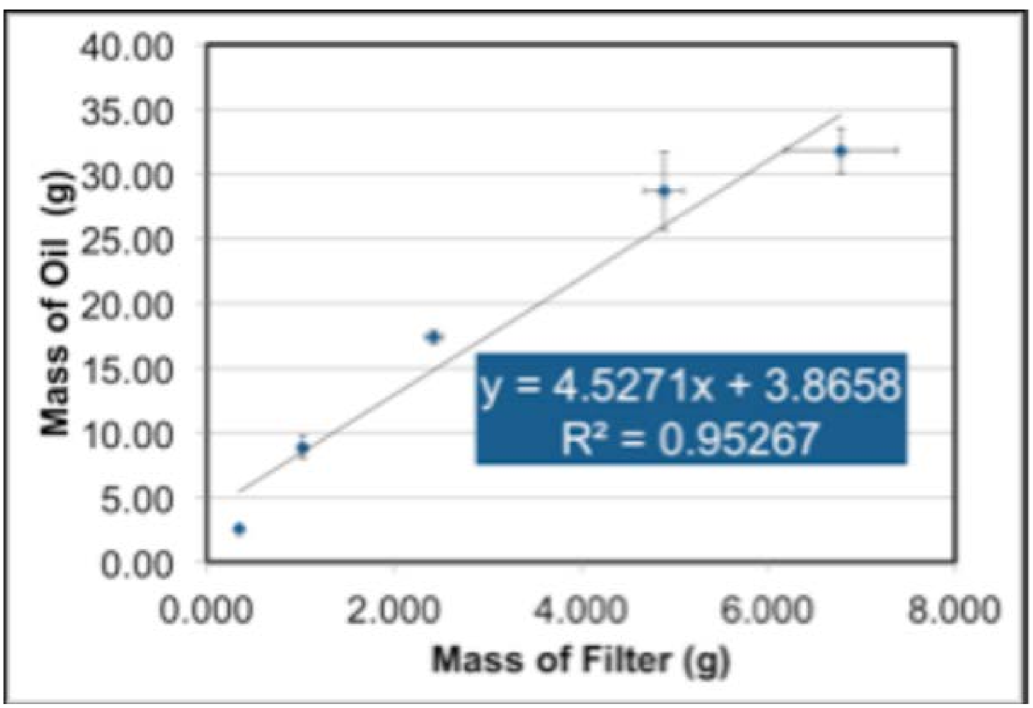

Figure A.5 : *Adsorb-It® Calibration Curve*

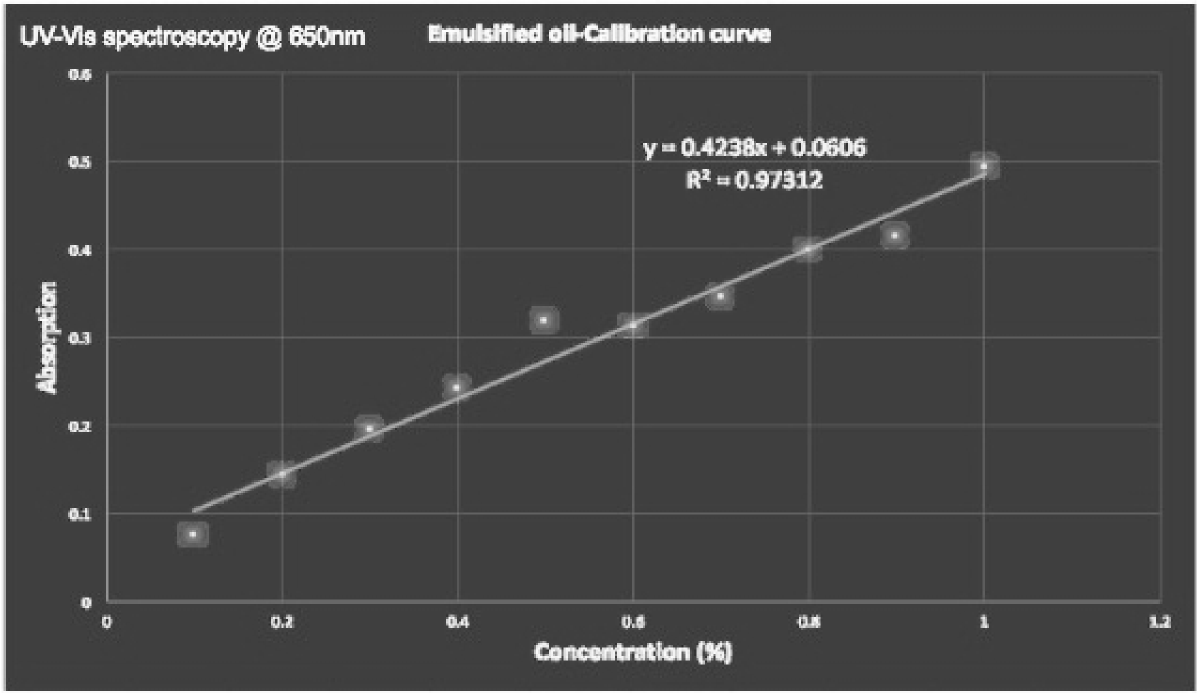

Figure A.6: *Emulsified Oil-Calibration Curve*

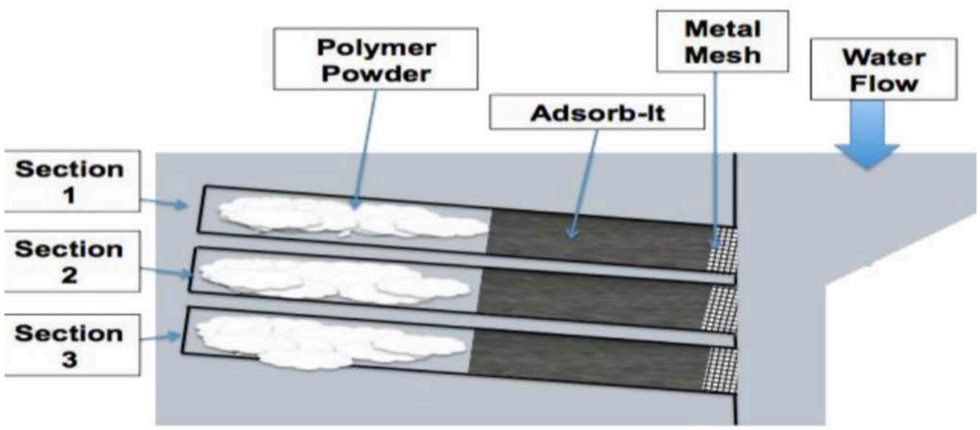

Figure A.7: *Indicator Cartridge Design*

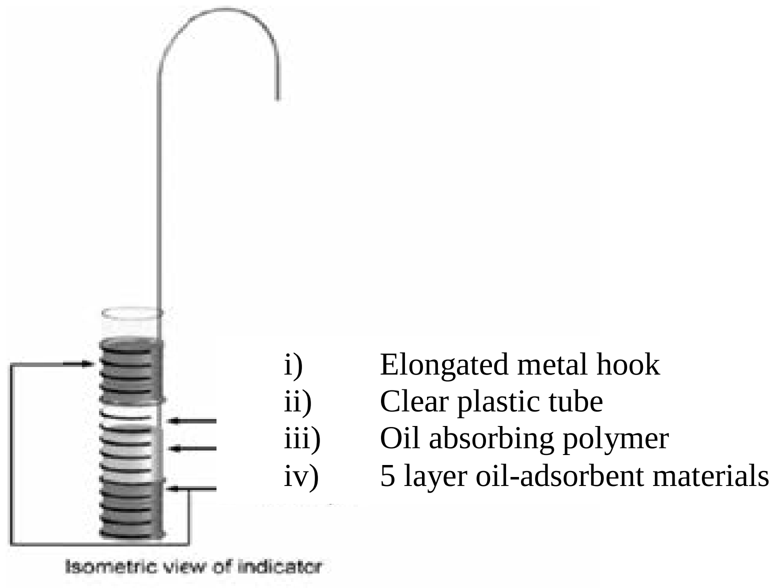

Figure A.8: *Indicator Pipe Design #1*

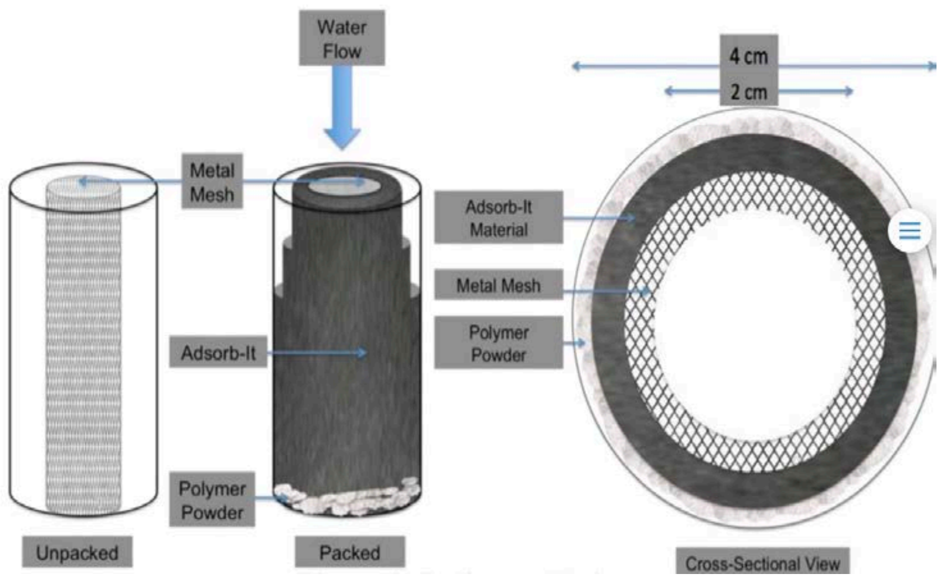

Figure A.9: *Indicator Pipe Design #2*

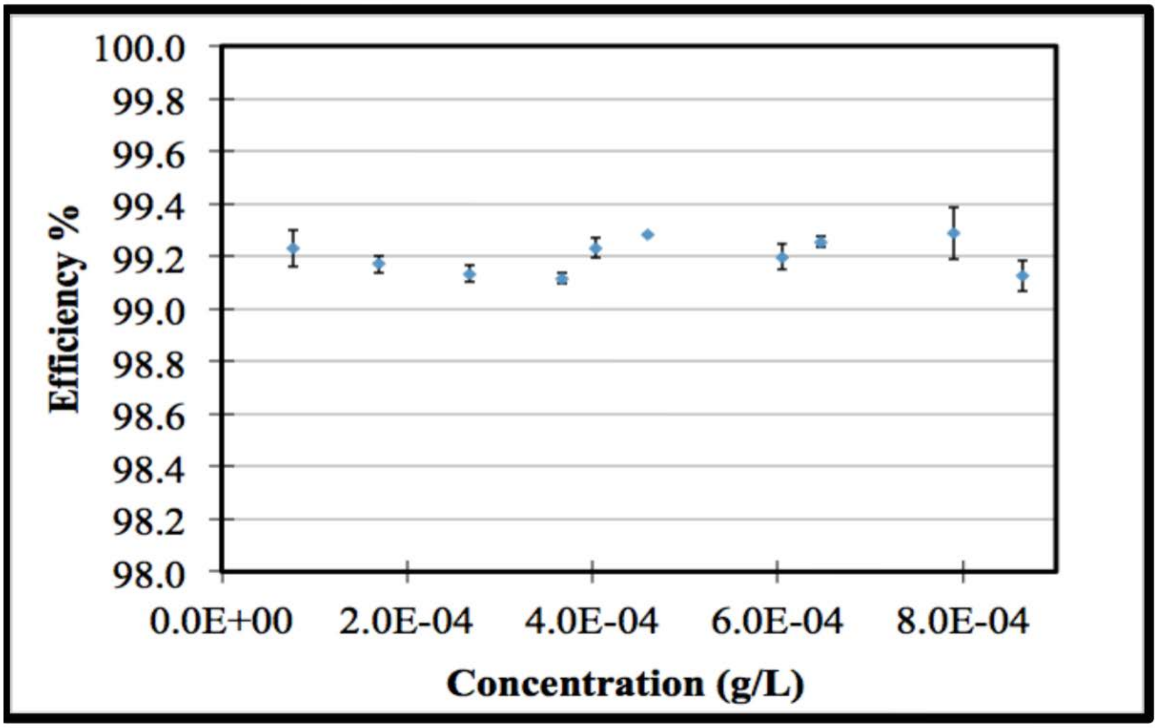

Figure A.10**:** Adsorption efficiency of Adsorb–It®

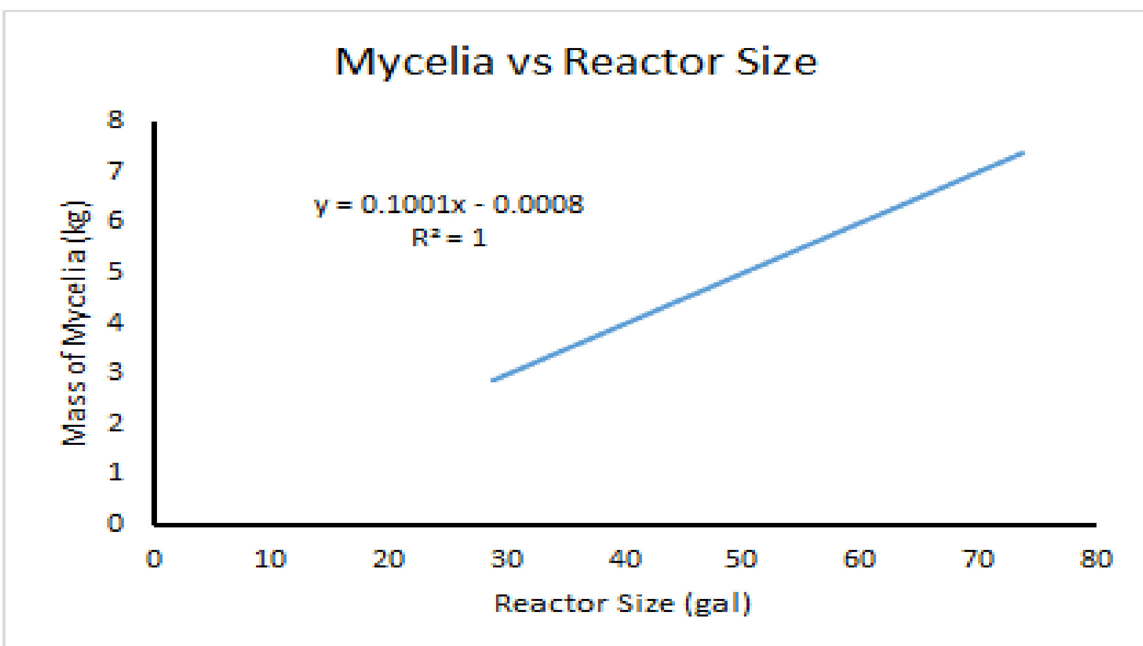

Figure A.11: *Plot of mass of mycelia required versus reactor size*

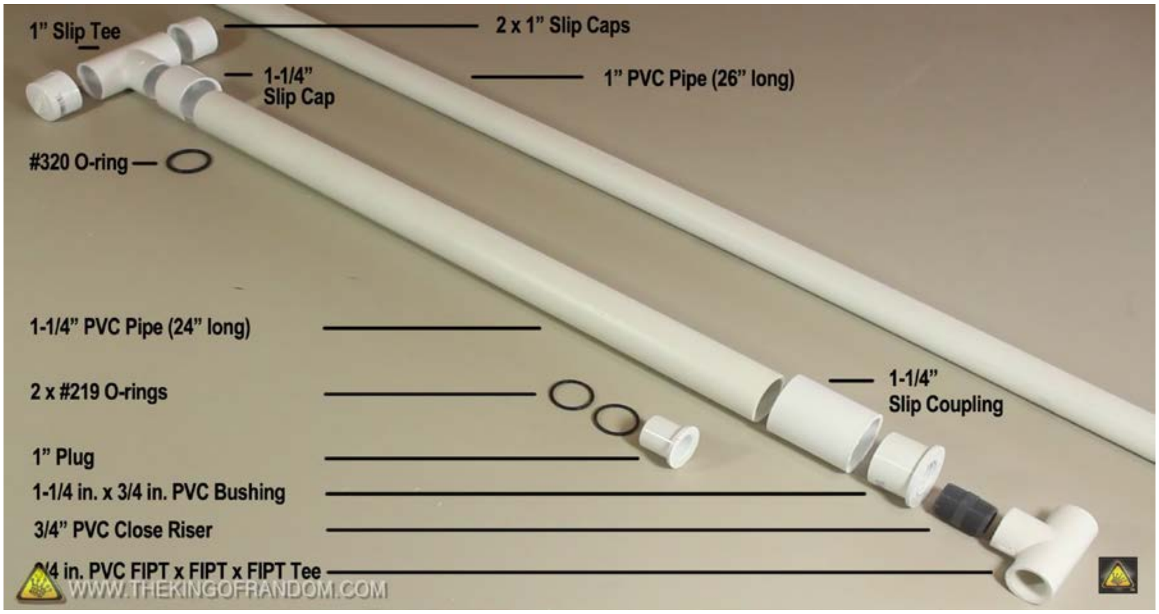

Figure A.12: *Pump Design*

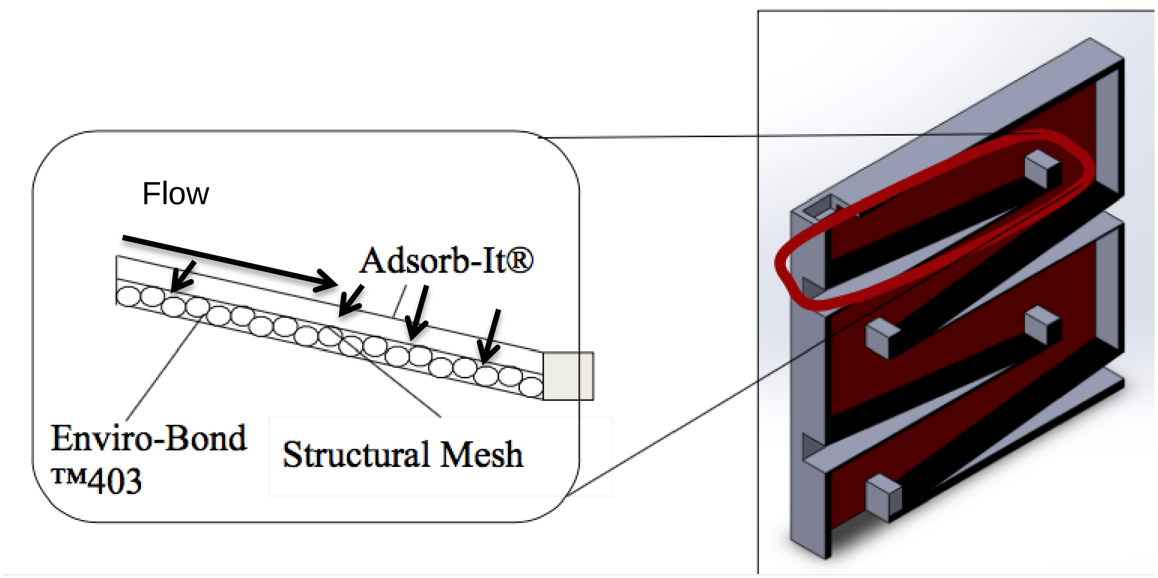

Figure A.13: *Indicator Ramp Setup*

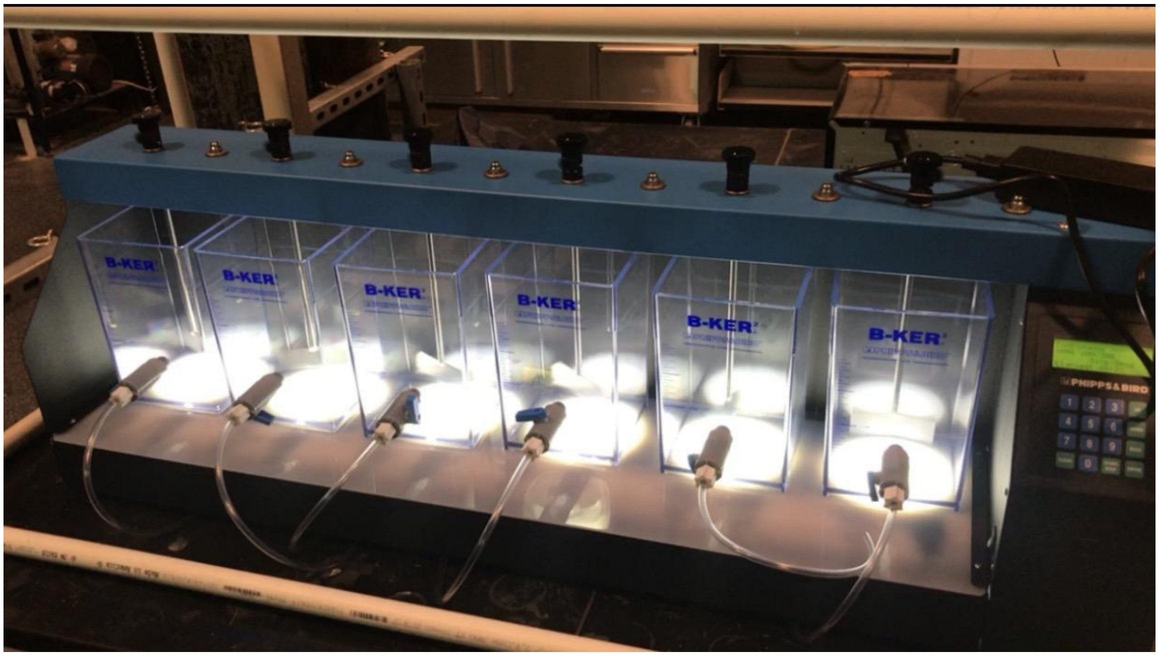

Figure A.14: *PB900 bioreactors setup and the PVC box*

Appendix B: Tables

Table B.1: *Volumetric flow rates of feed stream (F_1)*

Quarter	F_{H2O} (L/hr)	F_{Oil} (L/hr)	F_{Pb} (L/hr)	F_{Cu} (L/hr)	F_{Zi} (L/hr)
1	114	0.00814	1.15E-06	3.45E-07	2.46E-06
2	20	0.0014	2.0E-07	6.1E-08	4.3E-07
3	41	0.0029	4.1E-07	1.2E-07	8.8E-07
4	91.0	0.0065	9.15E-07	2.75E-07	1.96E-06

Table B.2: *Weather data collected for feed stream (F_1) calculations for 5 years*

Quarter	P_{avg} (in/day)	P_{total} (in/qu)	T_{avgm} (°F)	P_{avg} (m^3/day)	P_{total} (m^3/qu)
Q1 [2016]	0.04	3.74	61	5.211	487.2
Q2 [2016]	0.00	0.26	71	0	33.9
Q3 [2016]	0.00	0.00	80	0	0.0
Q4 [2016]	0.03	3.09	64	3.908	402.6
Q1 [2015]	0.01	0.91	63	1.302	118.6
Q2 [2015]	0.01	0.66	70	1.302	86.0
Q3 [2015]	0.04	3.28	80	5.211	427.3
Q4 [2015]	0.01	0.46	64	1.302	59.9
Q1 [2014]	0.01	0.62	62	1.302	80.8
Q2 [2014]	0.00	0.07	71	0	9.1
Q3 [2014]	0.00	0.32	80	0	41.7
Q4 [2014]	0.02	1.97	65	2.605	256.6
Q1 [2013]	0.02	1.82	58	2.605	237.1
Q2 [2013]	0.00	0.10	71	0	13.0
Q3 [2013]	0.00	0.12	79	0	15.6
Q4 [2013]	0.01	0.61	62	1.302	79.5

Q1 [2012]	0.02	1.51	59	2.605	196.7
Q2 [2012]	0.01	0.61	69	1.302	79.5
Q3 [2012]	0.00	0.00	81	0	0.0
Q4 [2012]	0.02	1.40	63	2.605	182.4
Q1 [2011]	0.03	2.89	57	3.908	376.5
Q2 [2011]	0.00	0.33	67	0	43.0
Q3 [2011]	0.00	0.38	78	0	49.5
Q4 [2011]	0.02	1.65	61	2.605	215.0

Table B.3: *Weather data averages for feed stream (F_1) calculation*

	P_{avg} *(in/day)*	P_{total} *(in/qu)*	T_{avgm} *(°F)*	P_{avg} *(m^3/day)*	P_{total} *(m^3/qu)*
1st quarter avg	0.0216667	1.92	60	2.822	249.5
2nd quarter avg	0.0033333	0.34	70	0.434	44.1
3rd quarter avg	0.0066667	0.68	80	0.868	89.0
4th quarter avg	0.0183333	1.53	63	2.388	199.3

Table B.4: *Mass flow rates of the components of feed stream (F_1)*

Feed Stream (F_1)					
Quarter	*H_2O (kg/hr)*	*Oil (kg/hr)*	*Pb (kg/hr)*	*Cu (kg/hr)*	*Zi (kg/hr)*
1	114	0.00741	1.30E-05	3.08E-06	1.76E-05
2	20	0.00127	2.3E-06	5.4E-07	3.1E-06
3	41	0.00264	4.6E-06	1.1E-06	6.3E-06
4	91.0	0.00592	1.04E-05	2.45E-06	1.4E-05

Table B.5: *Mass fractions of feed stream (F_1)*

Quarter	X_{H2O}	X_{oil}	X_{Pb}	X_{Cu}	X_{Zi}
1	1.00	6.50E-05	1.14E-07	2.70E-08	1.54E-07
2	1.0	6.3E-05	1.1E-07	2.7E-08	1.5E-07
3	1.0	6.5E-05	1.1E-07	2.6E-08	1.5E-07
4	1.00	6.50E-05	1.14E-07	2.70E-08	1.54E-07

Table B.6: *Mass of components of saturated filter stream (S_3)*

Saturated Filter Stream (S_3)					
Quarter	m_{filter} (g)	m_{oil} (g)	m_{pb} (g)	m_{cu} (g)	m_{zi} (g)
1	242.7	1099	1.95	0.460	2.63
2	242.7	1099	1.97	0.473	2.67
3	242.7	1099	1.95	0.449	2.64
4	242.7	1099	1.94	0.459	2.62

Table B.7*: Mass of components of cleaner for a batch (F_4)*

Cleaner (F_4)	
m_{h2o} (g)	m_{sg} (g)
9273	931
9273	931
9273	931
9273	931

Table B.8: *Mass of filter for clean Adsorb-It® (S_R)*

Recycle (S_R)
m_{filter} (g)
242.6733
242.6733
242.6733
242.6733

Table B.9: *Mass of components of the cleaning effluent stream (S_5) for a batch*

Cleaning Effluent Stream (S_5)					
m_{oil} (g)	m_{pb} (g)	m_{cu} (g)	m_{zi} (g)	m_{h2o} (g)	m_{sg} (g)
1099	1.95	0.460	2.63	9272.7	931.1
1099	1.97	0.473	2.67	9272.7	931.1
1099	1.95	0.449	2.64	9272.7	931.1
1099	1.94	0.459	2.62	9272.7	931.1

Table B.10: *Mass flow rates of the components of the filtered stream (S_2)*

Filtered Stream (S_2)		
t_{sat} (hr)	Oil_{out} (kg/hr)	H_2O_{out} (kg/hr)
150	5.93E-05	114
870	1.0E-05	20
420	2.1E-05	41
187	4.73E-05	91.0

Table B.11: *Mass of mycelia before and after bioremediation*

Mycelia (S_6)	**Mycelia (S_8)**
m_{myin} (g)	m_{myout} (g)
318	1388.809
318	1388.887
318	1388.810
318	1388.795

Table B.12: *Mass of components of the waste stream (S_7) in a batch*

Waste Stream (S_7)		
m_{oil} (g)	m_{H2o} (g)	m_{sg} (g)
32.96	9273	931
32.96	9273	931
32.96	9273	931
32.96	9273	931

Table B.13: *COD readings from Sample*

ID	Description	1st COD Reading	2nd COD Reading ~ 30 minutes after 1st readings
		Ultra Low Range vial-COD Test Reading mg/L	**Low Range Vial-COD Test Reading mg/L**
blank	DI Water	0	0
3a	Top Layer Sample	under range	under range
3b	Top Layer Sample	3.7	48.4
3c	Top Layer Sample	under range	29.2
3d	Middle-Mixed	under range	under range
3e	Bottom Layer	0.5	17
3f	Bottom Layer	0.7	under range

Table B.14: *HAZOP for bioremediation*

HAZOP: Bioremediation					
Parameter	**Guidewords**	**Potential Causes**	**Potential Consequences**	**Action**	**Safeguards**
Nitrogen Gas Concentr-ation	High	Nitrogen gas leak from sparger, fittings	Nitrogen asphyxiation/oxygen deficiency	Leave the room and call 911	Before releasing N2, Make sure all fittings and pipes are properly sealed. Use gas monitors to detect drops in O_2.
Power	No	short circuit	Loss of light and power. Bioremediation stops.	Do not reach for anything, pull out a flashlight/phone to be able to see to exit.	Have a phone/flash light handy

Toxicity of cleaning effluent	High	Oil and Heavy Metals adsorbed onto Adsorb-It fabric released into cleaning effluent	Contamination, skin and eye irritation, dependent on pollutants	Wash hands immediately and thoroughly if in contact, keep hands away from face and from others	Wear PPE (gloves, labcoat, protective eyewear) when collecting samples
pH	High	Reactions between Mushrooms and cleaning effluent	Will affect the efficiency of the rate at which the mushrooms take in oil/heavy metals	Apply measures to decrease pH. Add Acid that will not affect the mushrooms	maintain/regulate pH constantly
	Low	Reactions between Mushrooms and cleaning effluent	Will affect the efficiency of the rate at which the mushrooms take in oil/heavy metals	Apply measures to increase pH. Add base that will not effect the mushrooms	maintain/regulate pH using automatic readings
Mixing Speed	High	Mechanical Error	High sheer destruction of mycelia and enzyme	manually lower mixer speed or shut off impeller until repaired. Transfer to mixer that is not being used (backup mixer).	Have a backup mixer/ jar test apparatus available. Keep track
	Low	Mechanical Error	Reactor will no longer be well mixed. Poor distribution of N_2 gas in the reactor	manually increase mixer speed or shut off impeller until repaired. Transfer to mixer that is not being used	Have a backup mixer available
	None	Impeller failure or power failure	Reactor will no longer be well mixed. No distribution of air in the reactor	manually increase mixer speed. Transfer to mixer that is not being used (backup mixer)	Have a backup mixer available

Table B.15: *HAZOP for Cleaning Process*

HAZOP: Cleaning Process					
Parameter	**Guidewords**	**Potential Causes**	**Potential Consequences**	**Action**	**Safeguards**
Toxicity of Filter	High	Adsorbed Oil and Heavy Metals	Contamination, skin and eye irritation, dependant on pollutants	Wash hands immediately and thoroughly if in contact, keep hands away from face and from others	Wear PPE (gloves, labcoat, protective eyewear) when in contact with filter, store filter in a sealed container or large plastic bag.

Table B.16: *HAZOP for Collecting Samples/replacing filter components*

HAZOP Collecting Samples/replacing filter components					
Parameter	**Guide words**	**Potential Causes**	**Potential Consequences**	**Action**	**Safegua rds**
Toxicity of Stormwater	High	Oil Runoff, Heavy Metal runoff, biological pollutants	Contamination, skin and eye irritation, dependant on pollutants	Wash hands immediately and thoroughly if in contact, keep hands away from face and from others	Wear PPE (gloves, labcoat, protectiv e eyewear) when collectin g samples
Sample spills from Basin	High	Containers have a faulty seal. Containers not properly closed.	Contamination, skin and eye irritation, dependant on pollutants	Wash hands immediately and thoroughly if in contact, keep hands away from face and from others	Wear PPE (gloves, labcoat, protectiv e eyewear) when collectin g samples

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