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CRUMB RUBBER PRE-FILTER FOR USE WITH UV WATER TREATMENT SYSTEM

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ABSTRACT

Crumb rubber, made from recycled tires, is investigated for use as a pre-filter for an Ultraviolet (UV) drinking water disinfection system. We have designed and constructed a test stand that can pump water through a filter while measuring the flow rate, and pressures on either side of the filter. We have crafted a filter using crumb rubber as the filter media and a 4 inch diameter and variable length PVC tube as the structure. This filter was benchmarked against a Culligan brand paper cartridge filter, which is currently used in the UV system promoted by Clean Water for the World. It is made with a disposable cartridge housed inside of a plastic structure.

The EPA standard for the turbidity level for a municipal water system is 5 Nephelometric Turbidity Units (5 NTU's).The benchmark paper filter that we tested reduced the turbidity by 53% to a value of 70 NTU's. Our 1 foot crumb rubber filter reduced the turbidity by 85% to a value of 35 NTU's. Our 3 foot crumb rubber filter reduced the turbidity by 90% to a value of 22 NTU's. The crumb rubber filter should also remove particles above 5 μm in size. The removal of total suspended solids was also tested. For the benchmark filter, the percentage decrease in particles in the filtered water was 71.5%, where our 3 foot crumb rubber filter was able to produce a 97% reduction.

Additionally, this pre-filter needs to maintain the integrity of the water by not leaching any harmful chemicals or metals into the water. The results of the metals testing for water soaked with crumb rubber for 102 hours were within the range designated as safe by the EPA. The results of the Volatile Organic Compounds testing of the filtered water showed 6 compounds leached into the water that are not within the range designated as safe by the EPA water quality standards.These results may be improved by processing the crumb rubber before use in the filter.

NOMENCLATURE

α = Attachment efficiency factor
d_c = Diameter of the collector
d_p = Diameter of the particle (to be filtered)
ε = Porosity
g = Gravity
k = Boltzmann's constant
L = Filter Length
N_{in} = Number Concentration of particles (inlet)
N_{out} = Number Concentration of particles (outlet)
η = Overall single collector efficiency
η_{BM} = Brownian motion single collector efficiency
η_I = Interception single collector efficiency
η_S = Sedimentation single collector efficiency
ρ_l = Liquid density
ρ_p = Particle density
T = Absolute temperature
μ = Liquid viscosity
ν_o = Approach velocity
ν_s = Stokes velocity

INTRODUCTION

Crumb rubber is made from recycled tires. Used tires pose a disposal problem, as they are not allowed in landfills. Tires are a problematic source of waste. One of the issues is due to geometry issues. The used tires gather water and provide a perfect breeding ground for mosquitoes, which can cause public health problems. Tires can also trap methane gas, which can lead to tire buoyancy and damage to landfill liners that have been installed to keep landfill contaminants from polluting the groundwater. It has become evident that there is a need to search for alternatives in the disposal of used tires. Some current uses of crumb rubber are on sports fields, running tracks, roadways, and recently crumb rubber has been investigated for use in a ballast water filtering application. For this project we are looking into using crumb rubber as a filter media for use in a pre- filter for a Ultra Violet water treatment system.

The goal of this project is to make a filter test stand that will measure head loss and flow rate, and to use the crumb rubber pre-filter to reduce turbidity and solid particles in the water in order to allow the UV light to pass through the water. The UV filter will not function properly in water that is too cloudy, or that the UV light cannot pass through. The filter must also be able to meet EPA requirements [3] and NSF standards [4]. This project must also determine if there are any leeching characteristics of the crumb rubber that would cause the water to be hazardous for human consumption, which we determine based on the EPA Drinking Water Standards [3] and by performing metals testing and Volatile Organic Compounds testing on the water. Testing for heavy metals was performed by the Monroe County Department of Pure Waters, and the Volatile Organic Compounds testing was performed by Paradigm Environmental Services.

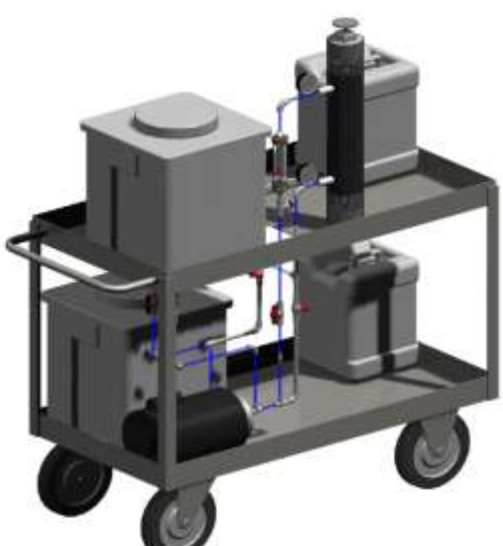


Figure 1: 3D model of test stand

In order to determine the success of the project, we tested the pre-filter from the Clean Water For The World UV Water Treatment System. This filter is a paper cartridge filter. This filter is successful in pre-filtering the water for UV treatment, and meets the EPA and NSF standards.
A 3D model of the test stand can be seen in figure 1.

PROCESS

Filter Model and Theory

The task to optimize the filter was completed by constructing a model of the filter media's efficiency.This was done to determine what filter length is needed to complete this project's objectives. The results of the model can be seen in Appendix 3 as Filter efficiency vs. Particle size.

Model Assumptions:
·Considers a single collector existing in an infinite medium
·The flow pattern is of a single sphere with no neighbors
·The velocity is sufficiently slow in order to ignore inertial terms, therefore Navier-stokes equations can be used to describe flow
·Steady state and steady flow

The single collector transport efficiency, η can be described as:

$$\eta = \frac{\text{Rate at which Particles are Predicted to Collide with Collector}}{\text{Rate at which Particles Approach Collector}} \qquad (1)$$

The attachment efficiency factor, α is necessary to find the optimal length and can be described as:

$$\alpha = \frac{\text{Rate at which Particles Attach to Collector}}{\text{Rate at which Particles are Predicted to Collide with Collector}} \qquad (2)$$

This factor will be experimentally determined through the following equation:

$$N_{out} = N_{in} \exp\left[-\frac{3}{2}\frac{(1-\varepsilon)\alpha\eta}{d}L\right] \qquad (3)$$

The overall single collector transport efficiency can be broken down into three parts; the efficiency of the collector by interception, sedimentation and Brownian motion:

$$\eta = \eta_I + \eta_g + \eta_{BM} \qquad (4)$$

Efficiency of single collector by interception:

$$\eta_I = \frac{3}{2}\left(\frac{d_p}{d_c}\right)^2 \qquad (5)$$

Interception occurs if a particle moving along a streamline comes within one particle radius of the

collector. The particle will collide with the surface of the collector and be “intercepted”.
Efficiency of single collector by sedimentation:

$$\eta_g = \frac{(\rho_p - \rho_l) g d_p^2}{18 \mu v_o} \quad (6)$$

The force of gravity causes particles to bend away from streamlines towards a collector until contact occurs. Sedimentation is the largest mechanism that influences the removal of particles.

Efficiency of single collector by Brownian motion:

$$\eta_{BM} = 0.905 \left(\frac{kT}{\mu d_c d_p v_o}\right)^{\left(\frac{2}{3}\right)} \quad (7)$$

Brownian motion is caused by the unequal distribution of collisions between the surface of a particle and the molecules of the solution that the particle is flowing in. The collector is treated as an infinite sink where concentration vanishes at the surface. This creates a concentration gradient with higher values away from the surface and lower values next to the surface. This leads to a diffusive particle flux towards the surface of the collector. [2] Figure (2) shows the different motions of particles interacting with the collector.

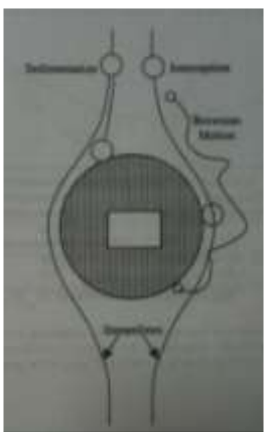


Figure 2: Particle motion around a collector

A Simulink model was constructed using the formulas provided, which is included in the appendix.

This model is used to optimize the length of the filter in equation (3). To do this the number concentrations in and out of the filter were determined experimentally by measuring the total suspended solids from inlet and outlet samples. The attachment efficiency factor α for 30 mesh crumb rubber was determined by first using known filter lengths.

$$\text{Porosity} = \frac{\text{Volume of void space}}{\text{Total volume of crumb rubber}} \quad (8)$$

The porosity for this type of crumb rubber was obtained by filling a liter container initially with crumb rubber, then filling the container with water and finding the difference in weight to determine how much water was added. In this case 400g of water (400 mL) was added.

$$\text{Porosity} = \frac{400mL}{1000mL} = 0.4$$

Porosity was used not only in equation (3), but also in equations (6) and (7) to find the approach velocity within the filter. Water entering the filter media accelerates due to a reduction in cross-sectional area of the flow path. To approximate this reduction in area the cross-sectional area of the filter is multiplied by the porosity.

$$v_s = \frac{\text{Flow rate through filter}}{\varepsilon * \pi * r^2} \quad (9)$$

Procedure: Testing of Water Filter Test Stand

Filtration flow path
For all testing, it is important to begin with the test stand power supply in the off position. The filter bypass line is in place. The dirty water reservoir is filled with water, and the clean water reservoir is empty. The test stand ran in the recirculation only mode first and this path inspected for leaks and proper function. After all filter flow path valves are opened, the gate valve is opened to allow flow through the flow meter and into the filtration section on the test stand. At this time, inspection is made to ensure that there are no leaks to the filtration path, and that the water is in fact entering the clean water reservoir. The filter pressure regulation valve is adjusted to ensure that 1 psi is registering on the front-side pressure gage which is the exit flow from the filter. The flow and pressure drop are now recorded. The whole system should now be inspected once again for leaks. See Figure 3 for flow diagram.

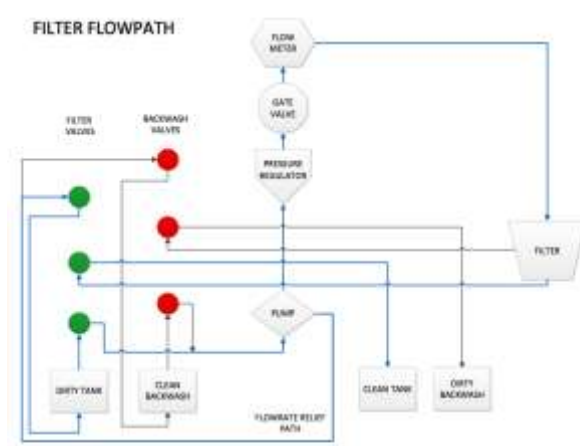


Figure #: Filter Flow Path

Backwash flow path
This testing will be performed as the filter flow path, with a few minor differences. The clean water

reservoir will be filled to start with, the dirty water reservoir will be empty. The system will be in recirculation mode first. Open the backwash Flow Path Valves, and adjust the gate valve before the flow meter to begin flow through the backwash path. Inspect the system for leaks and ensure that the water is entering the dirty backwash water reservoir. Adjust the Backwash Pressure Regulation Valve until 1 psi registers on the rear-side pressure gage. Record the flow and the pressure loss. Inspect entire system again for leaks. See figure 4 for flow diagram.

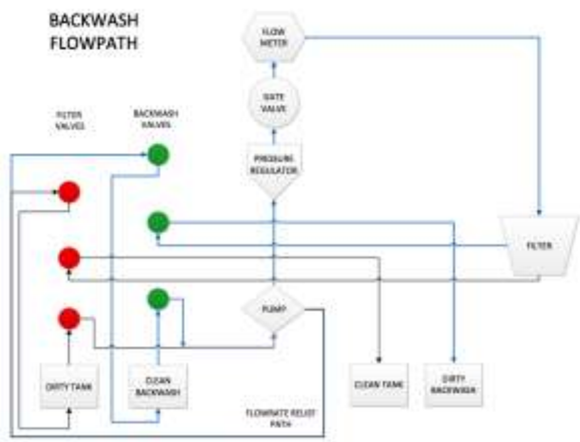


Figure 4: Backwash Flow Path

Procedure: Testing of Water Filter

Filter Flow Path
Begin test in the same way as the test stand testing is started. Be sure power is off and all valves are closed. When placing filter into the test stand, be sure that all connections are tightened appropriately. The dirty water reservoir will be full at the beginning of the test, and the clean water reservoir is empty. The water must be run in the recirculation mode for at least one minute to ensure constant mixing of particles. The inlet water samples are taken from the dirty water tank, once adequate mixing is obtained. Filter path valves are opened, and the gate valve is slowly opened to allow flow through the filter path. The system is inspected for any leaks. The pressure regulation valve is adjusted to display 1 psi on the front-side pressure gage, and the system pressure drop and flow rate are recorded on the testing sheet. Once the dirty water tank is 2/3 full, the post-filter water sample can be taken from the Sample Water Test Valve. See figure 2 for flow diagram.

Backwash Flow
Begin test in the same way as the filter test. Be sure all power is off and all valves are closed. When placing filter into the test stand, be sure that all connections are tightened appropriately. The clean water reservoir should be full at the beginning of the test, and the dirty water reservoir is empty. Backwash path valves are opened, and the gate valve is slowly opened to allow flow through the backwash path. The system is inspected for any leaks. The pressure regulation valve is adjusted to display 1 psi on the rear-side pressure gage, and the system pressure drop and flow rate are recorded on the testing sheet. A sample may be taken from the dirty tank to ensure that the backwashing is removing the contaminants from the filter. See figure 3 for flow diagram.

Outsourced Testing
The testing for Turbidity and Total Suspended Solids in the pre and post filtered water, as well as heavy metals leached into water soaked in crumb rubber were done by the County of Monroe Pure Waters Department, EPA Lab Code NY01266, NYSDOH ELAP # 10373. The testing for Volatile Organic Compounds in the crumb rubber and Volatile Organic Compounds leached into the water soaked in crumb rubber and into the water filtered through the crumb rubber were done using EPA method 8260B by Paradigm Environmental Services, NYSDOH ELAP # 10958.

Procedure: Sampling water for metals testing
Distilled DI water was soaked in a 1 liter container with approximately 500ml of >30 mesh crumb rubber for a time of 102 hours. The water was drained through a coffee filter to separate it from the crumb rubber and poured directly into the plastic sample container provided by the Monroe County Pure Waters Department.

Procedure: Measuring for porosity
Distilled DI water was added to a 1 liter container filled with >30 mesh crumb rubber until the water was filling all of the spaces in the crumb rubber. The container and the crumb rubber was weighed before the water was added. The porosity was found to be 0.4 as described in the modeling section above.

Procedure: Sampling water for turbidity and TSS testing
The water was collected in the plastic sampling containers provided by the Monroe County Department of Pure Waters. The samples were collected as described in the filter testing procedure section above using the Sample Test Valve.

Procedure: Sampling water for VOC testing
The water was collected in the glass sampling bottles that contained hydrochloric acid solution as provided by Paradigm Environmental Services. The sample from the filtered water was collected as described above in the filter testing section using the Sample Test Valve. The sample that had been soaked in crumb

rubber was distilled DI water that had soaked in the crumb rubber. There was approximately 500 ml of crumb rubber and water was added to fill the 1 liter container.The sample soaked for the time period between 2/8/2011 and 4/22/2011. This was approximately 10 weeks. The water was filtered through a paper coffee filter to remove the solid crumb rubber form the water. The water was poured into the glass container.

Experimental Approach

The primary concern of using crumb rubber as a filtration medium is the potential to contaminate the water being filtered. To begin this investigation, crumb rubber must first be tested to determine the composition of volatile organic compounds it contains. From there, potential hazards can be identified and further testing can be performed to determine the content the compounds that leaches into the water directly from the crumb rubber. Continuing with this investigation, testing was performed on the elemental compounds leached into water that has been in contact with crumb rubber for an extended period of time. Specific detail on the test setup and experimental results are listed below.

Experimental Setup

The crumb rubber used in this examination was donated by Animat Incorporate located in Sherbrooke, QC J1R 0S6, Canada. The crumb rubber was <30 mesh (<0.595mm) in size and black irregular shaped in appearance.

RESULTS AND DISCUSSION

Head loss through the filter

The head loss through the filter varied for the length of the crumb rubber column. The least amount of head loss was for the benchmark filter (CLFTW). The head loss can be translated into the height of the water column that must be provided in order for the water to flow through the filter. The maximum water height that we were hoping for was 1 meter. Neither our filter, nor the benchmark filter were able to meet this goal. The Clean Water for The World filter was able to function with a water height of 1.41 meters. There is significantly more head loss for the 3 foot crumb rubber, with a maximum water height of 4.93 meters required, as opposed to the 1 foot crumb rubber which had a height of 2.53 meters at our goal of 5 liters per minute, or required height of 1.69 meters with a flow rate of 3 liters per minute.

Date	Filter tested	flow rate (lpm)	head loss (psi)	height of water (m)
15-Apr	CWfTW	11	2	1.41
		11	2.1	1.48
14-Apr	1ft Crumb Rubber	5	3.6	2.53
		3	2.4	1.69
22-Apr	3ft Crumb Rubber	1.75	4.5	3.18
		1.75	4.5	3.18
25-Apr	3ft Crumb Rubber	3.8	5.2	3.66
		4	7	4.93

Figure 5: Head losses through filter at different times

Volatile Organic Compounds Testing Results:

For Solid Crumb Rubber:
In order to determine the volatile organic compounds in crumb rubber itself, 200 grams of solid crumb rubber were sent to Paradigm Environmental Services located in Rochester, New York. Analysis of the material was provided by purge and trap GC/MS, and evaluation of the output by computerized library search. Samples were prepared by using EPA method 8260B and the results are listed in Figure 6, and in Appendix 2.

Halocarbons	Results in ug / Kg
Bromodichloromethane	< 7.87
Bromomethane	< 7.87
Bromoform	< 19.7
Carbon Tetrachloride	< 7.87
Chloroethane	< 7.87
Chloromethane	< 7.87
2-Chloroethyl vinyl Ether	< 39.4
Chloroform	< 7.87
Dibromochloromethane	< 7.87
1,1-Dichloroethane	< 7.87
1,2-Dichloroethane	< 7.87
1,1-Dichloroethene	< 7.87
cis-1,2-Dichloroethene	< 7.87
trans-1,2-Dichloroethene	< 7.87
1,2-Dichloropropane	< 7.87
cis-1,3-Dichloropropene	< 7.87
trans-1,3-Dichloropropene	< 7.87
Methylene chloride	< 19.7
1,1,2,2-Tetrachloroethane	< 7.87
Tetrachloroethene	187
1,1,1-Trichloroethane	< 7.87
1,1,2-Trichloroethane	< 7.87
Trichloroethene	22.1
Trichlorofluoromethane	< 7.87
Vinyl chloride	< 7.87

Aromatics	Results in ug / Kg
Benzene	< 7.87
Chlorobenzene	< 7.87
Ethylbenzene	27.6
Toluene	45.4
m,p-Xylene	750
o-Xylene	34.2
Styrene	28.4
1,2-Dichlorobenzene	< 7.87
1,3-Dichlorobenzene	< 7.87
1,4-Dichlorobenzene	< 7.87

Ketones	Results in ug / Kg
Acetone	383
2-Butanone	< 39.4
2-Hexanone	< 19.7
4-Methyl-2-pentanone	4,260

Miscellaneous	Results in ug / Kg
Carbon disulfide	76.6
Vinyl acetate	< 19.7

Tentatively Identified Compounds	CAS Number	Retention Time	Results in ug / Kg	Percent Fit
n-methylfuran	N/A	3.60	22.9	N/A
3-methylhexane	589-34-4	4.67	23.7	94
5-methyl-2-hexanone	N/A	8.37	208	N/A
Unknown ketone	N/A	9.21	417	N/A
Unknown alkane	N/A	9.70	130	N/A
Unknown	N/A	10.01	117	N/A
Unknown alkane	N/A	12.12	249	N/A
Unknown heterocyclic compound	N/A	13.50	161	N/A

Figure 6: Volatile Organic Compound testing results of solid crumb rubber sample

For water passed throughCrumb Rubber filter:
Figure 7 Shows that there are a few compounds that are potentially above the EPA standards for Volatile Organic Compounds. The results were given as "less than" the number states, so further investigation of these results with a more sensitive test is required.

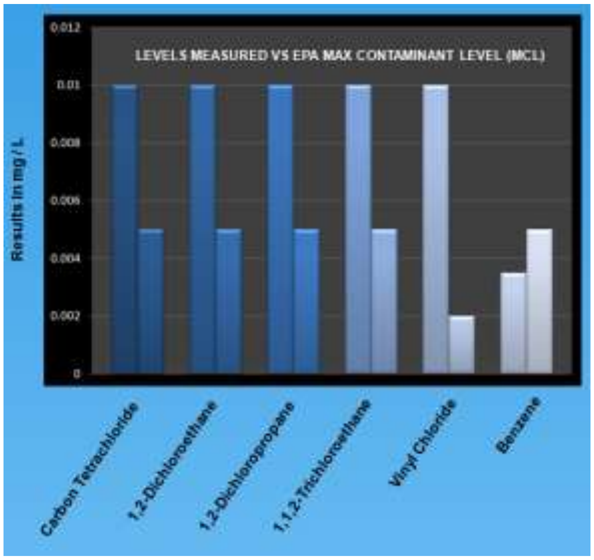


Figure 7: Volatile Organic Compounds in filtered water

The results shown in Figure 7 are of a sample taken from deionized water soaked in crumb rubber < 30 mesh for 10 weeks. Tests were also performed on water that has been passed through 3 ft of <30 mesh crumb rubber. Samples were taken after 8 minutes of run time. Less contact time resulted in passing all EPA standards except vinyl chloride. Vinyl chloride is a known carcinogen and methods of reducing the levels measured should be further investigated. There is a concern on the validity of these results. The precision of the testing equipment used by Paradigm will have to be verified. It is possible the actual levels of priority pollutants fall within the EPA standards.

Metals testing results:

For water soaked in Crumb Rubber for 102 hours:

Figure 8 shows the results for metals testing are below the levels allowed by the EPA drinking water regulations.

DEPARTMENT OF ENVIRONMENTAL SERVICES
HEAVY METAL TEST RESULTS
FOR WATER SOAKED IN CRUMB RUBBER FOR 102 HOURS
METHOD SM 18-19, 3113 B

		EPA MCL
Arsenic	0.00100 mg / L	0.01000 mg / L
Cadmium	0.00100 mg / L	0.00500 mg / L
Chromium	0.00100 mg / L	0.10000 mg / L
Copper	0.00500 mg / L	1.30000 mg / L
Lead	0.00100 mg / L	0.01500 mg / L
Manganese	0.17400 mg / L	0.05000 mg / L*
Nickel	0.00260 mg / L	**
METHOD SM 18-121311 B (99)		
Zinc	4.23000 mg / L	5.00000 mg / L*

*Secondary standard (not enforced)

**Not regulated by EPA

Figure 8: Metals Testing Results of water plus crumb rubber

The results in Figure 8 are from deionized water that was soaked in a 1 liter container with approximately 500ml of >30 mesh crumb rubber for a time of 102 hours. The water was drained through a coffee filter to separate it from the crumb rubber and poured directly into the plastic sample container provided by the Monroe County Pure Waters Department. Manganese levels were high, but Manganese levels are based on a list of secondary standards that are not enforced. Zinc levels are also high, but EPA only provides a goal that should be met. These goals are not enforced. All other metals met EPA standards.

Turbidity Test results:

The turbidity was tested by Monroe County using Method: SM 18-20 2130B ELAP Code: 1165. The results for the turbidity testing in figure 8 show that the crumb rubber filters were able to surpass the benchmark filter with both the 1 foot and the 3 foot crumb rubber filters. This was true for turbidity and also for total suspended solids removed. It can be seen here that there is not a huge difference between the results of the percent reduction in turbidity for the 3 foot filter and for the 1 foot filter. Due to the fact that the longer filter causes a more significant need for water height, it would likely be best to proceed by using a shorter crumb rubber filter.

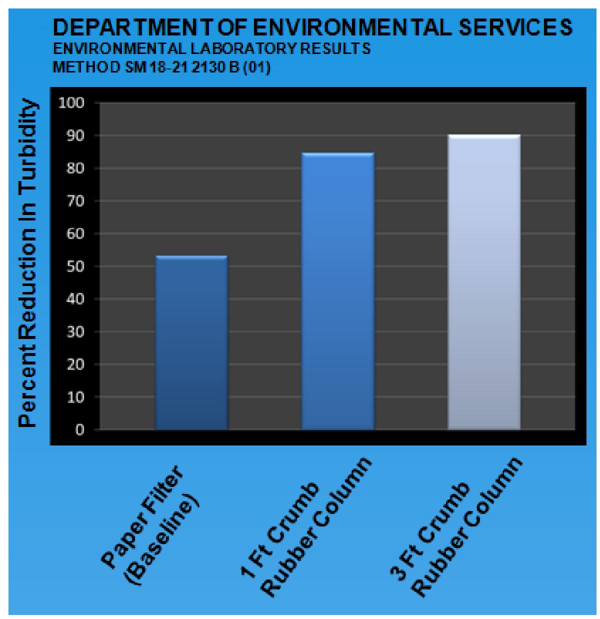


Figure 9: Turbidity Testing Results

Total Suspended Solids Test Results

The Total Suspended Solids were tested by Monroe County using Method: SM 18-20 2540D ELAP Code: 9065. We were not able to test specifically for particle smaller that 5 microns in diameter due to not having the expensive and specialized equipment available to us. As a result, we opted to test for total suspended solids. As can be seen in figure 10 below, our crumb rubber filter surpassed the benchmark Clean Water for The World Culligan brand paper filter in total suspended solids filtered.

Total Suspended Solids (mg/L)		
Filter	CWfTW	3 ft Crumb Rubber
Before	169	240
After	48	7
% Reduction	72%	97%

Figure 10: Total suspended solids

CONCLUSIONS AND RECOMMENDATIONS

The specific goals that we set out to meet for both the test stand and for the filter were in the areas of measuring head loss, turbidity, particle size and quantity removed, flow rates, and prevention of the addition of harmful compounds into the filtered water.

As far as the head loss, or required water height for water to flow through the filter, our benchmark was better than our prototype filter. The benchmark was able to function with 1.41 meters at a flow rate of 11 liters per minute. Our 1 foot crumb rubber filter had required water height of 2.53 meters at our goal of 5 liters per minute, or required height of 1.69 meters with a flow rate of 3 liters per minute.

The ideal flow rates that we were attempting to obtain through the filter was 5 lpm to 20 lpm. With the benchmark filter, we were able to attain 11 lpm, the best flow rate we came to with our filters was with the 1 foot crumb rubber at 5 lpm.

The turbidity results for our filters were much better thatn that of the benchmark, though still above the EPA requirement of 5 NTU's. Our filter was able to reduce the turbidity to 22 NTU's, where the benchmark filter was only able to reduce the turbidity to 70 NTU's.

The particle sizes that we were intended to remove from the filtered water was anything above 5 microns in size. We were not able to measure this due to the expensive specialized equipment required to accomplish this goal was not available to us. We were able to measure the total suspended solids before and after filtering, thanks to the County of Monroe Pure Waters Department. From these results, it was made clear that our filter surpassed the benchmark filter. The benchmark filter was able to reduce the total suspended solids from 169 mg/L to 48 mg/L, a reduction of 72%. Our 3 foot crumb rubber filter was able to reduce the total suspended solids from 240 mg/L to 7 mg/L, a reduction of 97%.

The Volatile Organic Compounds testing is going to require more investigation due to the inconclusive test results received from Paradigm Environmental Services. It is possible that the crumb rubber would require cleaning, or some sort of treatment process before being used as a filter media to prevent leaching of dangerous chemicals into the filtered water.

We were not able to test for the size of the particles due to budget constraints. We would need a vacuum filtration apparatus in order to test for particle size.

REFERENCES:

[1]Tang, Zhijan, and Butkus, Michael A., and Xie, Yuefeng, June 2005, "Crumb rubber filtration: A potential technology for ballast water treatment", Marine Environmental Research, 61 (2006), pp. 410-423.

[2] Benjamin, M.M. & Lawler, D.F. (2011). Water Treatment Engineering: Physical/Chemical Processes. Boston, MA: McGraw-Hill.

[3] EPA Drinking Water Contaminants List http://water.epa.gov/drink/contaminants/index.cfm#List

[4] NSF International Standard/ American National Standard for Drinking Water Treatment Units, ANSI Standard, American National Standards Institute, January 29, 2002

ACKNOWLEDGMENTS

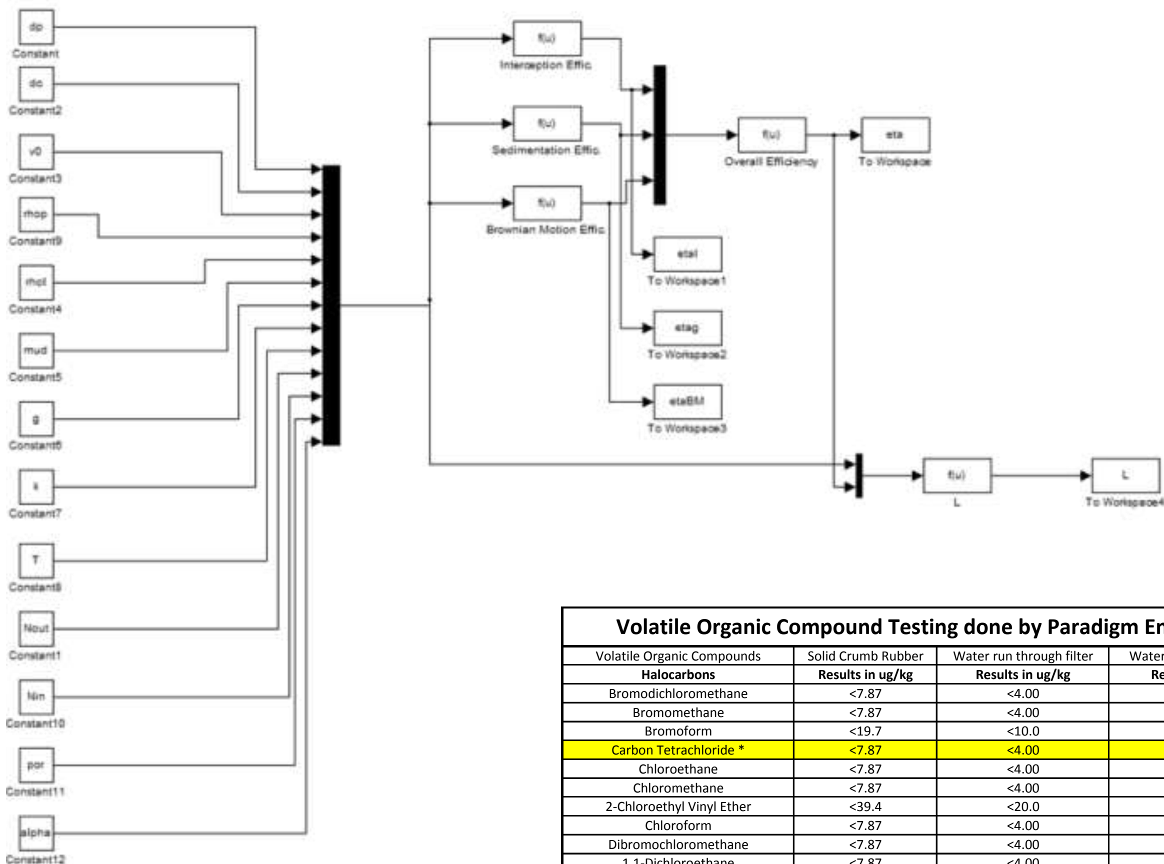
Special thanks to:

Animat - for donating crumb rubber samples.

Monroe County Pure Waters - for performing heavy metals testing, turbidity testing, and total suspended solids testing.

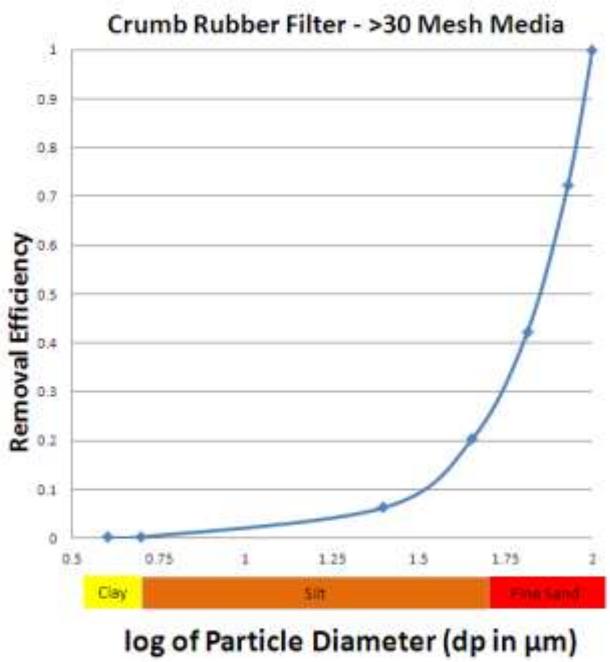
Paradigm Environmental Services - for donating Volatile Organic Compounds testing

Appendix 1: Simulink Model of the Filter



Volatile Organic Compound Testing done by Paradigm Environmental Services				
Volatile Organic Compounds	Solid Crumb Rubber	Water run through filter	Water Soaked in rubber	**EPA levels**
Halocarbons	**Results in ug/kg**	**Results in ug/kg**	**Results in ug/kg**	**Results in ug/kg**
Bromodichloromethane	<7.87	<4.00	<10.0	
Bromomethane	<7.87	<4.00	<10.0	
Bromoform	<19.7	<10.0	<25.0	
Carbon Tetrachloride *	<7.87	<4.00	<10.0	5
Chloroethane	<7.87	<4.00	<10.0	
Chloromethane	<7.87	<4.00	<10.0	
2-Chloroethyl Vinyl Ether	<39.4	<20.0	<50.0	
Chloroform	<7.87	<4.00	<10.0	
Dibromochloromethane	<7.87	<4.00	<10.0	
1,1-Dichloroethane	<7.87	<4.00	<10.0	
1,2-Dichloroethane *	<7.87	<4.00	<10.0	5
1,1-Dichloroethene	<7.87	<4.00	<10.0	
cis-1,2-Dichloroethene	<7.87	<4.00	<10.0	
trans-1,2-Dichloroethene	<7.87	<4.00	<10.0	
1,2-Dichloropropane *		<4.00	<10.0	5
cis-1,3-Dichloropropene		<4.00	<10.0	
trans-1,3-Dichloropropene		<4.00	<10.0	
Methylene chloride	<19.7	<10.0	<25.0	
1,1,2,2-Tetrachloroethane	<7.87	<4.00	<10.0	
Tetrachloroethene	187	<4.00	<10.0	
1,1,1-Trichloroethane	<7.87	<4.00	<10.0	200
1,1,2-Trichloroethane *	<7.87	<4.00	<10.0	5
Trichloroethene	22.1	<4.00	<10.0	
Trichloroflouromethane	<7.87	<4.00	<10.0	
Vinyl Chloride *	<7.87	<4.00	<10.0	2
				EPA levels
Aeromatics	**Results in ug/kg**	**Results in ug/kg**	**Results in ug/kg**	**Results in ug/kg**
Benzene *	<7.87	<1.40	<3.5	5
Chlorobenzene	<7.87	<4.00	<10.0	100
Ethylbenzene	27.6	<4.00	<10.0	700
Toluene	45.4	<4.00	<10.0	1000
m,p-Xylene	750	<4.00	<10.0	
o-Xylene	34.2	<4.00	<10.0	
Xylenes (total)	784.2	<8.00	<20.0	10000
Styrene	28.4	<10.0	<25.0	100
1,2-Dichlorobenzene	<7.87	<4.00	<10.0	
1,3-Dichlorobenzene	<7.87	<4.00	<10.0	
1,4-Dichlorobenzene	<7.87	<4.00	<10.0	
				EPA levels
Ketones	**Results in ug/kg**	**Results in ug/kg**	**Results in ug/kg**	**Results in ug/kg**
Acetone	363	Biased 23.9	Biased 189	
2-Butanone	<39.4	<20.0	<50.0	
2-Hexanone	<19.7	<10.0	<25.0	
4-Methyl-2-pentanone	4260	268	478	
Miscellaneous	**Results in ug/kg**			**EPA levels**
Carbon disulfide	76.6	<4.00	<10.0	
Vinyl Acetate	<19.7	<10.0	<25.0	

Appendix 2: Results of VOC testing. The * indicates a test failure that requires further investigation.



Appendix 3: Results of Model