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Efficiency and Effectiveness of a Low-Cost, Self-Cleaning Microplastic Filtering System for Wastewater Treatment Plants

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Abstract

Numerous studies have shown that marine life readily ingest microplastics that have adsorbed toxic pollutants in the environment, introducing them into the food chain. Microplastics are commonly released into the marine environment due to degradation of larger plastic debris, as microbeads in beauty products, as microfibers washed off of clothing, or by the breakdown of fishing nets and equipment, which is problematic because they are highly resistant to degradation. Because of their small size and density, which is similar to water, microplastics are currently not being filtered through most existing wastewater treatment plants. This research project aims to produce an easy, practical, and inexpensive engineering solution to be implemented in wastewater treatment facilities. The effect of varying the filtration material, water pressure, and filter orientation on the flow rate and microplastic recovery of the system was the main focus of this study. The gravity-powered filtration testing system contains a constant pressure basin and a mixer to try and simulate conditions inside a wastewater treatment plant. Analysis of testing shall include several statistical measures (for example: error bounds) that will provide guidance towards the design of a backflushing apparatus. Based on the test results of the previous undergraduate research microplastics team, a 3D filter at an angle of 90 degrees to the pipe with 1.68 kPa of water pressure shall provide the best flow rate for our system, but more tests will be needed to validate this data. By testing various configurations of filter type, filter angle, and pressure we hope to find support for the claim that the mentioned combination provides the best flowrate in the normal flow of the plant. We also hope to experiment with these configurations on the system in reverse to find the combination that will allow for quick and easy backflushing. Our optimal filter configuration will allow for the best flow rate in normal flow of the plant as well as best backflushing ability, and if successful, this system will greatly assist the health of the marine ecosystem, by reducing transmission of toxins across the food chain.

Keywords: microplastics, wastewater treatment plant, filtration

1. Introduction

In the last few years, the serious health effects imposed by microplastics to the purity and ecosystem in the Great Lakes have become increasingly apparent. These plastic particles, less than 5 mm in diameter, are most commonly found in cosmetics (such as face washes, soap, etc.) and shed from synthetic clothing (referred to as microfibers).[1] Higher concentrations of these plastics are also found near major cities, indicating that urban wastewater is a major source of these microplastics.[2] The small size of microplastics allows their passage through wastewater treatment plant filters, accumulating in freshwater lakes and oceans.[3] Since they are non-biodegradable, they end up absorbing toxins to their surfaces, which are then introduced into the food chain through aquatic life ingestion.[3] This ecological problem further extends to a human safety issue, as humans could consume fish who have in turn consumed harmful amounts of these toxin-filled microplastics.

1.1 Background - Literature Review

Plastic consumption is on the rise at a global scale, with the world plastic production reaching 299 metric tons in 2013 as compared to 204 metric tons in 2002.[4] Microfibers, composed primarily of polyester and acrylics, are currently not filtered by traditional wastewater treatment and is released into the environment through urban effluent.[5] This is a problem because persistent bioaccumulative toxins (PBTs) are absorbed by microplastics and microfibers as they exist in the ocean. They then float on the surface of large bodies of water, carrying these PBTs for potentially hundreds of miles.[6] Due to their size and color, aquatic life tend to view these microplastics as consumable plant matter or bugs, and will ingest them along with the PBTs that were absorbed.[6] The PBTs are then officially introduced to the food chain and accumulate within the bodies of secondary and tertiary consumers, with uncertain health effects.[5]

While technologies exist to filter microplastics, they can often be expensive and difficult to install into wastewater treatment plants and often go unimplemented unless effluent quality standards are high. Membrane bioreactors are an example of this -- occurring after primary and secondary treatment in wastewater treatment plants, they use cross-flow filtration, diffusing only water and small particles. For example, Traverse City, Michigan installed the world's largest membrane bioreactor in 2008, which is able to filter particles greater than .04 micrometers. Installing this bioreactor, however cost US$30 million, which may be a barrier to implementation at other wastewater treatment plants. In addition, it is found that membrane bioreactors also have a higher energy cost when compared to traditional filtration methods.[7]

The goal of this research project is to help prevent the issues mentioned above by developing a practical self-cleaning microplastic filter that can be retrofitted in wastewater treatment plants. This research project began in the fall of 2014 with Dr. Laura Alford and five undergraduate research assistants who developed an experimental design as well as a filtration simulator. It was determined that two main factors influenced the effectiveness of filtration of microplastics: filter material and pressure.[8] This past year, the team worked on gathering more data on the flow rate of water dependent on different configurations of the filter (based on the two factors) as well as testing these configurations in reverse to determine the optimum filtration system for backflushing. This paper will present our findings on optimum filter configuration for normal flow as well as backflushing in wastewater treatment plants.

2. Design

Microplastic filtration designs already exist, but many are costly and difficult to implement in pre-existing wastewater treatment plants. The aim of this project was to create a low-cost, energy efficient system that could be easily retrofitted into current wastewater systems. The design of our filtration system implements two key parts: a filtration system that filters microplastics out of the wastewater, and a backflushing system that cleans the microplastics out of the filters.

2.1 Filter Placement

Wastewater treatment plants have two main steps to filtration: a primary treatment and a secondary treatment. In primary treatment, most of the larger solid waste that settles to the bottom of wastewater is removed. In secondary treatment, most other smaller, dissolved biomasses are removed from the wastewater.[9] We recommend that our microplastic filter is placed during the secondary treatment phase after secondary clarification to prevent the filter from being easily clogged but before disinfection to prevent damage to the filter due to outside chemicals that are introduced to the water in that stage.

2.2 Filtration System

The microplastic filtration system takes secondary effluent from a high flux pipe and directs it into multiple smaller low-flux filter channels (Figure 1).

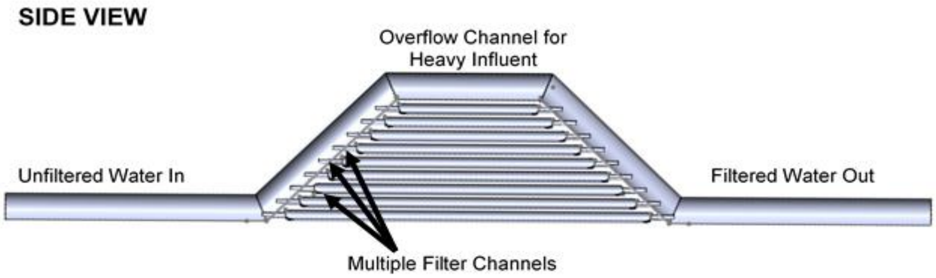

Figure 1. A side view of the filter design; multiple channels allow influent alternate paths if one path clogs

We chose to include multiple pipes for our filtration system to allow water to continually flow. While one filter is being cleaned via backflushing, water can flow through the other filters within our system. The multiple pipes also minimize turbulence at the filter by maintaining nearly closed-channel flow, even when the flux through the wastewater treatment plant changes. This is significant because turbulence at the filter can decrease the rate of flow through the filter. The filtration system also includes a large overflow pipe that does not include a filter. This exists so that, in the event that all channels are clogged at the same time, or during high-flux events, water can still flow through the wastewater plant without clogging the system.

2.3 Backflushing System

Our backflushing system consists of two phases. One phase is when backflushing occurs (Figure 2).

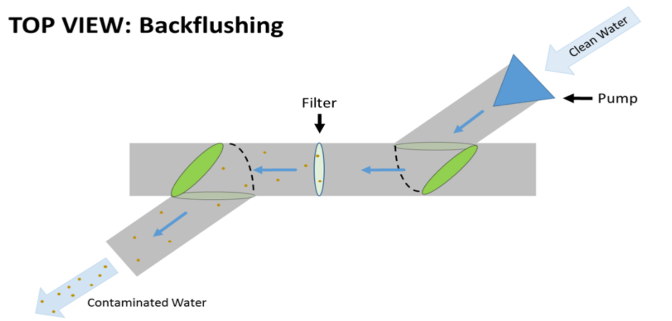

Figure 2. A top view of the filtration system during backflushing

During backflushing, a pump will activate in the intake valve, opening the two "doors" of the intake and outtake pipes. When the "doors" open, they block the flow coming in for filtration. A pump is then used to flush clean water through the filter in the opposite direction of filtration. This microplastic-contaminated water is then directed through the outtake pipe and contained for proper disposal.

The other phase is the main component of the system, which occurs during filtration (Figure 3).

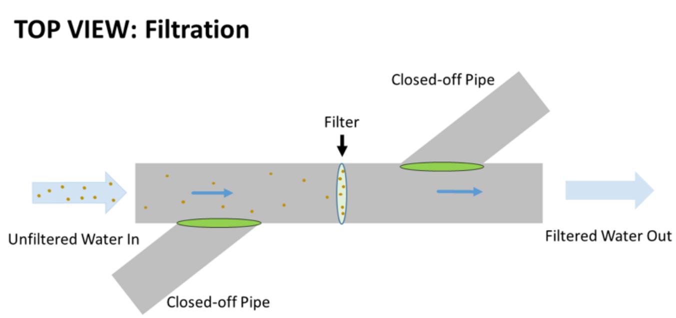

Figure 3. A top view of the filtration system during filtration

The filter will be in this phase for the majority of the time. During this phase, the intake and outtake valves are closed off by the "doors," and the pump is not active. This part of the process filters out microplastics from entering water systems.

3. Methods

Our testing system was designed to simulate a wastewater treatment plant after the secondary clarification stage of the overall water filtration process.

3.1 Variables Tested

The primary variable was filter material. Filter material has arguably the largest effect on how the microplastics are collected.[8] For this project, two filter types were tested, deemed "2D" and "3D." The 2D filter is an 80µm screen that would easily catch the microplastics due to its close stitching. The 3D filter is a thicker material with several layers that is commonly used for home aquariums. Two different pressures were also tested: 1.68 kPa was considered "low pressure" and 3.68 kPa was considered "high pressure." These pressures were chosen by the previous research team after touring and consulting with the plant manager at the Ypsilanti, Michigan wastewater treatment plant. They were chosen because they closely mimicked the pressures in the plant.[8]

3.2 Filtration Simulator

The filtration simulator was the main device used to test our variables. The simulator mimics a wastewater treatment plant with continual influent. The device can be seen below (Figure 4).

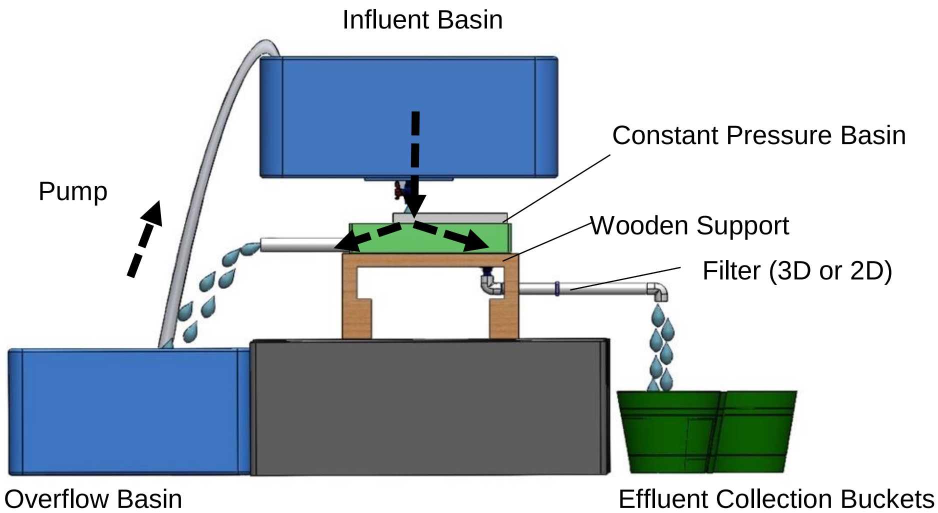

Figure 4: Filtration simulator used to test filters of varying material and with differing water pressure

The influent and overflow basins are identical bins that can each hold 200 liters of water (much more than the maximum amount of water used in our tests). The influent basin has a valve attached to the bottom to be opened or closed when needed. The constant pressure basin consists of two bins: a smaller fixed inside a bigger. Once the first, smaller bin overflows, we know that constant pressure has been reached. The bigger bin is used as an overflow mediator, and sends the extra water to the overflow basin. Under the constant pressure basin, there is another valve that connects to the filter. To vary pressure, we use different lengths of PVC pipe (which are 2.5 cm in diameter) to change the vertical distance the water has to fall before it reaches the filter, thus allowing more water into the pipe at one time and directly affecting the pressure. A 2-inch-long pipe represents 1.68 kPa of pressure and a 10-inch-long pipe represents 3.68 kPa of pressure. The effluent buckets are changed during testing at a previously determined time interval and allow for the measurement of the flow rate at any arbitrary point in time. The overflow basin holds the overflow from the constant pressure basin and is connected to a pump that brings the water back up to the influent basin.

3.3 Filtration Testing Procedure

Before testing began, that test's filter would be weighed while clean and dry in order to get a more accurate measurement of microplastics collected. After setting up the filtration simulator, the overflow and influent basins would then be filled with 60 and 40 liters of water, respectively. Then, 1.8 and 1.2 grams of microplastics (harnessed from a generic face scrub) would be weighed to put into the overflow and influent basins, respectively (to be consistent with a maximum load of 30 milligrams of microplastics per liter of water, which is the highest recommended amount of suspended solids at this stage of treatment).[10]

After set-up, the influent basin's valve would then be opened, the bilge pump would be turned on, and the constant pressure basin would fill up. The water was constantly stirred in the influent basin and the constant pressure basin to keep the microplastics in suspension, due to their positively buoyant tendencies. Once the system achieved constant pressure, the constant pressure basin's valve was opened and a timer was started to measure when to replace each effluent collection bucket. Buckets would be replaced with empty ones at previously determined time intervals and tests would end when water flow decreased sufficiently.

Finally, the volume of water captured in each bucket was recorded. The used filter was also set to dry overnight and the new weight was recorded the next day to determine the amount of microplastics captured overall.

3.4 Backflushing Testing Procedure

The backflushing testing data is obtained just as the filtration testing procedure is: by measuring in timed intervals the volume of water that exits the system. However, instead of starting with a microplastic-water solution, clean water is used to flush microplastics out of a clogged filter. Again, the constant pressure basin and varying pipe lengths were used to test different pressures, and effluent buckets recorded the amount of water exiting the system over time. Due to the Microbead-Free Waters Act being passed in the United States (which will take effect in 2018 and prevent the sale of microplastics in personal care products), we decided to use microfibers harnessed from washing machines.[9] There were some problems with these tests, as a significant amount of water was lost in the process of switching effluent buckets and most microfibers could be visibly seen to be flushed out within the first five seconds of testing. Because of these problems, we were unable to find a "correct" interval to switch buckets and observe data, and most of the resulting data was inconclusive.

4. Results

4.1 Filtration Results

After testing, it was found that the 2D filter consistently clogged faster than the 3D filter. As shown in the data below (Figure 5), the tests with 2D filter material (red lines) decrease very steeply around 2.5 minutes into the test, indicating that the filter has been clogged. This is in contrast to the tests done with 3D material (blue lines), which also seems to decrease around 2.5 minutes, but much more gradually. It was also found that the pressures of 1.68 kPa and 3.68 kPa turned out to have a similar curvature for decrease in the flow rate. In addition, the angle at which the PVC cut seemed to produce the same flow rate decrease.

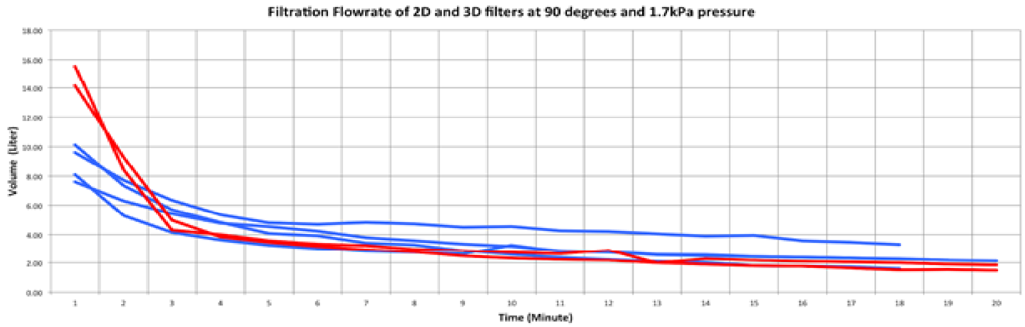

Figure 5: The above graph shows the flow rate of the water coming out of the filter with either 2D or 3D filter materials at 1.7 kPa: each line represents a test. Red represents the 2D filter and blue represents the 3D filter.

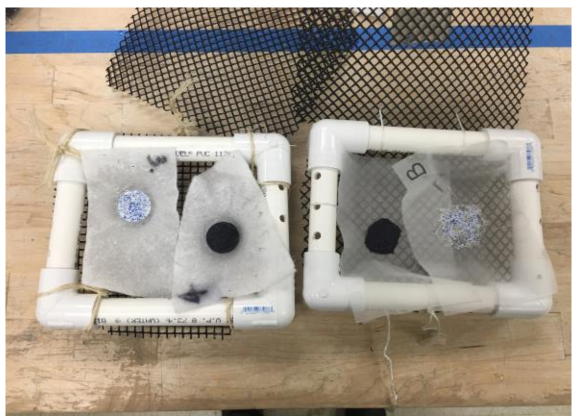

Figure 6: Image of the 3D (left) and 2D (right) filters after testing, while drying so that mass of collected plastics could be measured.

On average, the 3D material filters better over time. This is possibly because the 2D filter only has one surface to catch the microplastics, so it clogs faster than the 3D filter, which allows microplastics to embed themselves amongst the first few layers of the material and allows more water to pass through.

4.2 Backflushing Results

After extensive backflushing tests, the volume of water expelled through the filter every minute was plotted to see how the flow rate changed through time. Using the data displayed below, it was concluded that the 2D filter worked best for backflushing (Figure 7). This may be because the 2D filter had only one surface to be backflushed, while the 3D filter had some microplastics in between its layers.

Using the 3D filter, it was noted that the duration of the backflushing with the higher water pressure of 3.68 kPa seemed to be the shortest with an average close to 25 seconds. With a water pressure of both 1.68 kPa and 3.68 kPa, the filter design successfully backflushed 95-100% of the microfibers. With a 1.68 kPa pressure, the backflushing duration was averaged to about 45 seconds.

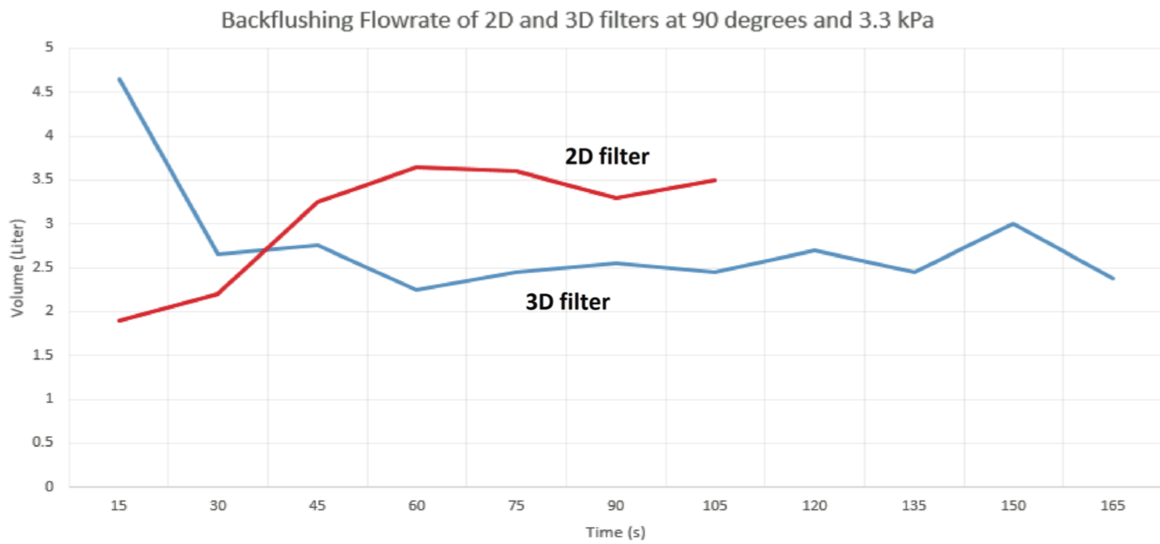

Figure 7: The above graph shows the flow rate of the water coming out of the filter with either 2D or 3D filter materials at 1.7 kPa pressure: each line represents a test. Red represents the 2D filter and blue represents the 3D filter.

4.3 Sources of Error

Unfortunately, there were some sources of error present in the testing procedure that, if eradicated, could make our results more conclusive. As effluent buckets were switched, there were times when water would spill in small quantities onto the floor, since the flow of water was relatively strong and buckets could not be switched out fast enough. A more sophisticated testing facility would be a good solution to avoid this problem.

There were also some problems with timing the swaps at the exact time interval desired. With only 5 people (and sometimes, less) to run each test, tasks were delegated, and sometimes the timer had to do multiple jobs. This resulted in the timer notifying the bucket-switcher a couple seconds too late to switch buckets. A solution to this might be to have the timer be visible to the bucket-switcher, or implementing an audible warning when there are 5 seconds left until a switch must occur.

The lack of a homogenous solution also caused problems. The water-containing basins were constantly mixed to attempt to reach a perfect mix, but it was noticed that a large portion of the microplastics would remain suspended in the surface of the water throughout the test. Due to the lack of a homogenous solution, and the fact that microplastics float, this source of error was one we struggled to fix. A large mixer, or a shaking water basin, might solve these problems, but they were not within the price range for the team.

5. Analysis

From the results, it can be concluded that the best filtration system to implement in a wastewater treatment plant would be one that has a straight-squared cut PVC pipe with a pressure of 1.68 kPa and 3D filter material. This was concluded after noting that flowrate significantly decreases under these conditions, which would decrease the amount of energy used to backflush a clogged filter. In analyzing the backflushing data, it was concluded that to minimize energy costs, the optimal backflushing system would include a 3D filter under 3.68 kPa. This would allow the duration of the backflushing to be relatively low (around 30 seconds) and would allow for less energy to go into the system. In the end, the results were in line with what was hypothesized would be the best design: 3D filter material, and high pressure.

6. Conclusions

Through our results, we found that a 3D filter at a lower pressure (1.68 kPa) would produce a combination that would have to be backflushed between longer time intervals. Our backflushing data also demonstrated that there was a small time difference between the 3D filter and the 2D filter to backflush the filter, and the 2D filter was slightly shorter. To achieve our goals of the filter being both relatively low-cost and effectively self-cleaning, the best material type would be the 3D material. Even though a pump would be needed for extra pressure during the backflushing phase, the increased time intervals between needed backflushings make the pump an acceptable addition despite its extra cost, weight, and energy needs.

7. Applications and Further Development

While many tasks were completed in the last two years, there is still a lot of work to finish on this project. First, a full working prototype of our filter design must be created and its feasibility in an actual wastewater plant must be tested. There were a few variables ignored in our testing, the largest one being that it was assumed that the wastewater would be a complete microplastic-water solution, which is not the case when applied realistically. The long-term durability of the filters must also be tested in order to ensure that microplastics cannot escape through tears that may eventually happen. In addition to this, it is acknowledged that the ideal pressure noted in this report will likely not be the pressure in a realistic situation, where pressure cannot be controlled to the filter's needs.

8. Acknowledgements

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