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The Removal of Polyethylene Microplastics in Water Using a Sawdust Filter Mediated with Polyphenol Coatings

Item Type	Thesis (Open Access)
Authors	Sentman, Julie
DOI	10.7275/55342
Download date	2026-06-09 00:22:31
Link to Item	https://hdl.handle.net/20.500.14394/55342

THE REMOVAL OF POLYETHYLENE MICROPLASTICS IN
WATER USING A SAWDUST FILTER MEDIATED WITH
POLYPHENOL COATINGS

A Thesis Presented

By

JULIE M. SENTMAN

Submitted to the Graduate School of the
University of Massachusetts Amherst in partial fulfillment
of the requirements for the degree of

MASTER OF SCIENCE

SEPTEMBER 2024

Plant and Soil Science

Stockbridge School of Agriculture Graduate Program

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ABSTRACT

THE REMOVAL OF POLYETHYLENE IN WATER USING A SAWDUST FILTER MEDIATED WITH POLYPHENOL COATINGS

SEPTEMBER 2024

Julie M. Sentman, B.S., UNIVERSITY OF MASSACHUSETTS
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The developing research into microplastics shows that the need to find ways to remove them are urgent. Through the modification of ligno-cellulosic frameworks with polyphenol coatings to create a filter, polyethylene can be captured. This novel filter was developed using a wet packing method and a commercial fish pump to move the plastics from the Milli-Q solution to the filter. Through π - π , electrostatic, and physical interactions, pristine and degraded polyethylene was removed from a microplastic solution being pumped through the filter. This filter provides a look at how an organic waste, such as wood, can be utilized to remove contaminants and used in commercial settings, such as wastewater treatment facilities.

TABLE OF CONTENTS

	Page
ABSTRACT.....	I
LIST OF FIGURES.....	IV
LIST OF TABLES.....	VII
CHAPTER	
1. Introduction.....	1
1.1 Literature Review.....	3
1.1.1 Additives.....	4
1.1.2 Toxicity in Humans.....	7
1.1.3 Microplastics in the Environment.....	9
1.1.4 Wastewater Treatment Plant Filtering Methods and Their Potential.....	12
1.1.5 Potential to Filter Microplastics.....	14
1.1.6 Wood Sawdust Filtration.....	15
2. MATERIALS & METHODS.....	18
2.1 Materials and Equations.....	18
2.2 PPE and Cleaning Procedures.....	19
2.3 Sawdust Preparation.....	19
2.4 BioCap Preparation.....	20
2.5 Fish Pump Preparation.....	21
2.6 Column Preparation.....	22

2.7 Microplastic Solution Preparation.....	23
2.8 Column Flowthrough Procedure and Effluent Collection.....	23
2.9 Polyethylene Degradation.....	24
2.10 Slide Preparation.....	24
2.11 LDIR Analysis.....	25
3. RESULTS & DISCUSSION.....	26
3.1 Packing Method Validation.....	26
3.2 Flowthrough Validation.....	26
3.3 Polyethylene Degradation.....	28
3.4 Flowthrough Results.....	32
3.4.1 Blank.....	32
3.4.2 Flowthrough of 150 μm Polyethylene	34
3.4.3 Flowthrough of 40 μm Polyethylene.....	36
3.4.4 Comparison.....	37
4. CONCLUSION.....	39
BIBLIOGRAPHY.....	40

LIST OF FIGURES

Figure	Page
1.1 Repeating unit of polyethylene (-mer).....	4
1.2 Repeating units (-mers) of PS, PVC, and PP.....	4
1.3 A diagram of primary plastics being degraded into MPs, adsorbing pollutants, and their fate afterwards (Yu et al., 2019).....	5
1.4 Exposure assessment and toxicity diagram in micro- and nanoplastics (Sun et al., 2023).....	9
1.5 Mechanism of coagulation/flocculation utilizing adsorption to remove contaminants from wastewater (Rashid et al., 2021).....	12
1.6 Illustration of MPs (blue) capture mechanism including π - π stacking and electrostatic attraction interactions, and physical trapping between the wood and MPs.....	16
2.1 A photo of unsieved and sieved sawdust for comparison.....	20
2.2 A photo of treated sawdust mixture, or bioCap (left), next to untreated sawdust (right).....	21
2.3 A photo of fish pump preparation, demonstrating the siphoned tubing feeding back into the solution.....	21
2.4 An empty glass column with 12.75 cm, or 5 inches, measured out.....	22
2.5 A diagram to show pouring the saturated BCP into the column, then packing it down with a glass rod to minimize breaks and large pores.....	22

2.6 The volume of a cylinder and the following calculations performed to find the Bed Volume of the filter.....	23
2.7 An image to describe the chamber that the petri dish with MPs is put in to, where the UVO radiation interacts with the MPs.....	24
3.1 Diagram of the HPLC set-up used to perform the second method.....	27
3.2 A photo showing the setup of solution, fish pump attachment to the column, and effluent collection.....	28
3.3 SEM (Scanning Electron Microscope) imaging of a pristine PE particle that has not undergone UVO radiation (Curi et al., 2024).....	29
3.4 SEM imaging of a PE particle, 40 μm , that had been degraded for 60 minutes in a UVO-Cleaner.....	30
3.5 SEM imaging of a PE particle, 40 μm , that had been degraded for 240 minutes in a UVO-Cleaner.....	31
3.6 SEM (Scanning Electron Microscope) imaging of a PE particle, 40 μm , that had been degraded for 360 minutes in a UVO-Cleaner.....	31
3.7 An LDIR scan of BV 70, which was the effluent from a flowthrough experiment performed with 40 μm PE particles.....	32
3.8 PE counts per 50 mL from flowthrough trials performed with blanks.....	32
3.9 The change in average PE Count per BV, as found in the blank effluents.....	33
3.10 PE Count per BV found in the effluent of the 150 μm flowthrough.....	34
3.11 A graph showing the average trend of the particle counts per BV found in the effluent of the 150 μm flowthrough.....	34
3.12 Graph depicting the average total particle count per BV.....	35

3.13 PE Count per BV found in the effluent of the 150 μm flowthrough..... **36**

3.14 A graph showing the average trend of the particle counts per BV found in the
effluent of the 150 μm flowthrough..... **36**

3.15 Graph depicting the average total particle count per BV..... **36**

3.16 A comparison of averages of 150 and 40 μm PE flowthrough effluent PE
counts..... **37**

LIST OF TABLES

Table	Page
1.1 The determination of a polymer's hazard ranking, based on the hazard class present in the monomer, the coinciding hazard level, hazard grade, and abbreviations (Lithner et al., 2011).....	8

CHAPTER 1

INTRODUCTION:

The word “pollution” relates to the introduction of contaminants to the environment that causes harmful or poisonous effects (Martin and Hine, 2008). Environmental pollution has been of great concern for hundreds of years, although has only been rigorously studied since the 20th century. The rise of populations and movement into cities directly leads to epidemics seen throughout history, such as the outbreak of bubonic plague, cholera, and typhoid fever (NOAA, 2005). High population density leads to overcrowding, and in eras like the late 1800s, industrial cities had contaminated water, dangerous levels of air pollution, and new pathogens that spread rapidly through dense housing (Crane-Kramer and Buckberry, 2023).

The illnesses caused by these conditions decreased with the discovery of germ theory, water sanitation methods, and the creation of modern plumbing systems. As the diseases muddling the early 1900s began to decrease, new issues arose relating to an increase in heavy metal and chemical pollution, such as Dichlorodiphenyltrichloroethane (DDT) and asbestos (Frank et al., 2014). Similar to the ancient Romans, who discovered the versatility of lead and the dangers it poses to human health, the discovery and use of asbestos and DDT was praised by many (Lewis, 1985). Both had incredible qualities, asbestos as an insulator and DDT as an insecticide, and both were later discovered to have a negative impact on environmental and human health.

In the 1930s, many chemicals considered to be lifechanging inventions were created, most of which had lifespans extending that of humans and were largely unknown in their hazardous effects. One group of compounds created was plastic polymers, a long

chain of C-H bonds with interspersed functional groups. Synthetic polymers are artificially produced, typically from petroleum oil in a controlled environment (Shrivastava, 2018). They have identical repeating units, though their chain lengths could vary based on the reaction conditions during synthesis, which utilizes heat and pressure in the presence of a catalyst to bond monomers.

Plastic was found to be highly durable and versatile, making it an attractive product to use in many different fields. In the medical field, many devices are made from synthetic polymers, as their high chemical purity provides a safe, sterile environment for many procedures (Hisyam Zainudin et al., 2020). Synthetic polymers make up suture materials, medical implants, IV bags and tubing are used to reduce a negative response from the patient, and degradable synthetic polymers are currently used in regenerative medicine and drug delivery systems (Han et al., 2024). On the agricultural side, utilizing plastic mulching decreases water evaporation, weed growth, runoff and soil loss while boosting the physical, chemical, and biological qualities of soil (Chauhan et al., 2024). Plastics also reduce food waste, by prolonging the life of foods stored within it while remaining light weight. This ability to remain light in weight whilst remaining sturdy makes it a great tool for construction and vehicle manufacturing (Andrady et al., 2009). However, the same reasons that make it so attractive also make it a persistent pollutant that could be incredibly harmful.

This is directly linked to increased usage of plastic, with the global plastic production increasing from 5 million tons in the 1950s to 300 million tons in 2020 (U.S. EPA, 2020). When combined with improper waste regulations, the already abundant plastic pollution will only continue to grow and lead to large environmental impacts.

1.1 Literature Review

Large pieces of plastic, referred to as macroplastics (>5 mm), are notably buoyant, allowing them to block radiation from the sun into water systems, disturb ecosystems, and cause death to oceanic organisms by entanglement and ingestion (Derraik et al., 2002). However, when plastics undergo degradation, they become smaller-sized plastics (<5 mm), known as microplastics (MPs) (Dewika et al., 2023). This process of degradation is caused by external forces, leading to a different characteristic of the material. This can be through processes such as biodegradation from microorganisms, oxidation from sunlight, or physical force such as turbulence (Woods et al., 2021). MPs can be categorized as either “primary MPs”, pristine MPs being manufactured for consumer use, or “secondary MPs”, meaning they were created by the degradation of a primary plastic (Sangkham et al., 2022). These particles, although small, have large impacts on the ecosystem. They are small enough to be ingested by small organisms, leading to biomagnification in the food chain, or inhaled, impacting the respiratory system (Ma et al., 2020; Dewika et al., 2023). MPs have become a growing concern due to the presence of them worldwide, and due to their durability, the ecological consequences are largely unknown (Yu et al., 2018).

The effect of MPs on an environment can change depending on the individual particle's physical and chemical properties as well as its distribution. The differences in polymers are largely based on the structure of their monomer, or the base part that repeats to make a long chain of carbon-carbon bonds (Billmeyer, 1984). The monomer for polyethylene (PE) is two carbons connected by a double bond with two hydrogens on

each end (Figure 1.1). As a repeating unit, it is two carbons connected by a single bond, with two hydrogens bonded to each carbon.

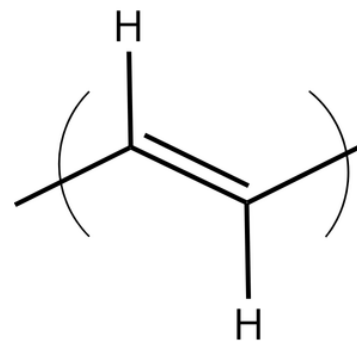


Figure 1.1: Repeating unit of polyethylene (-mer)

All forms of PE make up 31% of plastics produced (Geyer et al., 2020). Other polymers have one or more added groups bonded to the monomer, drastically changing the physical and chemical properties of it. Polystyrene (PS) contains a benzene

group, polyvinyl chloride (PVC) contains a chlorine atom bonded to the monomer, and polypropylene (PP) contains an added methyl (Figure 1.2). Along with an adjustment to a monomer, these polymers can also have adjustments in their shape and density, depending on

Polystyrene (PS)	
Poly(vinyl chloride) (PVC)	
Polypropylene (PP)	

Figure 1.2: Repeating units (-mers) of PS, PVC, and PP

whether it is linear or branched. If a polymer is branched, that indicates that the base chain has groups bonded to it, whether that is by itself or interconnecting (Billmeyer, 1984). These branches can have a large impact on a polymer, such as drastically changing the chemistry of it, and disrupting its regular arrangement (Shao et al., 2024). This can impact its stability, rate of degradation, and sorption capabilities.

1.1.1 Additives

The overall chemistry of a MP impacts its toxicity and distribution, as it gives the plastic the potential to adsorb toxic environmental particles and later leach those particles into the ecosystem. When pollutants adsorb to plastic, their lifespan in the ecosystem increases, so a pollutant can travel far from its source and pollute new areas. One type of

pollutant related to plastic are polychlorinated biphenyls, a type of persistent organic pollutant (POP) often associated with plasticizers and adhesives. They are used in the synthesis of plastics to reinforce, plasticize, or color a plastic (Timbrell et al., 2002). When degraded due to either mechanical, chemical, biological, or UV degradation, the surface functional groups may change. This gives plastics the ability to adsorb a nearby molecule, often another co-polluting material (Yu et al., 2019). Additionally, when degraded the plastic may leach the polychlorinated biphenyls into the environment, which is of concern as this chemical has been classified as a carcinogen (Lauby-Secretan et al., 2013).

The degradation process of plastics often leads to free radical groups, which make it a perfect host for pollutants like metals, polycyclic aromatic hydrocarbons, and

polybrominated diphenyl ethers to extend their life cycle (Figure 1.3). Different types of plastics have different uptake rates, giving them either a higher or lower pollutant binding affinity. The sorption capabilities of a plastic depends on its physical and chemical properties, such as its monomer, surface area, and crystallinity

(Karapanagioti and Klontza, 2008, Pascall et al., 2005). Once adsorbed, the non-plastic pollutant can be transported, due to the buoyancy of the MP, and can be consumed by organisms, increasing their bioaccumulation of that pollutant and transferring it through the food chain (Yu et al., 2019).

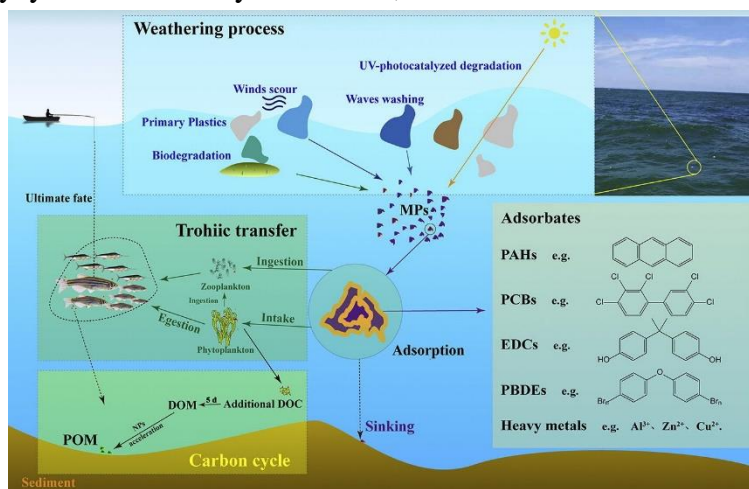


Figure 1.3: A diagram of primary plastics being degraded into MPs, adsorbing pollutants, and their fate afterwards (Yu et al., 2019).

MPs may have the potential for a toxic effect, as their impact is determined by the environment and their interactions with nearby organisms. Higher rates of toxic chemical exposure results in greater effects to those exposed organisms. Depending on an area's coastline, wind and wave conditions, and proximity to sources of MPs, the likelihood of MPs having a large effect on the biota varies (Yu et al., 2020).

Peer reviewed studies have confirmed the existence and circulation of MPs, but the rate of MPs ingestion among pelagic fish, meaning species swimming in the open ocean, is much higher than previously estimated (Choy and Drazen, 2013).

It can be inferred that fish swimming near the surface of the water encounter floating plastic debris, such as bottles, bags, and discarded fishing gear. Surface-level species of animals such as sea turtles often come into contact with and consume plastic pollution such as plastic grocery bags.

Fish species that are generally found in intermediate depths of the sea, known as mesopelagic species, are thought to be farther away from floating debris and MPs. They are thus expected to have less large-scale plastic and subsequently less degraded MPs in the contents of their stomachs. Despite this, anthropogenic debris, meaning plastics and other forms of man-made pollution, are increasingly being found in the stomach contents of many different mesopelagic fishes (Choy and Drazen, 2013). Many mesopelagic species, such as squid and swordfish, are commonly fished for the international seafood market. This has led scientists to understand that MPs are affecting not only oceanic organisms, but also human beings, as MPs and co-contaminants in mesopelagic fish tissues can be transferred to the humans that are consuming them. MPs can have acute toxic effects on small fish, as a smaller dose of a toxin can have a larger impact on

smaller fish than larger fish. However, large oceanic organisms, such as predatory fish, can face toxicity of MPs through bioaccumulation, which can also be detrimental to humans who consume these fish (Alberghini et al., 2023).

1.1.2 Toxicity in Humans

When researched to a fuller extent, human ingestion of MPs leads to a more personal level of understanding of the dangers of MPs. When consumed, MPs can be absorbed in the gastrointestinal tract, leading to oxidative stress and cytotoxicity. Additionally, any additives or pollutants adsorbed to the MP can be released, leading to more stress on the body (Alberghini et al., 2023). In a study in Thailand, retail shellfish were measured and found to have an average abundance of MPs of 2.625 particles/g wet weight (Hongsawat et al., 2024). From there, researchers estimated that the annual intake of MPs ranged from 20.23 to 1178.42 particles/person/year, and the risk assessment in bivalve mussels and cockles exhibited high polymer risk index values of risk level IV. Risk levels were determined by Lithner et al., 2011 based on the physical hazard classes and a polymer's risk of affecting the environment and human health (Table 1.1). Hazard levels V (the highest risk) was determined based on the criteria developed by the Swedish Chemicals Agency for "phase out" substances, while level IV is based on the criteria for the "risk reduction" substances. Each level (I-V) increase by a factor of 10, and the calculations are determined based on the classifications of the monomer. The toxicity combines aquatic environment acute and chronic, specific target organ toxicity, and acute oral toxicity for example, to determine their score. The reading made by this study did not determine the toxicity of polymers, but specifically the toxicity of the monomers they are made of. A hazard level I includes monomers that are flammable, oxidizing

Hazard class (category)	Abbreviation	Hazard level	Hazard grade
Carcinogenicity (cat. 1A; 1B) Germ cell mutagenicity (cat. 1A; 1B) Reproductive toxicity (cat. 1A; 1B) Persistent, bioaccum., toxic/very persistent, very bioaccum. ^a Hazardous to the ozone layer Explosives (unstable)	Carc. 1A; Carc. 1B Muta. 1A; Muta. 1B Repr. 1A; Repr. 1B PBT/vPvB Ozone Unst. Expl.	V	10,000
Germ cell mutagenicity (cat. 2) Acute toxicity (cat. 1; 2 – oral; dermal; inhalation) Respiratory/skin sensitisation (cat. 1) Specific target organ toxicity – single exposure (cat. 1) Specific target organ toxicity – repeated exposure (cat. 1) Hazardous to the aquatic environment (chronic cat. 1; 4)	Muta. 2 Acute Tox. 1; Acute Tox. 2 Resp. Sens. 1; Skin Sens. 1 STOT SE 1 STOT RE 1 Aq. Chronic 1; Aq. Chronic 4	IV	1000
Carcinogenicity (cat. 2) Reproductive toxicity (cat. 2; lact.) Acute toxicity (cat. 3 – oral; dermal; inhalation) Aspiration hazard (cat. 1) Skin corrosion/irritation (cat. 1A; 1B; 1 C) Serious eye damage/eye irritation (cat. 1) Specific target organ toxicity – single exposure (cat. 2) Specific target organ toxicity – repeated exposure (cat. 2) Hazardous to the aquatic environment (acute cat. 1; chronic cat. 2) Explosives (Div 1.1)	Carc. 2 Repr. 2; Lact Acute Tox. 3 Asp. Tox 1 Skin Corr. 1A; Skin Corr. 1B; Skin Corr. 1 C Eye Dam. 1 STOT SE 2 STOT RE 2 Aq. Acute 1; Aq. Chronic 2 Expl. 1.1	III	100
Acute toxicity (cat. 4 – oral; dermal; inhalation) Skin corrosion/irritation (cat. 2) Serious eye damage/eye irritation (cat. 2) Specific target organ toxicity – single exposure (cat. 3) Hazardous to the aquatic environment (chronic cat. 3) Explosives (Div 1.2)	Acute Tox. 4 Skin Irrit. 2 Eye Irrit. 2 STOT SE 3 Aq. Chronic 3 Exp. 1.2	II	10
Explosives (Div 1.3; 1.5) Flammable gas/aerosols/liquids (mainly cat. 1) Self-reactive substance or mixture (type A; B) Pyrophoric liquids/solids Oxidising liquids/solids Organic peroxide (type A; B)	Expl. 1.3; Expl. 1.5 Flam. Gas 1; Flam. Aerosol 1; Flam. Liq.1 and 2 Self-react. A; Self-react. B Pyr. Liq. 1; Pyr. Sol. 1 Ox. Liq. 1; Ox. Sol. 1 Org. Perox. A; Org. Perox. B	I	1

^a The classification of PBT and vPvB substances are not yet included in the CLP-regulation. The Stockholm Convention on Persistent Organic Pollutants (POPs) has been searched.

Table 1.1: The determination of a polymer's hazard ranking, based on the hazard class present in the monomer, the coinciding hazard level, hazard grade, and abbreviations (Lithner et al., 2011).

liquids/solids, or organic peroxides for example. While hazard level V includes carcinogenicity, germ cell mutagenicity, reproductive toxicity, hazardous to the ozone layer, persistent. A risk level IV indicates that the chemicals making up the polymers, when broken down, could lead to germ cell mutagenicity, acute toxicity, specific target organ toxicity, and respiratory/skin sensitization.

As seen in Figure 1.4, exposure to MPs is not limited to ingestion. Inhalation and dermal contact are two other ways humans can be exposed to this pollution and the potential toxicity associated with it. This widens the scale of possible contact and consumption of MPs from

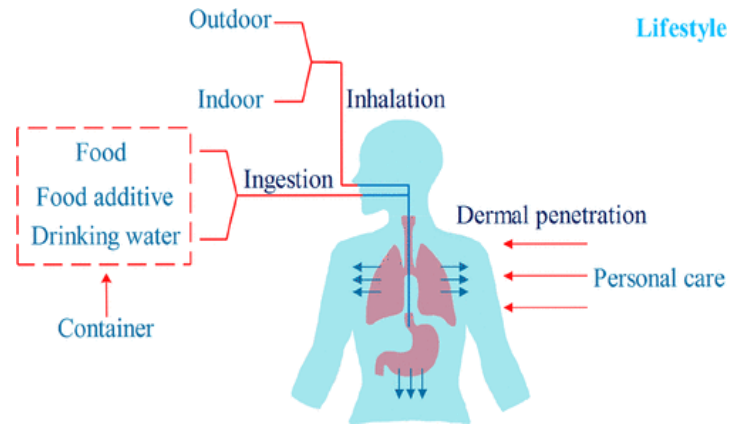


Figure 1.4: Exposure assessment and toxicity diagram in micro- and nanoplastics (Sun et al., 2023).

a relatively limited source, such as seafood, to one that is virtually impossible to avoid, such as the air. Annually, Americans are estimated to consume roughly 39,000 to 52,000 particles of MPs (Cox et al., 2019). In addition to this, research on MPs is limited, as there is yet to be an affordable standard instrumentation to analyze MPs contamination in the field, and the actual analysis is highly variable. Because plastic use in laboratory settings are high, with the use of plastic pipettes and nitrile gloves, for example, there is high risk of contamination in all samples, which can lead to inaccurate data. Due to this, the aforementioned numbers of particles consumed by humans are assumed, by researchers, to be underestimated (Cox et al., 2019).

1.1.3 Microplastics in the Environment

The shape and density of MPs determine their destination, where a lower density means it will float in water or be blown by the wind, and heavier particles will sink or be moved terrestrially (Ma et al., 2020). On average, MPs found in the atmosphere were between 50 μm – 5000 μm in size and with an abundance ranging from 100-300 particles $\text{m}^{-2} \text{d}^{-1}$ in both urban and remote areas (Zhang et al., 2020). Often depositing onto the

surface via rain or snow, MPs can travel far distances through multiple modes of transport. The most prominent type of polymer in ambient outdoor air has been PE, and the main contributors leading to MPs in the air were found to be rubber erosion, incineration of household waste, resuspended polymer fragments in urban dust, synthetic fibers from clothing, and landfills (Mehmood et al., 2022, Amato-Lourenço et al., 2020).

Despite these plastics being a newly introduced technology, they are discovered in areas with limited contact. In 2021, samples taken from the central part of the Vatnajökull ice cap in Iceland found several types of microplastic particles, including polyurethane (PU), polyvinyl chloride (PVC), polyamide (PA), and acrylonitrile butadiene styrene (Stefánsson et al., 2021). A study performed in the Jakarta, Indonesia discovered microplastics in marine protected and recreational areas, with polyethylene (PE) and polypropylene (PP) polymers abundant in these areas, which were expected to be free from debris accumulation (Reza Cordova et al., 2024).

Alongside remote areas, studies have found great MPs abundance in urban areas (Vijayan et al, 2022). The most common sources of MPs in urban areas are atmospheric deposition (Cai et al., 2017), tire and road wear particles (Klößner et al., 2019), urban litter from single-use plastic products (Hodson et al., 2017), domestic laundry drier vents (Galvao et al., 2020), urban stormwater runoff (Piñon-Colin et al., 2020), and wastewater treatment plant effluents (Gatidou et al., 2019). In a study of the Chao Phraya River in Thailand, results found that population density was directly correlated with increased microplastic abundance (Tuan Ta et al., 2023). With this, PE and PP were the most commonly found polymer types, and strong heavy metal contamination was also detected due to a high abundance of MPs. However, this study also found that low-population

density zones, such as agricultural regions, had the lowest abundance of MPs, but the highest number of heavy metals in MPs. This was estimated to be due to the fertilizers and pesticide usage in agriculture, as those are primary sources of heavy metals in agricultural zones (Srivastava et al., 2017).

More recently, a significant point source of MP pollution has been identified to be wastewater treatment plants (WWTP) (Carr et al., 2016). Due to its anthropogenic sources, MPs are highly concentrated in sewage. Whether it's laundry or bathroom wastewater, dishwashers, or from the plumbing that carries it to a treatment facility, MPs accumulate at different concentrations within a wastewater treatment facility. Once the sewage is processed, it is either used to irrigate decorative plants, repurposed for agriculture, or discharged into a nearby body of water (Hasan et al., 2023). These facilities have advanced methods of removing heavy metals, pathogens, and other contaminants that may be present. However, there is still no sustainable and wide-spread technique to remove MPs, meaning these harmful particles, and anything adsorbed to them, make their way through the treatment and into the "cleaned" effluent.

This is a significant concern, as wastewater has the potential to be reused in many situations if properly treated. In many countries, water supplies are running low due to the increased demand brought on by population growth, which is exacerbated by lack of rainfall and increasing dry areas (Tarawneh et al., 2024). It is estimated that the largest usages of water are in agriculture and industry, however this is expected to grow, with increasing socio-economic growth around the world alongside increased use of fertilizers to improve agricultural productivity (Burek et al., 2016). The International Institute for Applied Systems Analysis found that in the 2010s, 1.9 billion people were living in

potentially severe water scarce areas. They estimated this to increase to between 4.8 and 5.7 billion in 2050, with 73% of the affected people living in Asia (Burek et al., 2016).

Since the majority of the already scarce freshwater resources are being used in agriculture, the potential to use reclaimed water as an alternative source is one that should be developed. Whether using the water for irrigation, or biosolids for fertilizer, wastewater treatment facilities have the potential to clean sewage for it to be reused. However, the technology must be updated so that difficult to remove contaminants, like MPs, won't be transferred to and accumulate in agricultural fields.

1.1.4 Wastewater Treatment Plant Filtering Methods & Their Potential

Wastewater treatment facilities already utilize a variety of methods for cleaning water, some of which can be adjusted for the removal of MPs. One method currently in use is treatment with an adsorption media (Figure 1.5). Here, the contaminants in the water are adsorbed to the pore spaces on the surface of the adsorptive media as it passes through. When paired with the water quality conditions matched to the media, the process can remove target contaminants to concentrations below regulatory limits. Once the adsorptive media is exhausted, or at capacity, it can be regenerated via an acid wash and caustic wash.

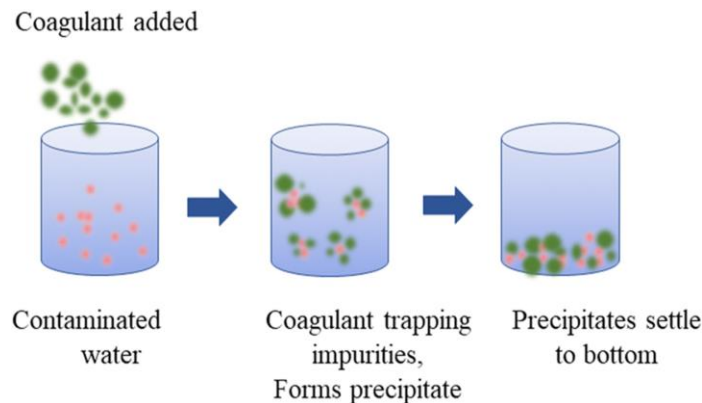


Figure 1.5: Mechanism of coagulation/flocculation utilizing adsorption to remove contaminants from wastewater (Rashid et al., 2021).

One adsorption media commonly used is Granular Activated Carbon (GAC) (USEPA, 2000). Many wastewater treatment facilities utilize GAC to filter and remove

soluble organics, such as aromatic solvents, surfactants, pesticides, and herbicides. GAC is an adsorption media with high porosity, a high internal surface area, and a high carbon percentage (Snyder et al., 2007). Already, it has a high removal efficiency (up to 99.9%) for many volatile organic compounds (VOCs), natural organic matter, and synthetic organic compounds. There are two GAC setups; one being the bed is contained in pressure vessels whereas the other is in open concrete basins, utilizing gravity or direct filtration.

Another method is ion exchange, where water passes through a bed of synthetic resin which removes dissolved ions. This can include calcium, magnesium, heavy metals, and per- and polyfluoroalkyl substances (PFAS) (Reungoat et al, 2010). When the capacity of the resin is exhausted, it can be regenerated to restore it to its initial condition. The regeneration process uses a saturated solution, usually sodium chloride. An alternative is to dispose of the exhausted resin and replace it with fresh resin, as often done with PFAS-spent to avoid secondary environmental contamination (Gagliano et al., 2023).

The methods flocculation and coagulation are also used to clean wastewater. For these processes, coagulants destabilize the colloidal suspensions, through the neutralization of charges, leading to the aggregation of smaller particles (Saravanan A, 2021). On the other side, in flocculation, destabilized particles are agglomerated into larger particles through mechanical agitation.

These methods are targeted towards certain organic and inorganic pollutants that have been studied thoroughly over the years. All methods have the potential to remove MPs, but due to their high cost, high variability, and the difficulty in detecting these

polymers to validate the procedures, none have been proven to be efficient in removing MPs.

1.1.5 – Potential to Filter Microplastics

MPs vary in their size, arrangement, and surface charges, which makes them a unique contaminant to try to remove. A study performed by Kim et al., 2024 analyzed commercially available MP filters and the potential of a MP ceramic membrane filter for washing machines. They found commercially available MP filters to have a removal efficiency of only 19.7-24.8%, whereas the ceramic membrane filter had a 99% removal rate while also removing a significant portion of hydrophobic compounds. Filters for washing machines have been a point of interest, as the synthetic fiber fragments from washing clothes are a large source of MPs in sewage (Gavigan et al., 2020). However, the cost of fiber retention has proven to be high, estimating to increase the cost of household washing by 37% (Kimmel et al., 2024).

Filters have also been suggested to remove MPs from drinking water, such as the stainless-steel filters coated with poly(alkyl acrylate)-based adhesives as studied by Ramkumar et al., 2024. This material utilized adsorption methods as well as mechanical filtration, capturing >90% of MP contamination within 60 min. While also providing the ability to remove the adhesive coatings to reuse the captured MPs, adhesive, and SS mesh. In a study of stormwater runoff, Rullander et al., 2023 utilized horizontal flow sand filters to remove MPs, and found a high success rate. This was estimated to be due to MP agglomeration, favorable particle-to-media size ratios, and particle sedimentation of heavy fibers.

These filters utilize a range of materials, such as sand, stainless steel, and artificial membranes, due to their porous features and ability to utilize adhesive coatings.

However, it would be beneficial to make a filter out of recycled materials. Wood sawdust would be a great filter material due to its high chemical and physical stability, and its structure that is already made for efficient water transport.

1.1.6 Wood Sawdust Filtration

Renewable materials, particularly in the light of biopolymers, have been of great interest due to their high versatility and sustainability capabilities. Structures containing polysaccharides (such as cellulose and chitin), polyphenols (such as lignins and tannins) and proteins have high potential to be useful biomaterials (Tardy et al., 2021). In particular, nanocellulose is a renewable material with a high strength, low density, and tunable surface chemistry, already being used for foams and aerogels (Lavoine et al, 2017). Cellulose nanofibers contain strong noncovalent interactions due to the cellulose-cellulose interactions, meaning they must be chemically modified to be useful. For example, the surface-confined water abundant in most cellulosic fibers can be utilized to mediate chemical reactions, whether through increasing the reaction rate and efficiency or controlling accessibility of selected hydroxyl groups (Beaumont et al, 2021).

More recently, cellulosic materials have been assembled with metal-organic frameworks (MOFs), increasing their strength and decreasing shrinkage (Mattos et al., 2023). Plant-based polyphenols can chelate metal cations, which leads to a broader spectrum of metal-centered functions in structures. Already, multivalent metal ions are combined with plant polyphenols, such as in the preparation of hydrogels (Rahim et al., 2016), coatings (Chen et al., 2019), and supramaterials (Guo et al., 2016). Often used in

metal-phenolic networks (MPNs) is tannic acid (TA), a natural polyphenol with a high content of trihydroxyphenyl (galloyl), which is known to strongly bind to diverse surfaces through covalent and non-covalent interactions (Wei et al., 2015). Utilizing a material structured with cellulose, hemicelluloses, and lignin and treating it with a metal compound and a natural polyphenol, the metal and TA molecules will interconnect to make a supramolecular nanocoating on the wood (Wang et al., 2023). The combination of TA and Fe^{3+} was found to cause a shift in photoelectron energy, from 531.1 to 531.3 eV,

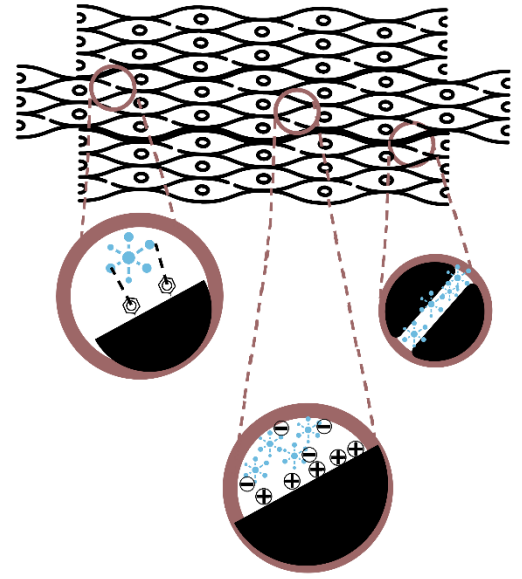


Figure 1.6: Illustration of MPs (blue) capture mechanism, including π - π stacking and electrostatic attraction interactions, and physical trapping between the wood and MPs.

enhancing the hydrophilicity of the wood and increasing its effectiveness as a water filter.

Wood modified with TA and Fe^{3+} has been found to adsorb MPs through hydrogen bonding, electrostatic attractions, and π - π stacking (Figure 1.6) (Chen et al., 2024). The negatively charged PE is seen to have a strong attraction to the positively charged wood surface.

As for π - π interactions, the positive or negative electrostatic potential creates a When used as a water filter, this biomaterial has high potential to remediate water through removing MPs, and has the potential of being reused as another material, such as being pyrolyzed to produce biochar. Future research should be done to design a beneficial use for the modified wood filter once spent.

This MP filter can further improve our water cleaning technologies and has the potential to be used on both a small and large scale. In this study, the sawdust was

modified with TA and Fe^{3+} and tested in a controlled setting to analyze its ability to remove PE from water. These tests were used to analyze the filter's efficacy when using more common products, such as sawdust from spruce-pine-fir wood materials and a basic pump-flowthrough method. This will give insight into how cost-efficient and applicable the filter is to use in a commercial setting. The ligno-cellulosic filter mediated with polyphenol coatings will remove PE from contaminated water, resulting in fewer PE particles than in the influent. We expect the different sizes and aging of PE to affect the filter's retention efficacy by observing differences in breakthrough points based on PE properties.

CHAPTER 2

MATERIALS & METHODS:

2.1 Materials

Polyethylene (PE) particles (powder, 100-150 μ m and 40-48 μ m), ferric chloride anhydrous (FeCl_3), sodium phosphate (Na_2HPO_4), were purchased from Sigma-Aldrich (USA). Tannic acid, citric acid monohydrate (granular, $\text{HOC}(\text{COOH})(\text{CH}_2\text{COOH})_2 \cdot \text{H}_2\text{O}$), reagent alcohol ($\text{CH}_3\text{CH}_2\text{OH}$) (Anhydrous ethyl alcohol 90%, methyl alcohol ~5%, isopropyl alcohol ~5%) were purchased from Thermo Fisher Scientific (USA). Sawdust was collected from the Wood Mechanics Lab at the University of Massachusetts Amherst.

To sonicate, the Fisherbrand CPX3800 Ultrasonic Bath was used. The fish pump used was an AQUANEAT BP-80 submersible pump. Agilent 8700 LDIR Chemical Imaging System was used for analysis using MirrIR Low-e Microscope Slides from Kevley Technologies. In conjunction with the microscope slides, two types of CoverWell Imaging Chambers from Grace Bio-Labs were used. One type had one 20 mm diameter x 2.5 mm depth, while the other had two 15 mm diameters x 1.5 mm depths. To degrade the MPs, a UVO-Cleaner Model 342 was used.

Calculations of tannic acid, iron chloride, citric acid, and sodium phosphate were determined by Wang et al., 2023, who compared surface morphologies of sawdust treated with different amounts of each chemical. The concentration and measurement of each chemical used was determined to have the most effective impact on the sawdust to increase sorption properties.

2.2 PPE and Cleaning Procedures

Throughout the experiment, nitrile gloves and cotton lab coats were utilized to avoid contamination of samples while ensuring the wearer's safety. Beakers, petri dishes, columns, and slides were all made from glass to reduce plasticware in the lab. This was to reduce the lab's environmental impact through this experiment while also preventing contamination from the plasticware to the samples. When removing the filter, HexArmor with SuperFabric gloves were used to ensure safety when adding pressure to the column, which may cause it to break, or when handling sharp objects.

Prior to use, all beakers and columns were soaked overnight in a 10% nitric acid bath then rinsed with Milli-Q water and left to dry. Along with that, all slides were rinsed with ethanol, sonicated in Milli-Q water and rinsed, which was repeated three times, then left to dry. New pumps were used for each PE size, two pumps were used for the flowthrough of 150 μm PE, two for the 40 μm PE, two for the degraded 40 μm PE, and two that were kept to use for no PE. The single-use pipette tips used were kept in a sterile bag. The cover wells were cleaned in the same method as the slides, and kept in a clean, covered beaker. All materials were kept in cleaned and covered beakers or erlenmeyer flasks.

2.3 Sawdust Preparation

The sawdust used was collected from the Wood Mechanics Lab at the University of Massachusetts Amherst, which utilizes engineered wood products in their projects. In

this case, spruce-pine-fir (SPF) was collected, which is a commonly used lumber in construction, particularly in North America (International Code Council) .

Due to the sawdust being mixed with larger wood chips, the collected wood had to be sieved using 1 cm, 100 mm, and 150 μm sieves to remove the larger particles. The initial sieve utilized had a mesh of 1 cm in diameter, removing the largest particles. Immediately after, the wood <1 cm was sieved with a 100 mm mesh. Each step of sieving took at least five minutes to ensure complete

removal of large wood particles. The final sawdust utilized in the experiment had been sieved using a 150 μm mesh filter, meaning the particles themselves were less than 150 μm .

2.4 BioCap Preparation

Wood sawdust < 150 μm (5g, dry) was rinsed with Milli-Q water in a 75 μm -mesh stainless steel filter three times to remove impurities, then saturated in 20 mL of Milli-Q water. Tannic acid (3.5 mL, 24 mmol L⁻¹) and FeCl₃*6H₂O solution (3.5 mL, 37 mmol L⁻¹) were added and the dispersion was mixed. Following this was an adjustment of the pH value of the dispersion to 7.4 with buffers (containing 200 mmol L⁻¹ of Na₂HPO₄*12H₂O as a basic buffer, 100 mmol L of citric acid monohydrate as an acidic buffer). The treated sawdust mixture (henceforth referred to as bio-related capture



Figure 2.1: A photo of unsieved and sieved sawdust for comparison.

technology, bioCap, or BCP) was spread onto a Pyrex glass tray and dried at 40°C for 24 hours. The change in color, due to the ferric chloride, is highlighted in Figure 2.2.

2.5 Fish Pump Preparation

Wastewater treatment plants utilize different methods of treating, all of which involve different types of water pressure. To simulate this best in the lab, a commercial fish pump was connected to a modified silicone tube (15 cm length). 8 cm from the unconnected end of the tube, it was punctured with a 100-1000 μL pipette tip. The tip remained attached to the tube to act as a siphon, and another modified silicone tube (8 cm length) was attached to the pipette tip end. The siphoning of the tube allows for increased water flow and will keep the water flowing through the filter a continuous stream. The column was kept under pressure and wet at all times.



Figure 2.2: A photo of treated sawdust mixture, or bioCap (left), next to untreated sawdust (right).



Figure 2.3: A photo of fish pump preparation, demonstrating the siphoned tubing feeding back into the solution.

2.6 Column Preparation

Glass wool (0.1 g) was packed into the end of a hollowed glass column (20 cm length, 1 cm diameter) with at least 1 cm of space between the glass wool and end of the column. To pack the column, the wet packing method often used for chromatography columns was used, as shown in Figure 2.4.

Dried BCP (1.5 g) was hydrated with 50 mL of Milli-Q water and mixed until homogeneous. Using a glass funnel, the BCP mixture was slowly poured into the column with the glass wool retaining the BCP at the end point of the column. The column would be filled with the saturated solution allowing the BCP to gravimetrically settle at the bottom while the water dripped out.

After most of the water filtered through, then a glass rod (15 cm length) was used to pack the BCP down until firm. This process was repeated until the packed BCP column reached 12.75 cm in length.

A clean and prepared fish pump would be placed into a beaker filled with 2 liters of Milli-Q water. The end of the tubing would be placed on the top of the column (opposite the glass wool), and the end of the tubing that acted as a siphon would be placed back into the beaker.

The pump, set to the lowest flow setting, would be turned on so Milli-Q water can flow through the column, rinsing



Figure 2.4: An empty glass column with 12.75 cm, or 5 inches, measured out.

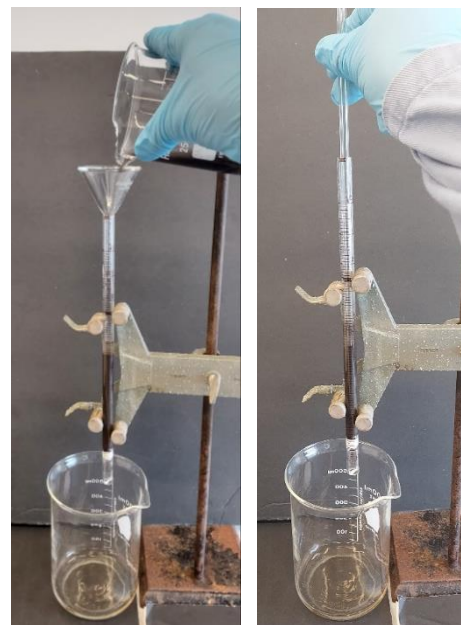


Figure 2.5: A diagram to show pouring the saturated BCP into the column, then packing it down with a glass rod to minimize breaks and large pores.

the impurities and ensuring an even compaction. This would run overnight before the experiment begins.

2.7 Microplastic Solution Preparation

Using a (Mettler Toledo scale, range of 0.0001g to 125g) and 3” x 3” Fisherbrand weighing paper, 175 mg of PE (50 mg/L), either pristine size 40 μm or 150 μm , or degraded size 40 μm , was measured. The PE on the weighing paper was then poured into a beaker filled with 3.5 L of Milli-Q water and a magnetic stir bar was added. The beaker was then placed on a magnetic stirrer and set to medium-high to homogenize the solution. After 15 minutes, the fish pump with the siphoned tubing are placed into the beaker and connected to the column.

2.8 Column Flowthrough Procedure and Effluent Collection

The pump being used to rinse the column is removed and the pump in the PE solution is connected to the top of the column. Once turned on, the first 15 bed volumes are collected. After, 5 bed volumes are collected in clean beakers until 100 bed volumes have been collected in total. Bed volume (BV) refers to the volume of the filter bed. The calculation of BV was determined based on the volume of the column that is taken up by the filter. In this case, this portion of the column had a diameter of 1 cm (radius of 0.5 cm) and 12.75 cm in length, which was predetermined based on the following calculations. Using the equation from figure 2.6 to calculate the volume of a cylinder, the bed volume of the filter with 1 cm x 12.75 cm was determined to be ~10 mL.

$$\text{Volume of a Cylinder} = \pi * r^2 * h$$

$$\pi * 0.5 \text{ cm}^2 * 12.75 \text{ cm} = 10.014 \text{ cm}^3 = 10.014 \text{ mL.}$$

Figure 2.6: The volume of a cylinder and the following calculations performed to find the Bed Volume of the filter.

Once collected, one beaker of 5 BVs is gravity filtered with a 5 μm -stainless steel mesh. Then, the filter is placed back into the beaker and suspended in 2 mL of reagent alcohol and sonicated for 1 minute. The filter is then removed from the beaker using stainless steel tweezers, rinsed with 1 mL reagent alcohol into the beaker, then set aside. The remaining solution is poured into a 9 mL glass test tube, the beaker is rinsed with 1 mL reagent alcohol and poured into the tube. The tube is covered with aluminum foil and set in a 60°C oven to dry overnight.

For blanks, the flowthrough was performed with a solution of Milli-Q water with no added PE particles. Due to an oversight of the materials, a control was not performed with a column containing untreated sawdust.

2.9 Polyethylene Degradation

The UVO-Cleaner Model 342 was used to degrade the PE to simulate MP weathering. To prepare, 3g of 40 μm PE was placed in a glass petri dish and set inside the UVO-Cleaner drawer and set to run for 4 hours (Figure 2.7).

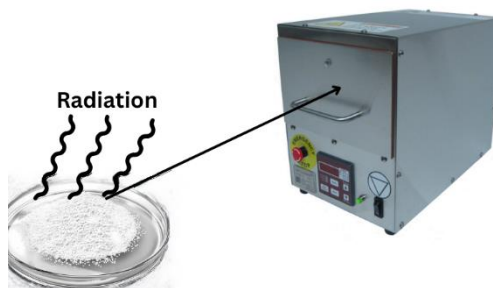


Figure 2.7: An image to describe the chamber that the petri dish with MPs is put in to, where the UVO radiation interacts with the MPs.

2.10 Slide Preparation

Once the glass tube with the effluent was dry, 450 μL of reagent alcohol was pipetted to the sample using a FinnPipette, then sonicated for 30 seconds. Using a Kevley slide, 2 cover wells are placed next to each other on one slide. The solution in the glass tube is then pipetted onto the slide, in the open coverwell circle, and left to dry in a 40°C

oven. Once dried, the coverwells are removed and the slide is taken to the Agilent 8700-LDIR for analysis.

2.11 LDIR Analysis

The Agilent 8700-Laser Direct Infrared Instrument was used to analyze the samples collected through the experiment. The Kevley slide with 1-2 samples on it would be placed into the machine, then it would take an IR scan of a chosen area and obtain the spectra of every particle detected on the slide. Following that, it will compare to a library in its system.

CHAPTER 3

RESULTS & DISCUSSION:

3.1 Packing Validation

The first method to validate was the packing of BCP. Imitating the wet packing method for chromatography columns, 1.5 g of dry BCP was hydrated with 50 mL Milli-Q water. Using a small funnel, the mixture was poured into the column, left to settle, packed down, then repeated. The other methods tested involved packing the column with only dry BCP and wet BCP. Both of which proved to be inefficient, taking at least 15 hours to complete one column, whereas the wet packing method only takes ~4 hours.

3.2 Flowthrough Validation

The next method to determine was how the MP solution would pass through the filter. The methods tested were as follows; first, the solution was transferred from the beaker to the top of the packed column 10 mL at a time via pipetting. The second method was by using a burette to slowly drip the solution onto the top of the column. The third method was by setting up an HPLC machine to input the microplastic solution into the column at a constant rate, this way the column would stay under constant pressure. The final method tested, and later used in the experiment, was a fish pump submerged in the MP solution, pumping it into the top of the packed column. The amount of time it took for the solution to pass through the filter varies between the columns, relating to the impact packing would have on it. Although each column was made with BCP from the same batch, a slight variation in the packing of the column could change the pore sizes throughout. The smaller the pore sizes, the longer it would take water to pass through the filter.

The first method tested, transferring the solution from the beaker to column using a pipette, was not a viable solution due to the infrequencies between replications and lack of applicability in a water treatment facility. Each time the PE solution was transferred into the column, the top layer of the filter would be disturbed. Along with that, because there was no continuous source of the PE solution, the filter was more likely to dry out if it was left too long without adding more of the influent. Human error also led to the contamination of the effluent, both if the filter itself was disturbed or if the top overflowed with influent, leading to PE entering the effluent without passing through the filter.

The second method tested was to flow water through the column using a PerkinElmer series 200 high pressure liquid chromatograph (HPLC). The MPs solution acted as the mobile phase, as seen in Figure 3.1, and connected directly to the pump and column. The MPs solution was sampled by a line

directly connected to the LC pump, which was then connected immediately to the prepared BCP column. The flow rate of the HPLC can be manually chosen, so the pump can run continuously and keep the filter at saturation. However, this method was not a viable option, as the PE particles would coagulate and clog the connections between the pump and flow lines within the HPLC, leading to leaks and a decreased or stopped flow rate. In between tests, the HPLC had to be flushed out so the PE particles would not

High Performance Liquid Chromatography (HPLC)

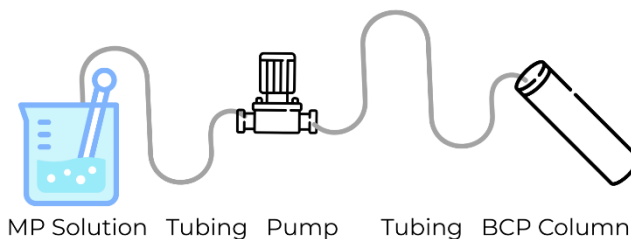


Figure 3.1: Diagram of the HPLC set-up used to perform the second method.

interfere with future samples and would take several hours and direct manual labor to repair and clean the machine. Along with that, there are several joints and tubing that can cause clogging and would require cleaning. This method only allowed one column to be run at a time and would make the flowthrough time for one column to take too long. With that, this method was deemed to not be a viable option.

The third method tested was by using an AQUANEAT BP-80 submersible pump, this pump was a cheap option that can be purchased commercially from local pet stores and retail stores. This pump was able to keep the filter at saturation while maintaining a consistent flow of water without the media being disturbed. The only attachments needed for the pump was tubing to connect the pump to the column, and a pipette tip to siphon. The few segments required for this flowthrough method led to its success, as there were fewer variables to cause an error. Along with that, the pump could be used for repeated experiments, and move water in the same manner each time. This made it a reliable tool when performing experiments.

3.3 Microplastic Degradation

The UVO-Cleaner utilizes a photosensitized oxidation process to excite the material within its drawer via short-wavelength radiation. The machine generates O_2 and the wavelengths 184.9 nm forms ozone, and from there the wavelengths 253.7 nm dissociate the ozone to form atomic and molecular oxygen (Jelight, 2010). The atomic

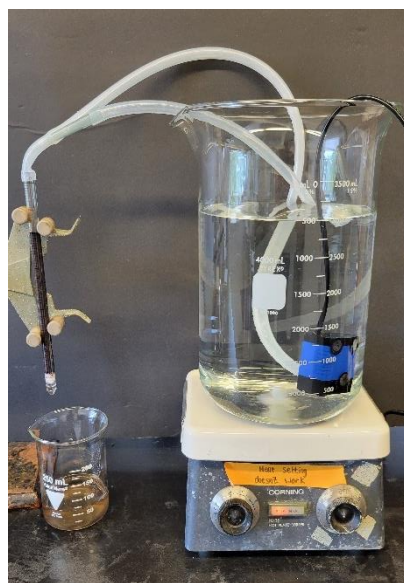


Figure 3.2: A photo showing the setup of solution, fish pump attachment to the column, and effluent collection.

oxygen acts like a strong oxidizing agent, resulting in an energetic surface which increases hydrophilicity and chain mobility (Sabreen, 2018). All of which increases the aging process of the polymer.

The main characteristic peaks of PE are bands around 1295 cm^{-1} , 1130 , and 1070 cm^{-1} , which relates to methine (CH) twisting and C-C stretching (Bredács et al., 2021). Often shown as well are peaks at 1467.76 cm^{-1} , which represents C-H scissoring. There was a high accumulation of bonds in these peaks, however, after being treated by the UVO-Cleaner for 240 minutes, or 4 hours, many spectra of different PE particles were seen to vary in their absorbance. In particular, an increase of particles at wavelength 1717.68 cm^{-1} were seen, particularly after 360 minutes of degradation.

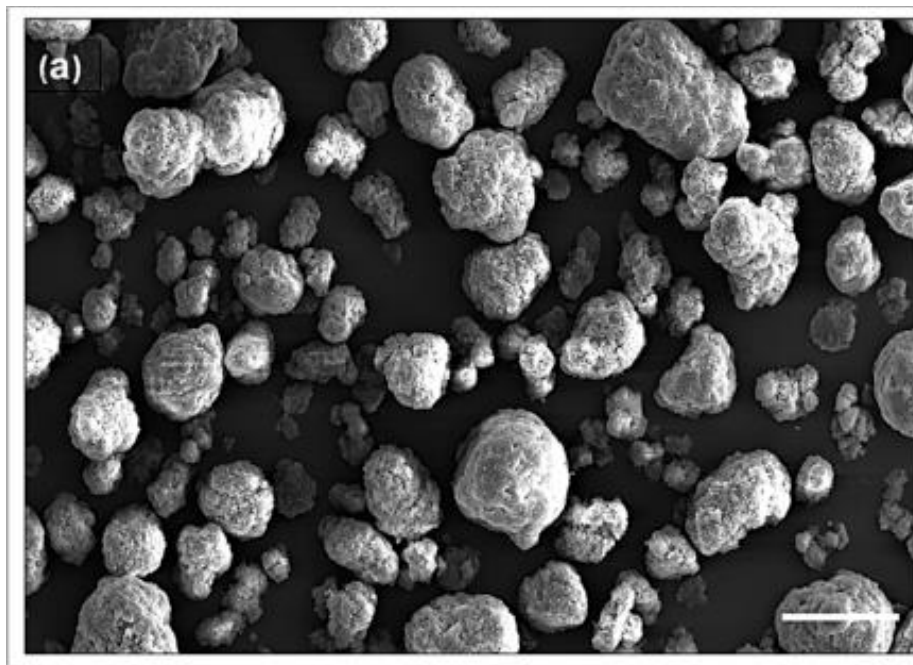


Figure 3.3: SEM (Scanning Electron Microscope) imaging of a pristine PE particle that has not undergone UVO radiation (Curi et al., 2024).

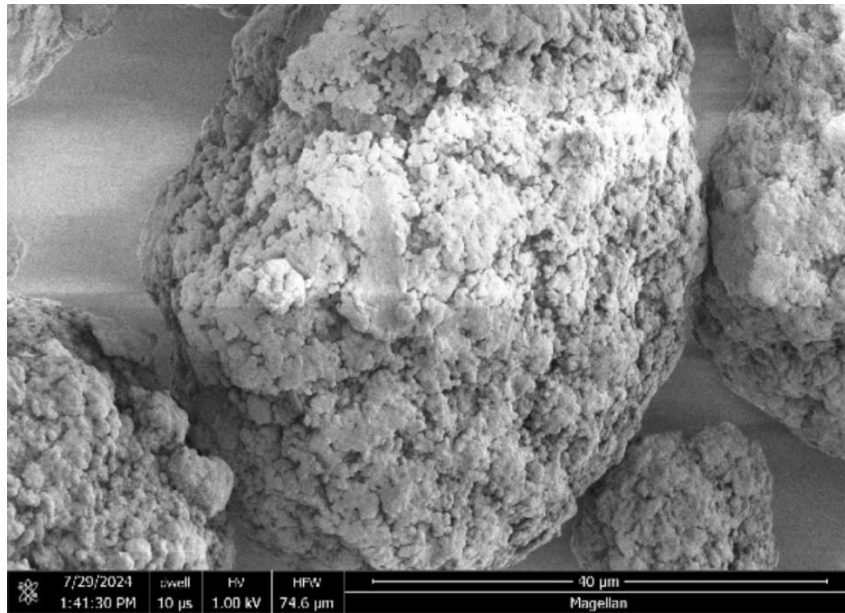


Figure 3.4: SEM imaging of a PE particle, 40 μm , that had been degraded for 60 minutes in a UVO-Cleaner.

Figure 3.3 shows a pristine PE particle, as a comparison on how the degraded PE compares to the pristine ones. These have a similar shape with a relatively smooth surface, but already at 60 minutes of UVO treatment (Figure 3.4), PE particles have already begun to deteriorate. When compared to figures 3.5 and 3.6, the PE particle only continues to deteriorate, exposing more surface area for pollutants to sorb to or to use for sorption.

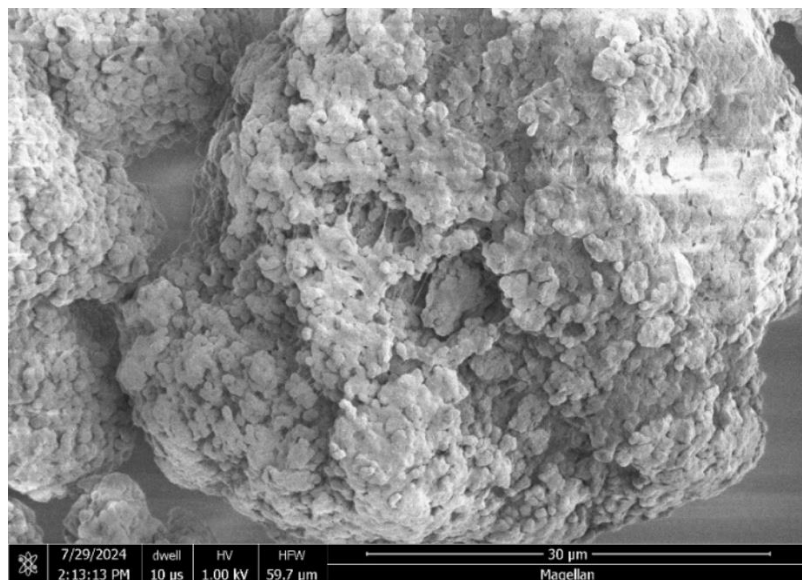


Figure 3.5: SEM imaging of a PE particle, 40 μm , that had been degraded for 240 minutes in a UVO-Cleaner.

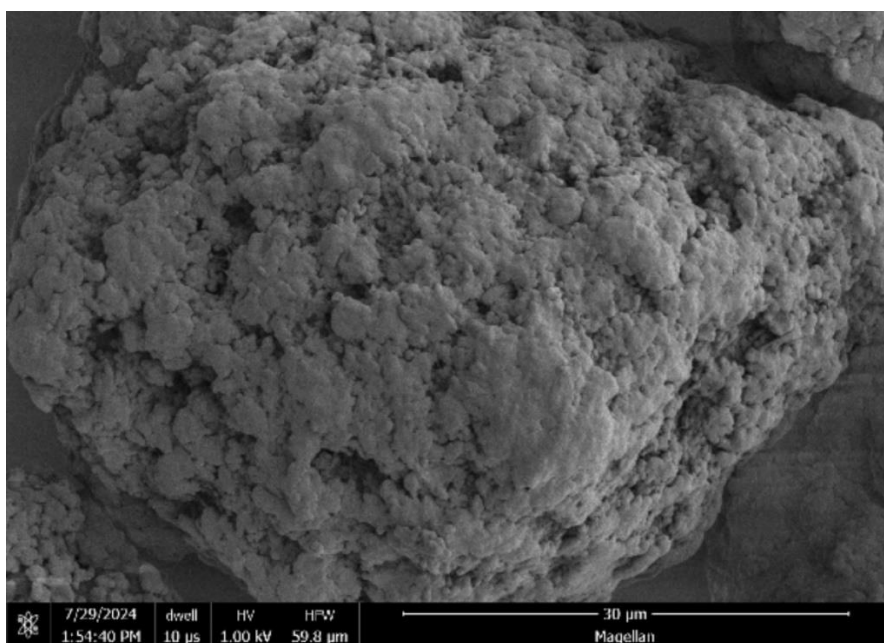


Figure 3.6: SEM (Scanning Electron Microscope) imaging of a PE particle, 40 μm , that had been degraded for 360 minutes in a UVO-Cleaner.

As the particles are exposed to more radiation, they begin to form holes, such as the ones seen above. This can lead to a change in chemistry, possibly changing the physical, chemical, and toxicological impacts this PE may have.

3.4 Flowthrough Results

The following results were taken from the effluent of the BCP filter flowthrough experiment and analyzed on the Agilent 8700-LDIR. Figure 3.7 displays what results for an LDIR scan may look like. To the right is an image of the particle with its dimensions and an IR scan of the chosen particle. The IR scan shows a comparison between the real spectra of the particle and a spectra of a type of polymer that matches the spectra up to 65% accuracy.

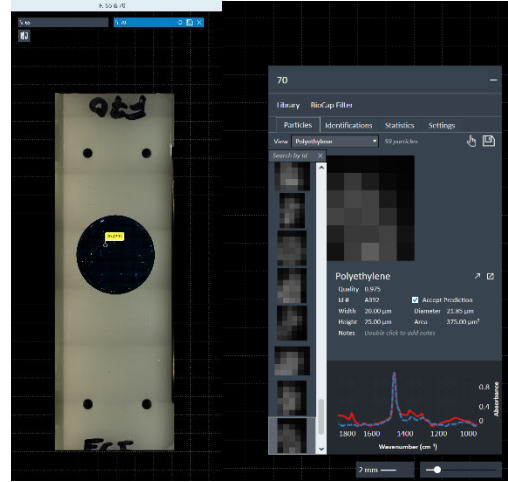


Figure 3.7: An LDIR scan of BV 70, which was the effluent from a flowthrough experiment performed with 40 µm PE particles.

3.4.1 Blank

The experimental procedure for the blanks was identical to that of the PE 150 µm and PE 40 µm samples, except that the blank influent’s solution was Milli-Q water without added MPs. Figure 3.8 shows the PE count found in the effluent, which could

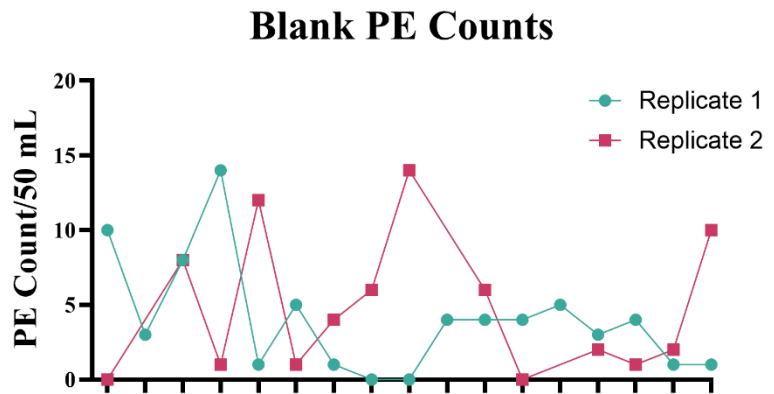


Figure 3.8: PE counts per 50 mL from flowthrough trials performed with blanks.

then be identified as experimental procedure contamination and subtracted from the final results total PE count. The blank subtraction was done by taking the average PE Count

value in per 5 BVs,

and subtracting that

from the PE Count

value of PE 150 μm

and PE 40 μm

values. For example,

the average count of

PE at BV 45 in

Figure 3.9 is 3 PE

particles/50 mL. For all PE counts at BV 45, the number 3 is subtracted to find the total

value. However, there is no correlation between the blank's increasing BVs and PE

count, so any increase seen in the experimental data would be an indication that there is a

correlation between increasing BVs and PE count. The average of each BV for the blank

flowthrough's is seen in Figure 3.9. The comparison between the average PE count

between the blank, 150 μm PE, and the 40 μm PE can be seen in Figure 3.12. Where a

large peak can be seen at BV 80 in the PE 150 μm average, but is not seen in the blank

BV 80. The particle counts of the 150 μm flowthrough and 40 μm flowthrough are

analyzed further in the following sections, however, they will be adjusted with the blank

calculation. This way, the values shown in the figures are representing the data that is not

from outside contamination.

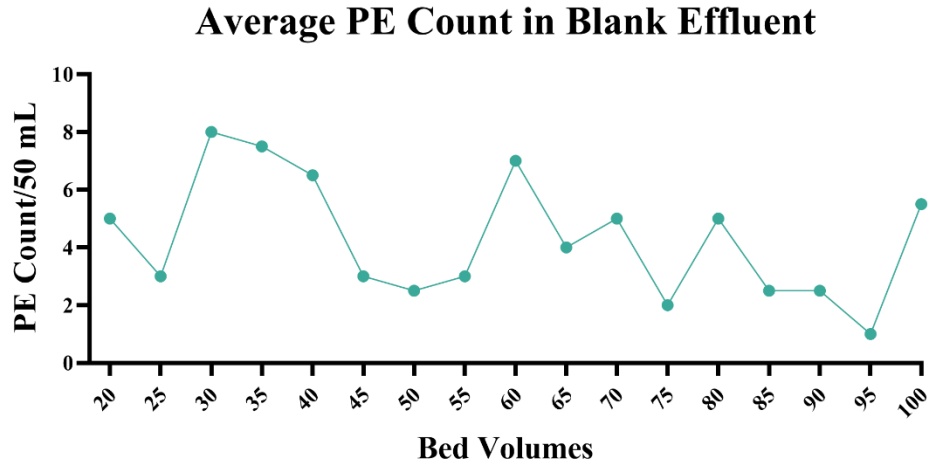


Figure 3.9: The change in average PE Count per BV, as found in the blank effluents.

3.4.2 Flowthrough of 150 μm Polyethylene

As seen in Figure 3.10, a potential breakthrough point can be seen around BV 80, where the average number of 150 μm PE particles found in the effluent were 67.5

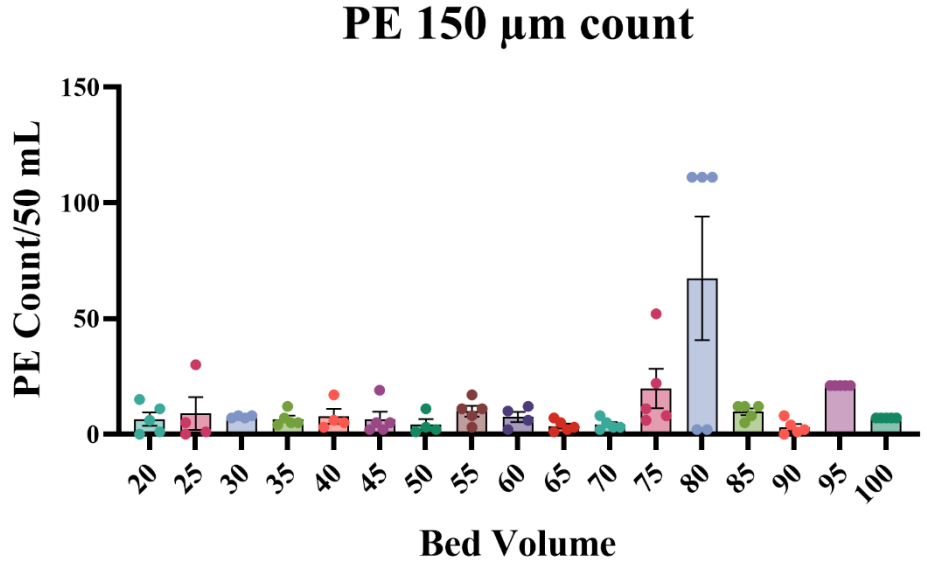


Figure 3.10: PE Count per BV found in the effluent of the 150 μm flowthrough.

particles. A breakthrough point indicates a

point at which the filter does not capture contaminants, but instead they are passed through to the effluent. This could provide insight as to how long the filter can last before fouling, or no longer being effective at capturing a contaminant. It is unclear if a

breakthrough point occurred at BV 80, as the PE count decreased and varied greatly afterwards, as seen in figure 3.11. Where the average amount of PE particles released remains close, then

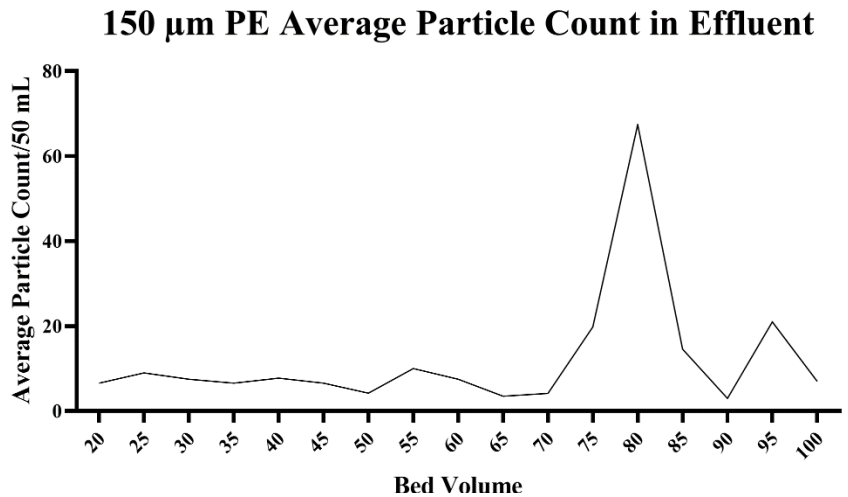


Figure 3.11: A graph showing the average trend of the particle counts per BV found in the effluent of the 150 μm flowthrough.

decreases, but jumps once more

at BV 95 and drops again after. This is conflicting, as one would assume that once the breakthrough point is reached, the same number of PE that is in the effluent will remain the same. However, because this is not the case, one may have to look at other properties of the filter as to why particles are still being captured, and whether that is due to electrochemical or physical properties.

Although the PE count is the primary focus, only a small percentage of particles found are PE (Figure 3.12). The BCP particles seen likely leached out during the flowthrough process,

as any disturbance or change may lead to small particles flowing through an open pore space. The total particles include the PE count, BCP

count, and any other unscanned particles that were present. The LDIR

only compares each particle to a predetermined standard. These other particles may be other types of MPs, chemicals both healthy and unhealthy found during the experiment, but will not be able to identify it as either a PE or BCP particle.

This shows that particles leach out of the filter throughout the flowthrough process, however, it is at low concentrations and does not include many PE particles

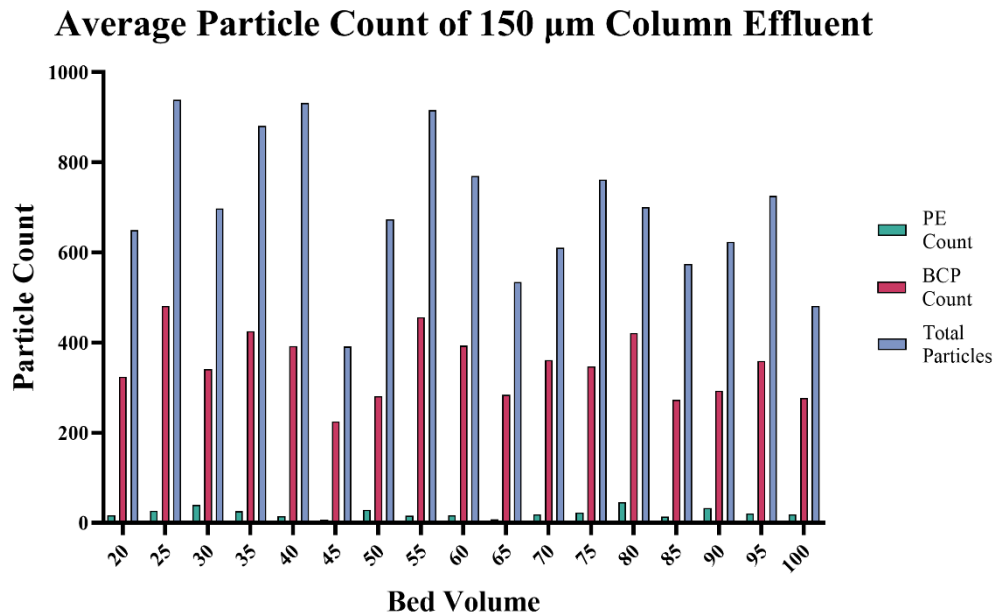


Figure 3.12: Graph depicting the average total particle count per BV.

3.4.3 Flowthrough of 40 μm

Polyethylene

The flowthrough of 40 μm PE particles saw varying results, as shown in Figure 3.13. There seems to be an equal distribution of particles around the 24-particle mark, as seen in BVs 25, 40, 55, 65, 80, 85, and 90. However, at BV 60, 70, and 75, there was one flowthrough that saw a large increase in PE particles in the effluent.

The average values across the BVs does not show a clear trend of increasing PE with increasing BV. This does not mean that the filter is not collecting PE particles, but that particles continue to find their way into the effluent. This would indicate that there is more studying that must be done to understand why there was no significant positive correlation between the PE particle count and the increasing bed volumes.

PE 40 μm count

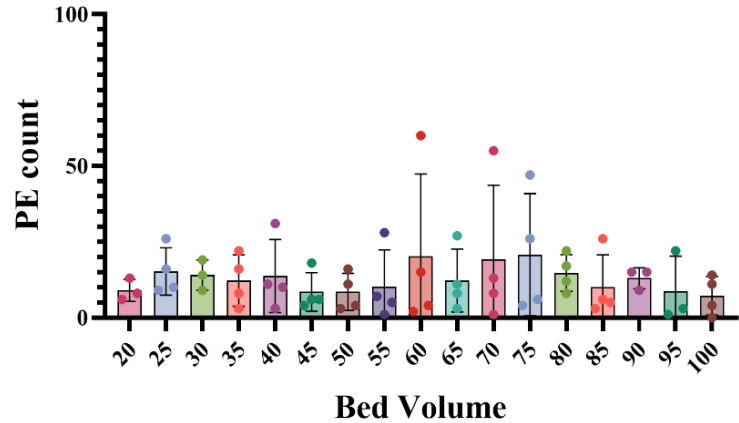


Figure 3.13: PE Count per BV found in the effluent of the 150 μm flowthrough.

40 μm PE Average Particle Count in Effluent

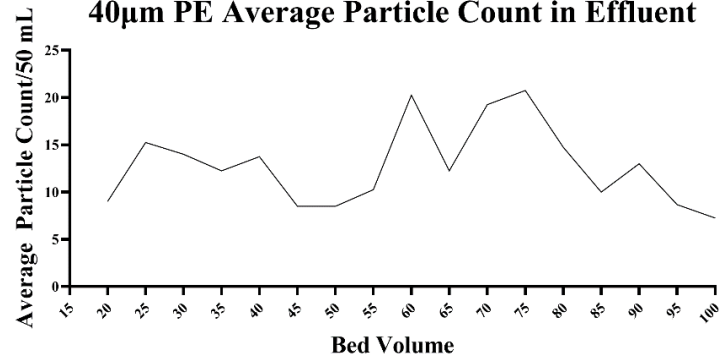


Figure 3.14: A graph showing the average trend of the particle counts per BV found in the effluent of the 150 μm flowthrough.

Average Particle Count of 40 μm Column Effluent

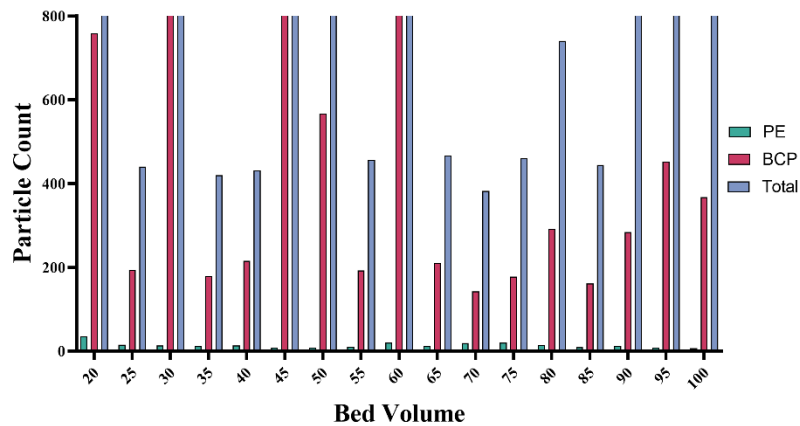


Figure 3.15: Graph depicting the average total particle count per BV.

The total particle count of the PE size 40 μm flowthrough was incredibly large. At BV 30, the average total particle count was calculated to be 2230.33 particles per 50 mL. Only 14 of those particles in BV 30 on average were PE, so the remaining count should be looked into. Even if it is only BCP, a wood product, that is flowing through, there would be reason for concern, as the filter may be holding onto some chemical. This would make BCP a carrier, rather than an adsorbent that removes pollutants.

3.4.4 Comparison

While the filter preparation maintained consistent through the experiment, the collection of PEs of different sizes did not show a clear trend. As seen in figure 3.16, there is an increase in PE particles collected in BV 80 for 150 μm particles, and in BV 85 for 40 μm particles, but it is not

maintained. Because it is not maintained, it is unclear if the filter is physically stopping the PE from flowing through, or if it is due to the chemical properties of the BCP.

The expected results were to see a breakthrough point in later BVs for the 150 μm particles, and to see a breakthrough earlier in the 40 μm particles. Mainly due to the physical separation that is involved more so in the larger particles. There are plenty of reasons why this may not have been the case in this set of experiments, be it the type sizing or type of our wood fibers, or some form of contamination led to the MPs finding their way into our testing supplies. However, through this research, there are several steps forward one can take. Whether this is through continuing this research or looking these synthetic polymers' chemical characteristics

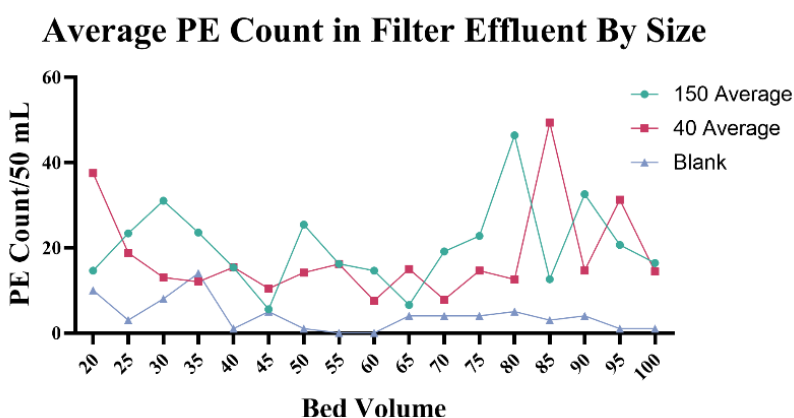


Figure 3.16: A comparison of averages of 150 and 40 μm PE flowthrough effluent PE counts.

and how they interact with lignin and bioCap, the future of water systems and fresh water resources needs to be looked into and solved urgently.

Although only speculation, one can make many assumptions on the mechanism of removal based on the chemistry of the materials. Regarding pristine PE, it would mainly be removed from physical trapping, where the particles are trapped in the small pores throughout the filter as well as on top. Visibly, PE particle could be seen accumulating at the top of the column throughout the experiment. Molecularly, there are likely Vanderwaal forces that trap the polyethylene and keep it in the filter. However, the degraded PE would likely see less PE flowthrough, due to more chemical mechanisms being introduced. Through the degradation process, more functional groups are introduced. As seen from the analysis of the wavelengths, the degradation introduces more carbonyl groups to the surface of the plastic. Because of this, there is more potential for hydrogen bonding between the tannic acid on the sawdust and the PE carbonyl groups.

Looking at the potential mechanisms of PE capture, one could infer that the filter would have success in capturing other types of plastic particles with varying stages of degradation. A filter that can capture a broader range of MPs would be more beneficial in a wastewater treatment plant, where the contaminated water is widely variable in concentration and type of plastic pollution.

CHAPTER 4

CONCLUSION:

Through studying the ligno-cellulosic filter mediate with polyphenol coatings to remove PE from contaminated water, there has been many steps forward in the terms of environmental research and how it can change the world down the road. This research furthers the field in academic writing on metal-phenolic coatings on wood to increase adsorbance but it also opens new paths for practical applications of environmental remediation. Doing so, we may be able to decrease the harmful effects MPs have on humans, and our exposure to them may decrease as a result. Along with decrease effects on humans, there is a high possibility that this technology holds the potential to reduce the prevalence of MPs in aquatic systems.

Enhancing adsorbance-characterized materials is important in developing cost-efficient and sustainable filtration systems for water in treatment plants. This can be done by replacing or augmenting the methods currently used by thousands of facilities. However, the adjustment may lead to cleaner water bodies, preserving life, reducing the ecological environment.

With plenty of access to cleaner waters, there would be a profound impact on health through the reduction of risk through exposure to dirty water and its associated health risks.

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