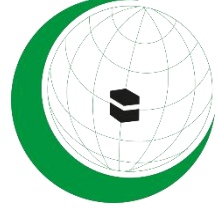




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*UNIVERSITE ISLAMIQUE DE TECHNOLOGIE*  
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## **BACHELOR OF SCIENCE IN CIVIL AND ENVIRONMENTAL ENGINEERING**

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# **Microplastic Removal from Surface Water through Coagulation-Flocculation-Filtration Process**

by

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**Gazipur, Bangladesh.**

**October, 2025**

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University of Technology (IUT), Gazipur in partial fulfillment of the  
requirements for the degree  
of

**BACHELOR OF SCIENCE IN CIVIL & ENVIRONMENTAL  
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**Islamic University of Technology**

**Gazipur, Bangladesh.**

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# **APPROVAL OF SUPERVISOR**

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The thesis titled “**Microplastic Removal from Surface Water through Coagulation-Flocculation-Filtration Process**” submitted by Mohsinat Ahmed Laboni, Student ID: 200051103 & Wafia Sadiqa, Student ID: 200051262 has been found as satisfactory and accepted as partial fulfillment of the requirement for the degree of Bachelor of Science in Civil & Environmental Engineering on October, 2025.

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# DECLARATION OF CANDIDATES

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It is hereby declared that this thesis/project report or any part of it has not been submitted elsewhere for the award of any Degree or Diploma (except for publication).

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**October 2025**

# DEDICATION

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We dedicate this thesis to our beloved parents and all our teachers, whose guidance, support, and encouragement have shaped us and helped us reach this milestone.

# TABLE OF CONTENT

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APPROVAL OF SUPERVISOR .....	III
DECLARATION OF CANDIDATES .....	IV
DEDICATION .....	V
TABLE OF CONTENT .....	VI
LIST OF FIGURES .....	VII
LIST OF TABLES .....	VII
ACKNOWLEDGEMENTS .....	VIII
ABSTRACT .....	IX
LIST OF ABBREVIATIONS .....	X
CHAPTER 1: INTRODUCTION .....	1
1.1. Background .....	1
1.2. Objectives of the study .....	3
CHAPTER 2: LITERATURE REVIEW .....	4
CHAPTER 3: METHODOLOGY .....	7
3.1. Materials & chemicals .....	7
3.2. Experimental procedure .....	7
3.2.1. Study area and selection of sampling location .....	8
3.2.2. Preparation of microplastic solution .....	9
3.2.3. Coagulation experiment .....	9
3.2.4. Effect of gravity .....	10
3.2.5. Quality assurance and control .....	10
3.2.6. Collection of sand & biochar .....	11
3.2.7. Determination of grain size distribution .....	11
3.2.8. Characterization of biochar .....	<b>Error! Bookmark not defined.</b>
3.2.9. Experimental setup .....	15
3.2.10. Filtration of post-coagulation water .....	16
3.2.11. Measurement of residual microplastics .....	16
CHAPTER 4: RESULT ANALYSIS & DISCUSSIONS .....	17
4.1. Coagulation-Flocculation result analysis for different parameters .....	17
4.1.1. Efficiency of coagulants .....	17
4.1.2. Effect of pH .....	18
4.1.3. Effect of MP size .....	20

4.1.4. Effect of gravity .....	20
4.2. Filtration result analysis for different sizes .....	24
CHAPTER 5: CONCLUSIONS .....	26
5.1. Findings of the study .....	26
5.2. Limitations of the study .....	26
5.3. Future scope of the study .....	27
REFERENCES .....	28

## LIST OF FIGURES

---

Figure 1 . Experimental procedure of the study .....	7
Figure 2 . Water collection from Turag river .....	8
Figure 3 . Microplastic solution preparation .....	9
Figure 4 . During rapid mixing & after settlement .....	10
Figure 5 . Filtered supernatant .....	10
Figure 6 . Vaccum filter .....	<b>Error! Bookmark not defined.</b>
Figure 7 . Collected sand & biochar .....	11
Figure 8 . Graph of grain size analysis for sand .....	13
Figure 9 . Graph of grain size analysis for biochar .....	14
Figure 10 . Sieve shaker .....	14
Figure 11 . Sand & biochar filter .....	15
Figure 12 . Strainer .....	16
Figure 13 . Average efficiency of coagulants for different sizes of PET MPs .....	18
Figure 14 . Effect on pH on the removal efficiency of coagulants .....	20
Figure 15 . Removal efficiency of PET MPs by coagulants .....	23
Figure 16 . Comparison between removal efficiency of PAC, SSF & biochar in MP size 0-0.3 mm .....	24
Figure 17 . Comparison between removal efficiency of PAC, SSF & biochar in MP size 0.3-1.18 mm .....	25

## LIST OF TABLES

---

Table 1 . Measured parameters of sample water .....	8
Table 2 . Grain size analysis for sand .....	12
Table 3 . Grain size analysis for biochar .....	13

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# ABSTRACT

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Microplastics (MPs), defined as plastic particles ranging from 1  $\mu\text{m}$  to 5 mm in size, have emerged as a significant environmental pollutant in recent years. These particles pose serious risks to aquatic ecosystems and potentially to human health. Wastewater treatment systems face growing challenges in effectively removing microplastics, with inconsistent removal rates reported across various treatment facilities. There is currently limited guidance on how to optimize coagulation-to-filtration processes, including which operational factors most influence removal efficiency. To address this, a treatment sequence consisting of coagulation, flocculation, and filtration was developed and tested to evaluate the effectiveness of different coagulants. The study compared the performance of ferric chloride, polyaluminum chloride (PAC), ferrous sulfate, and alum. Chloride-based coagulants, particularly PAC, showed the highest effectiveness. PAC achieved an average removal efficiency of 45.26% ( $\pm 24.64$ ) for smaller microplastic particles, with a maximum of 84%, and 61.24% ( $\pm 26.35$ ) for larger particles, with a maximum of 88%. The study identified pH level and coagulant dosage as the most critical factors influencing removal success. The findings suggest that combining PAC-based coagulation with precise control of pH and dosing, followed by treatment through biochar and slow sand filtration (where applicable), can result in near-complete microplastic removal. This approach offers practical and scalable solutions, especially for policy implementation and plant upgrades in resource-limited areas. For two distinct MP sizes, this study went one step further and passed the PAC treated water separately through a slow sand filter and biochar. In both sizes (0-0.3 mm and 0.3-1.18 mm), biochar outperforms slow sand filters in terms of removal efficiency.

# LIST OF ABBREVIATIONS

---

ASTM	American Society for Testing and Materials
BET	Brunauer–Emmett–Teller (method for surface area analysis)
EC	Electrical Conductivity
HDPE	High-Density Polyethylene
LDPE	Low-Density Polyethylene
MP(s)	Microplastic(s)
PAC	Polyaluminum Chloride
PAM	Polyacrylamide
PET	Polyethylene Terephthalate
PS	Polystyrene
pH	Potential of Hydrogen (measure of acidity/alkalinity)
SEM	Scanning Electron Microscope
TOC	Total Organic Carbon
WWTP	Wastewater Treatment Plant

# CHAPTER 1: INTRODUCTION

---

## 1.1. Background

Microplastics (MPs) are defined as plastic particles smaller than 5 mm (Arthur et al., 2009). MPs are divided into primary and secondary categories according on their place of origin. Secondary MPs are produced when bigger plastics break down to a size of less than 5 mm (Uddin et al., 2020) by thermal, hydrolytic, chemical, mechanical, and biological degradation (Wawer et al., 2025). Primary MPs are commercially made for usage in various goods. About 390 million tons of plastic were manufactured worldwide in 2021, with China accounting for 29–32% of production, Japan for 3-4%, and other Asian nations for 17%. Among the most produced materials are polypropylene (PP), low-density polyethylene (LDPE), and high-density polyethylene (HDPE). 24.2 million tonnes, or 6.2% of all plastics, were made with polyethylene terephthalate (PET) (PlasticsEurope, 2022).

The amount of plastic produced worldwide has grown at an unprecedented rate throughout the previous 70 years. By 2020, annual production has increased to approximately 370 million metric tons from less than 2 million metric tons in the early 1950s. If current trends continue, this number may double by 2040 (Geyer et al., 2017). This exponential expansion is a reflection of the cost and versatility of plastics, which are widely employed in a variety of industries, including electronics, construction, packaging, textiles, and transportation. Plastics are valued for their light weight, durability, and resistance to deterioration features that make them essential to modern life but also problematic due to their environmental persistence.

Environmental contamination occurs along multiple pathways. When precipitation and surface runoff occur, particles from the atmosphere that have been deposited on soil are carried into bodies of water (Zhou et al., 2021). Primary and secondary sludges concentrate MPs, wastewater treatment plant (WWTP) effluent adds to loads in receiving waters, and biosolids applied to land create a source of soil (Uddin et al., 2020, Zhou et al., 2021, Hu et al., 2019). There are roughly 18,000 plastic garbage items per km<sup>2</sup> on the ocean surface (Eriksen et al., 2013). There are documented biological impacts to support the concern. Polycyclic aromatic hydrocarbons and heavy metals can be adsorbed on MP surfaces and then desorbed in biota, adding hazardous risk (Azizi et al., 2023, Tabatabaieia et al., 2023, Zhou et al., 2021). Ingestion has also been linked to

negative results in aquatic creatures (Rajala et al., 2020). In microalgal experiments, the presence of MPs has increased pharmaceutical toxicity (Prata et al., 2018).

The coagulation, flocculation, clarifying, and filtering processes used in conventional water and wastewater trains were not initially developed with MPs as target contaminants (Ogwu et al., 2024, Cherniak et al., 2022). Significant MP reductions have been shown in studies throughout these steps; however, results differ greatly depending on the polymer chemistry, size, shape, background organic matter, and operation conditions (Novotna et al., 2019; Iyare et al., 2020; Tang et al., 2022; Rajala et al., 2020; Kwon et al., 2022; Khan et al., 2023, Esfandiari et al., 2021, Hidayaturrahman et al., 2019, Shao et al., 2020, Zhou et al., 2021). Systematic gaps are found through reviews and plant studies. The regulating roles of pH and dose are not mapped for particular polymer–size classes, and removal is frequently uneven across coagulant classes. Differences in reporting and methodology make cross-study comparison and design transfer more difficult. PET is given less size-resolved attention than PS and PE, which are the focus of the majority of datasets (Kovačić et al., 2024). Controlled, optimization-based laboratory investigations that address mechanism and operating windows are motivated by these restrictions, which are described for drinking water and wastewater contexts.

Though reported efficacy varies from moderate to very high, coagulation-flocculation is often cited as a possible front-end control for MPs. Evidence from plants and benches indicates that the balance between charge neutralization and sweep flocculation is determined by the coagulant hydrolysis state, particle size and shape, and polymer identity. While some studies show improved capture of larger fragments and fibers through bridging flocculation and enmeshment, others claim higher removals for tiny MP sizes under charge neutralization (Eydi et al., 2024, Huang et al., 2024, Javed et al., 2024, Lin, J.-Y et al., 2023, Leppänen et al., 2022). Water chemistry, pH, and coagulant dosage have all been connected to these differences. Research demands size-resolved, consistent reporting and systematic optimization, including transparent accounting of the locations of MP partitioning in sludge streams that subsequently re-enter the environment (Novotna et al., 2019; Tang et al., 2022; Khan et al., 2023; Pivokonský et al., 2020).

## **1.2. Objectives of the study**

The objectives of this study are as follows:

- i. Evaluation of efficiency of coagulation-flocculation in removal of microplastic.
- ii. Developing a filtration unit-preparation & optimization of slow sand & natural filter.

## CHAPTER 2: LITERATURE REVIEW

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Several studies have investigated the effectiveness of various coagulants for microplastic (MP) removal from different water matrices. The performance of polyaluminum chloride (PAC) in three wastewater treatment plants (WWTPs) in Daegu, Republic of Korea, using dosages of 29–32 mg/L (Hidayaturrahman et al., 2019). The removal efficiencies varied across plants, ranging from 47.1% to 81.6%, reflecting differences in operational conditions. In another study, the combined application of PAC, polyacrylamide (PAM), and  $\text{Fe}_3\text{O}_4$  in a constructed wetland in Tianjin, China, achieving removal efficiencies of 73.8% on sunny days and 77.9% on rainy days, demonstrating the method's consistency under varying environmental conditions (Zhou et al., 2022). The study of aluminum chloride ( $\text{AlCl}_3$ ) and calcium chloride ( $\text{CaCl}_2$ ) for lake water treatment and found removal efficiencies exceeding 80% at pH values above 6, indicating the strong influence of pH on coagulation efficiency (Chen et al., 2020). Similarly, magnetic magnesium hydroxide [ $\text{Mg}(\text{OH})_2$ ] and iron oxide ( $\text{Fe}_3\text{O}_4$ ) in simulated wastewater, achieving 66.3–87.1% removal at neutral pH 7 (Zhang et al., 2020). Further comparing between iron(III) chloride ( $\text{FeCl}_3$ ) and PAC in simulated water systems at dosages between 30 and 180 mg/L, reporting removal efficiencies of 77.83% for polystyrene (PS) and 29.70% for polyethylene (PE) (Zhou et al., 2021). Collectively, these studies highlight that coagulant type, dosage, pH, and sample characteristics significantly affect MP removal efficiency.

Microplastic (MP) contamination in Bangladeshi river systems has been increasingly documented in recent years. The presence of MPs in both sediment and surface water of the Karnaphuli River was reported, with concentrations of 103.67 items/kg in sediment and 164,444.44 items/km<sup>2</sup> in water, where fibers were the dominant type and polyethylene terephthalate (PET) was the predominant polymer (Fatema et al., 2023). Similarly, MPs were detected in fish and sediment samples of the Jamuna River, with an average abundance of  $1.80 \pm 1.65$  items/individual in fish then accordingly in predominantly fibers and sediment samples ranging from  $17.33 \pm 1.53$  to  $133.67 \pm 5.51$  items/kg, primarily consisting of fragments (Khan et al., 2022). Although the polymer type in fish was not determined, polypropylene (PP) was identified as the dominant polymer in sediments (Khan et al., 2022). In another study, MP concentrations ranging from  $4.33 \pm 0.58$  to  $43.67 \pm 0.58$  items/L were found in the water of the

Buriganga River, with similar fragment-dominated characteristics in sediments (Islam et al., 2022). Polypropylene (PP) was again identified as the dominant polymer (Islam et al., 2022). Collectively, these studies highlight the widespread occurrence of microplastics in major Bangladeshi rivers, with fibers and fragments being the most common forms and PET and PP emerging as dominant polymers, reflecting the influence of urban and industrial pollution sources (Fatema et al., 2023; Khan et al., 2022; Islam et al., 2022).

Recent studies have continued to highlight the growing presence of MPs in Bangladesh's aquatic systems. MP concentrations of  $37.5 \pm 8.3$  items/L were detected in surface water of the Padma River, with fibers as the dominant morphological type (Khan et al., 2023). Polyethylene (PE) was identified as the primary polymer, reflecting inputs from domestic and industrial plastic wastes (Khan et al., 2023). Similarly, high MP concentrations of  $123,000 \pm 35,000$  items/m<sup>3</sup> in surface water and  $25,000 \pm 6,000$  items/kg in sediments were reported in the Buriganga River (Mercy et al., 2023). In both matrices, fibers were the most abundant type, and PET was the dominant polymer (Mercy et al., 2023). These findings emphasize that MP pollution is pervasive across major rivers in Bangladesh, with fiber-shaped MPs, primarily PET and PE being the most prevalent, likely due to textile effluents, household wastewater, and improper plastic disposal (Mercy et al., 2023). PET, one of the most dominant polymers found in major lakes and rivers in Bangladesh. Less studied because of its high density and low theoretical buoyancy (Kovačić et al., 2024).

Several studies have investigated the use of coagulants for the removal of MPs from water. The effectiveness of alum, ferric chloride, and polyaluminum chloride (PAC) was explored for removing PE microplastics ranging in size from 0.125 to 0.355 mm (Azizi et al., 2023). The coagulant doses used were 40 mg/L for alum, 20 mg/L for ferric chloride, and 10 mg/L for PAC, achieving removal efficiencies of 77%, 84%, and 94%, respectively (Azizi et al., 2023). PAC was found to be the most effective coagulant among those tested (Azizi et al., 2023). In another study, aluminum-based coagulants were used for removing PE microplastics sized between 0.03 and 1 mm, achieving a 98% removal efficiency at a dose of 30 mg/L (Rajala et al., 2020). These findings underscore the importance of selecting appropriate coagulant types and doses to optimize MP removal from water systems (Azizi et al., 2023; Rajala et al., 2020).

Further investigations have continued to explore the use of various coagulants for MP removal. Aluminum chlorohydrate (ACH) and PAC were assessed for the removal of polystyrene (PS) microplastics in the 0.1 to 0.5 mm range (Luu et al., 2025). At a coagulant dose of 10 mg/L, removal efficiencies were 93% for ACH and 95% for PAC (Luu et al., 2025). Ferric chloride was used for removing PE MPs ranging from 0.1 to 1.0 mm, achieving a 92% removal efficiency at a 30 mg/L dose (Ziembowicz et al., 2023). Aluminum sulfate was also investigated for removing PS MPs sized between 0.01 and 0.3 mm, with a coagulant dose of 50 mg/L yielding an 85% removal efficiency (Zhang et al., 2021). These studies collectively show that both the type of coagulant and MP characteristics, such as size and polymer type, significantly influence removal efficiency, with PAC and ferric chloride emerging as particularly promising options (Luu et al., 2025).

In addition to coagulation, various treatment approaches have been employed to remove MPs from water systems. Dissolved air flotation (DAF) was utilized to remove PE MPs, achieving a high removal efficiency of 91%, with bubble size and flow conditions being critical to performance (Wang et al., 2020). Sand filtration was applied for removing PP MPs and resulted in 83% removal efficiency, with filter grain size and bed depth being significant factors (Olubusoye et al., 2024). A membrane bioreactor (MBR) system was used to treat a mix of PE and PP microplastics, achieving a removal efficiency of 95% (Ahmad et al., 2023). Membrane pore size and fouling control were identified as essential operational considerations (Ahmad et al., 2023). Electrocoagulation was employed to remove PS MPs, reaching an 88% removal rate due to enhanced aggregation and settling of MPs under applied electric fields (Bhagwat et al., 2024). Collectively, these findings underline that a range of physical, biological, and electrochemical methods can offer effective MP removal when process parameters are carefully optimized (Wang et al., 2020; Olubusoye et al., 2024; Ahmad et al., 2023; Bhagwat et al., 2024).

# CHAPTER 3: METHODOLOGY

The experimental methods used to assess the effectiveness of flocculation, coagulation, and filtration in eliminating microplastics from natural surface water are described in this chapter. It explains the tools, supplies, sample preparation, experimental setup, and analytical methods used.

## 3.1. Materials & chemicals

Using conventional sieves, PET microplastics were separated into two size ranges (0–0.3 mm and 0.3–1.18 mm) after being gathered from a nearby recycling facility. The particles were cleaned with 1 M HCl and oven-dried at 70°C for 24 hours following (Adib et al., 2022). We used four analytical-grade coagulants alum ( $\text{Al}_2(\text{SO}_4)_3 \cdot 16\text{H}_2\text{O}$ ),  $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ , PAC ( $\text{Al}_2(\text{Cl})\text{OH}_5$ ), and  $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$ . Also 0.1 M NaOH and HCl (37% w/v) solutions were used to adjust the pH. Additionally, sand and biochar were collected for filtration purpose.

## 3.2. Experimental procedure

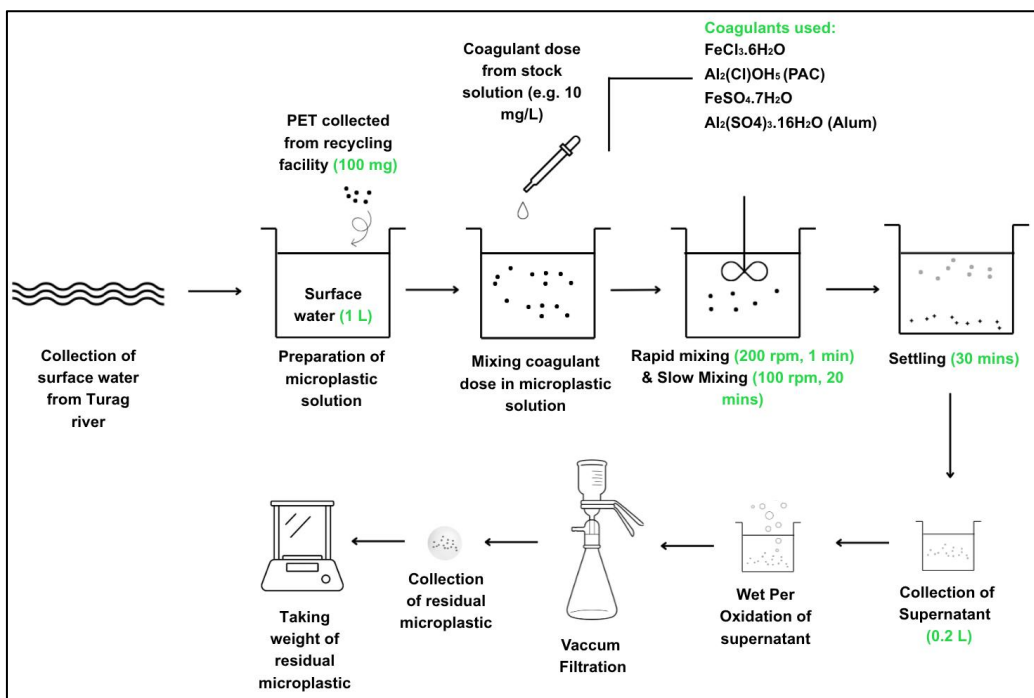


Figure 1. Experimental procedure of the study

### 3.2.1. Study area and selection of sampling location

Surface water samples were collected from the Turag River at the coordinates 23.9511° N, 90.3456° E. And then parameters were checked.



*Figure 2. Water collection from Turag river*

*Table 1. Measured parameters of sample water*

<b>Water quality parameter</b>	<b>Value</b>
EC ( $\mu\text{S}/\text{cm}$ )	118.72
DO (mg/L)	6.63
TDS (mg/L)	57.6
Salinity (%)	0.06
Temperature ( $^{\circ}\text{C}$ )	24.17
Color (PtCo)	127
COD (mg/L)	79
Turbidity (NTU)	27.88
pH	6.83

### 3.2.2. Preparation of microplastic solution

100 g of microplastics (MPs) were dispersed in 1000 mL of deionized water and stirred for 10 minutes to ensure uniform suspension.



*Figure 3. Microplastic solution preparation*

### 3.2.3. Coagulation experiment

Coagulant doses of 10, 20, 30, 50, 70, and 80 mg/L were tested. The MP solution was mixed at 200 rpm for 1 minute, 100 rpm for 20 minutes, and allowed to settle for 30 minutes. Then, 200 mL of the supernatant was collected and filtered through PALL Nylon 47 mm, 0.2  $\mu\text{m}$  filters. Filters were dried at 60°C for 30 minutes and weighed. Removal efficiency was calculated using:

$$\text{Removal efficiency of coagulants (\%)} = \frac{m_0 - m_1}{m_0} \times 100$$

Where,  $m_0$  and  $m_1$  represent the initial and final MP masses (mg/L). Tests were performed at pH 7, 5.5–6, and 8–9, adjusted with NaOH and HCl.



*Figure 4. During rapid mixing & after settlement*



*Figure 5. (a) Filtered supernatant, (b) Vacuum filter*

### **3.2.4. Effect of gravity**

Blank samples without coagulant were settled for 30 minutes to measure MP removal caused by natural sedimentation.

### **3.2.5. Quality assurance and control**

To minimize contamination, all experiments were conducted in a controlled lab following strict protocols (Jones et al., 2024). Glassware and Petri dishes were covered and rinsed with ultrapure water. Two blanks were included: (i) settling blanks for natural sedimentation and (ii) deionized water blanks to assess background contamination. The latter showed an average contamination of 0.003 g, which was subtracted from total MP removal (Munno et al., 2023).

All instruments were calibrated, and experiments were performed in triplicate to ensure accuracy and reproducibility.

The water obtained after the coagulation process was subjected to filtration. Among the tested coagulants, the highest removal efficiency was achieved using PAC, with the pH maintained at approximately 7.

### **3.2.6. Collection of sand & biochar**

The sand was commercially sourced, ensuring a well-graded condition with variant sizes of sand particles - coarse sand (2-4.75 mm), medium sand (0.425-2 mm), and fine sand (0.075-0.425 mm). Biochar was collected as an organic fertilizer material. This biochar is a soil amendment produced by heating organic matter such as leaves, wood, and plants in a low-oxygen environment (such as a stove or oven) until complete carbonization occurs, leaving behind a black, carbon-rich residue. Before using the biochar as a filter medium, it was oven-dried to remove any moisture. This step ensures that water passes easily through the biochar filter during the filtration process. For the drying process of biochar, it was oven-dried at 105°C for 24h.



*Figure 6. Collected sand & biochar*

### **3.2.7. Determination of grain size distribution**

The sand & biochar sample were individually oven-dried at 105°C for 24h to remove moisture and ensure accurate measurement. A set of standard sieves (#4, #8, #16, #30, #40, #50, #100, and #200) were used for the grain size analysis.

*Table 2. Grain size analysis for sand*

Sieve no.	Sieve size (mm)	Materials retained + Sieve/Bowl (g)	Weight of sieve/bowl (g)	Materials retained (g)	% retained	Cumulative % retained	% Finer	FM
4	4.75	244.25	209.55	34.7	1.09	1.09	98.91	
8	2.36	445.46	209.55	235.91	7.41	8.5	91.5	
16	1.18	2676.14	209.55	1837.94	57.72	66.22	33.78	
30	0.6	1374.71	209.55	955.61	30.01	96.23	3.77	
40	0.425	405.7	312.71	92.99	2.92	99.15	0.85	
50	0.3	306.7	290.43	16.27	0.51	99.66	0.34	2.28
100	0.15	296.09	285.85	10.24	0.32	99.98	0.02	
200	0.075	274.31	273.93	0.38	0.01	99.99	0.01	
Pan		298.66	298.44	0.22	0.01	100	0	
				3184.26				
<b>D<sub>10</sub></b>	<b>D<sub>30</sub></b>	<b>D<sub>60</sub></b>	<b>C<sub>u</sub></b>					
0.71	1.1	1.6	2.25					
<b>Fine sand</b>						5.15%		
<b>Medium sand</b>						35.00%		
<b>Coarse sand</b>						82.00%		

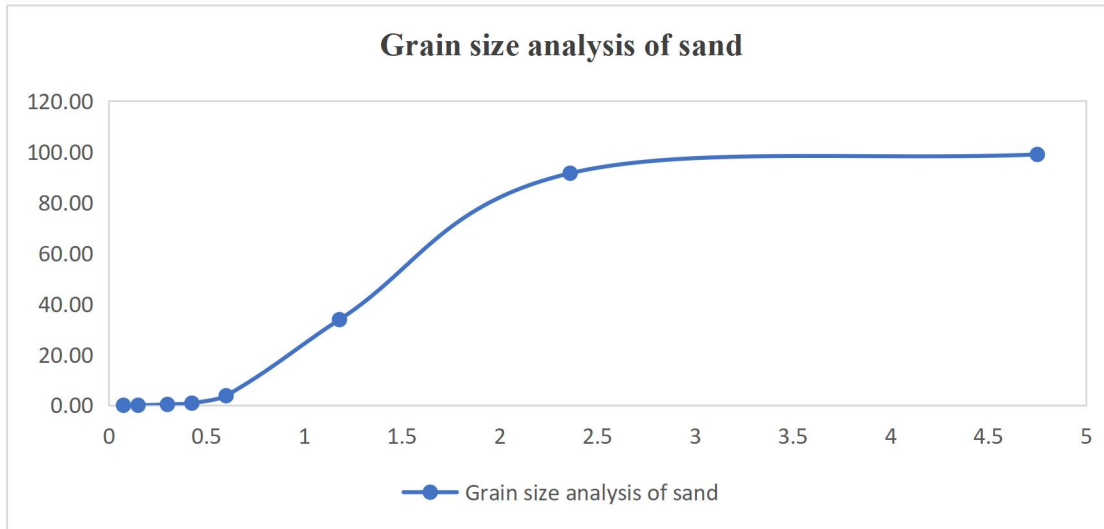
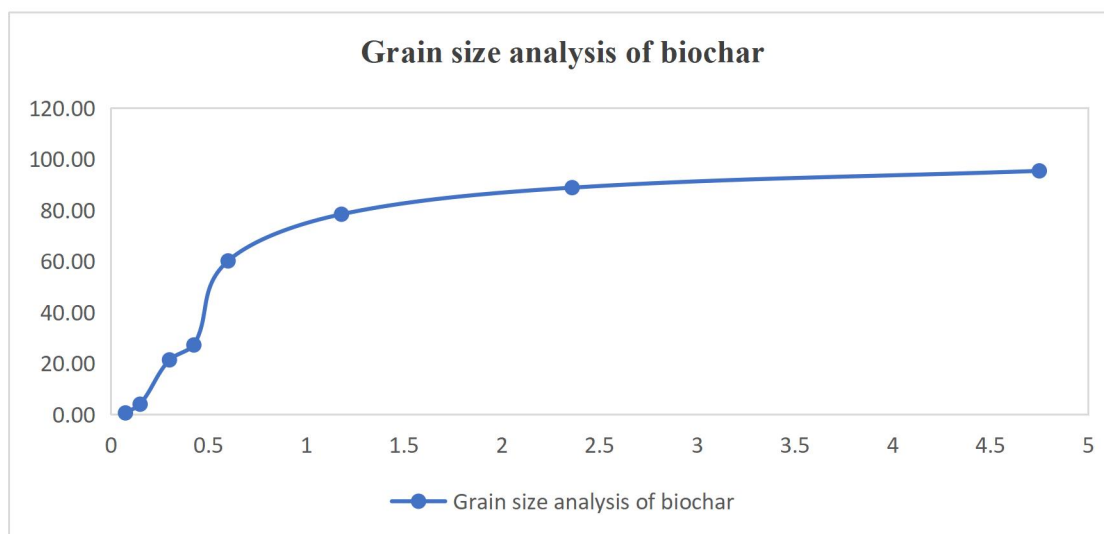


Figure 7. Graph of grain size analysis for sand

Table 3. Grain size analysis for biochar

Sieve no.	Sieve size (mm)	Materials retained + Sieve/Bowl (g)	Weight of sieve/bowl (g)	Materials retained (g)	% retained	Cumulative % retained	% Finer	FM
4	4.75	366.05	345.51	20.54	4.64	4.64	95.36	3.48
8	2.36	355.88	326.79	29.09	6.57	11.21	88.79	
16	1.18	372.78	326.67	46.11	10.42	21.63	78.37	
30	0.6	389.5	308.59	80.91	18.28	39.91	60.09	
40	0.425	458.47	312.71	145.76	32.93	72.84	27.16	
50	0.3	316.26	290.43	25.83	5.84	78.68	21.32	
100	0.15	362.66	285.85	76.81	17.35	96.03	3.97	
200	0.075	289.06	273.93	15.13	3.42	99.45	0.55	
Pan		300.89	298.44	2.45	0.55	100	0	
				442.63				
<b>D<sub>10</sub></b>	<b>D<sub>30</sub></b>	<b>D<sub>60</sub></b>	<b>C<sub>u</sub></b>					
0.2	1	0.6	3					
<b>Fine biochar</b>					26.61%			

<b>Medium biochar</b>	68.20%
<b>Coarse biochar</b>	4.64%



*Figure 8. Graph of grain size analysis for biochar*

Coarser portions of the biochar samples were taken and adjusted in a way to obtain  $d_{50}$  around 1.4 mm which is similar to that of medium sand.



*Figure 9. Sieve shaker*

### 3.2.8. Experimental setup

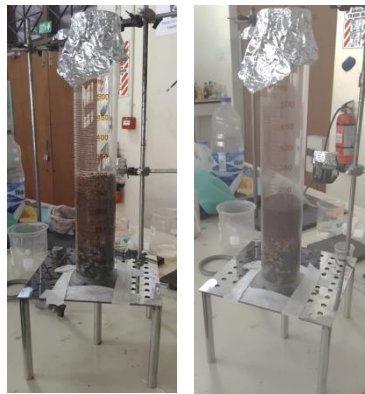
Prior to the experiment, both cylinders were thoroughly cleaned, and their dimensions were checked. The diameter of the cylinder is 5 cm and height is 650 mm. Two cylinders of the same dimensions were used.

#### **First cylinder (used for slow sand filter)**

The first cylinder was packed with multiple layers of filter media. Gravel (100 mm) was placed at the bottom followed by medium sand (200 mm) at the top. The free-board was measured 16.5 cm.

#### **Second cylinder (used for biochar filter)**

The second cylinder contained gravel (100 mm) at the bottom, with biochar (200 mm) placed above it as the primary filter medium. The free-board was also measured 16.5 cm.



*Figure 10. Sand & biochar filter*



*Figure 11. Strainer*

### **Strainer design**

A stainless steel strainer was fabricated with dimensions of approximately 7.5" × 7.5" and a stand height of 12 cm. The plate thickness was 2 cm, and it contained circular openings with a radius of 0.25", spaced at 0.75" center-to-center. Both measuring cylinders were placed on top of the strainer. The bottom glass portions of the cylinders were carefully cut and attached to the strainer using tape to allow filtered water to pass through. Two 250 mL beakers were positioned below each cylinder to collect the final treated water.

### **3.2.10. Filtration of post-coagulation water**

Treated water in which microplastics were removed using PAC as a coagulant, was poured into the filter setup. Basically, passing the residual MP collected treating water from coagulant PAC. The pH of the water close to 7 in 1000 mL. The filtration process was allowed to continue for about ten hours.

### **3.2.11. Measurement of residual microplastics**

After collecting the passed water from the beaker, it was transferred to a vacuum filtration system using filter paper with a pore size of 0.2 micrometers. The filtered water now treated, was then collected. Subsequently, all relevant parameters of the treated water were measured. The 0.2-micrometer filter paper, which retained the residual microplastics (MPs), was carefully collected. The amount of residual MPs was determined by weighing the filter paper using an analytical balance.

## CHAPTER 4: RESULT ANALYSIS & DISCUSSIONS

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### 4.1. Coagulation-Flocculation result analysis for different parameters

Coagulation-Flocculation process involves the addition of chemical coagulants that destabilize fine particles, followed by the formation of larger flocs through gentle mixing. The efficiency of coagulation-flocculation largely depends on several parameters such as coagulant type and dosage, pH, mixing conditions, and characteristics of the raw water. Analyzing the results of this process under different parameter conditions helps determine the optimal treatment efficiency and provides insights into the mechanisms governing particle aggregation and removal. Such analysis is essential for optimizing treatment performance and ensuring cost-effective and sustainable water purification.

#### 4.1.1. Efficiency of coagulants

Two primary comparisons can be used to assess the coagulants' efficacy: the impact of the central metal ion (iron versus aluminum) and the accompanying anion (chloride versus sulfate).

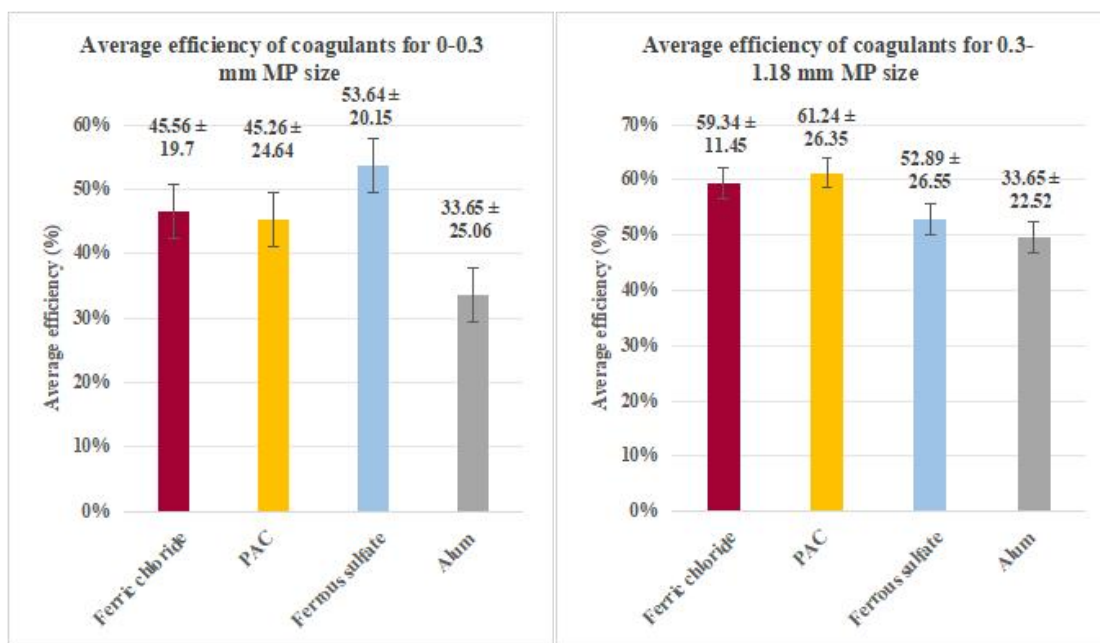
When coagulants based on sulfate (Ferrous sulfate, Alum) and chloride (Ferric chloride, PAC) were compared, the chloride group performed better. PAC continuously performed better than any other coagulant, achieving clearance efficiencies that were higher than 90%. Additionally, ferric chloride demonstrated superior removal at a lower dose than its sulfate counterpart (ferrous sulfate), indicating that chloride salts improved the flocculation and instability of microplastics more successfully.

Chloride anions may improve hydrolysis and charge neutralization capacities more efficiently than sulfate anions, as sulfate-based coagulants required higher dosages and showed poorer efficiency. The results are consistent with earlier research indicated that PAC removed 97.5% of MP, while aluminum sulfate removed only 67.5% (Li et al., 2024). This suggests that the chloride-based coagulant is significantly more effective.

Although this variance was greatly influenced by the particular formulation utilized, aluminum (PAC, Alum) showed a clear advantage over iron (Ferric chloride, Ferrous sulfate) in the comparison of the two metals. Because of its pre-polymerized structure, which makes it easier to create dense and robust flocs, PAC in particular showed the highest efficiency and preference.

Aluminum sulfate (~84.4% at a dose of 40 mg/L) performs more effectively than ferrous sulfate salt (~76% at a dose of 40 mg/L) at eliminating MPs at a lower dose for PS particles, which have a higher density than water like PET and a stronger negative zeta potential (Iyare et al., 2020, Lu et al., 2024).

Alum, on the other hand, performed worse in this investigation when it came to removing microplastics than both iron-based coagulants. Among the iron salts, ferric chloride was more effective than ferrous sulfate, confirming the idea that the chloride form is better than the sulfate form in this situation. Later, machine learning was used to examine the further dependence of the rate of MP removal on the kind of coagulant as a variable.



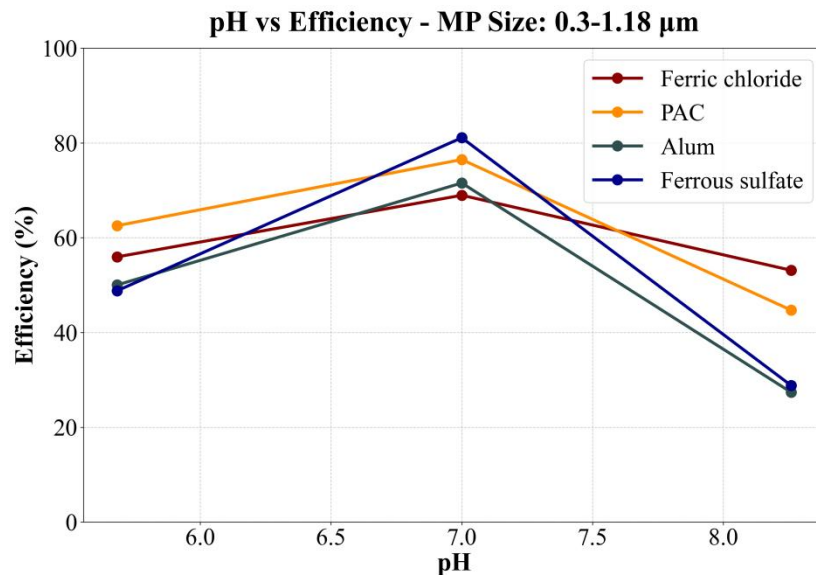
*Figure 12. Average efficiency of coagulants for different sizes of PET MPs*

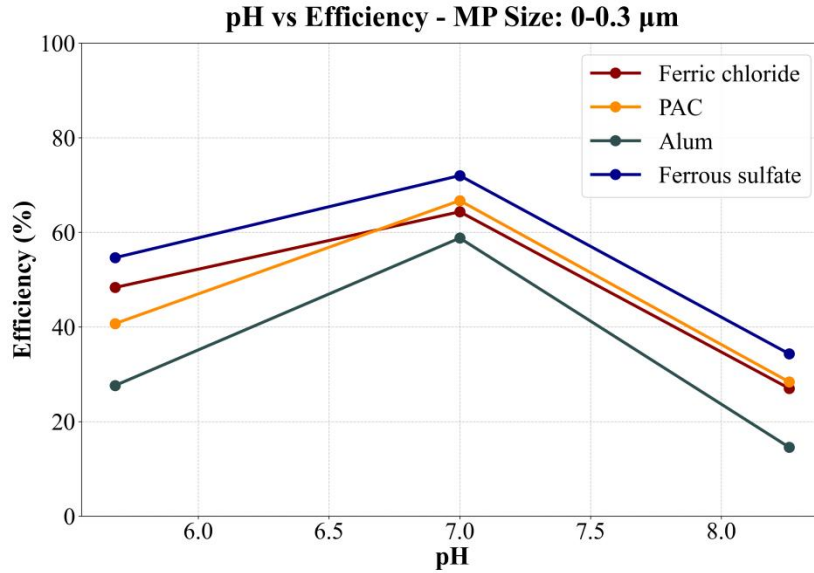
#### 4.1.2. Effect of pH

Ferrous sulfate had the highest mean efficiency at pH 7 compared to the rest of the coagulants for both MP sizes, which shows its strong dependency on pH control to achieve higher rate of removal. PAC followed next, achieving 70-75% removal efficiency for both small and large MP particles. For all tested coagulants, the most effective pH for microplastic removal was identified to be slightly acidic to neutral. At this pH level, the processes of hydrolysis and polymerization of metal salts are optimally balanced, which enhances coagulation efficacy. Changes to either

acidic or alkaline environments led to decreased efficiencies, with sulfate salts experiencing a notable drop in effectiveness at higher pH levels. This suggests that a neutral pH provides the optimal conditions for charge neutralization and floc formation, independent of the coagulant type employed. In a study, ferric chloride achieved a 65% removal efficiency at pH 6 with a dose of 1.95 g/L (Fadlilah et al., 2024). Both ferric chloride and aluminum sulfate showed their highest removal efficiency at pH 6, while increasing the pH toward alkaline conditions decreased the efficiency, which matches the pattern found in this study. An excessively high dose of such salts can also cause the flocculated microplastics to be released back into the water (Lee & Jung, 2022)

PAC achieved the highest removal efficiency (84% for 0-0.3 mm MPs, 88.4% for 0.3-1.18 mm MPs) at a dose of 70 mg/L at pH 7, including settlement due to gravity. Ferric chloride had the highest mean removal efficiency (45.56%) for smaller MP sizes (0-0.3 mm), closely followed by PAC (45.26%), whereas PAC had the highest mean removal efficiency for larger particles (0.3-0.18 mm). Considering the overall distribution of efficiency across all the doses and pH conditions, ferric chloride had the most consistent removal rate. This proves that chloride salts had a higher and more consistent removal rate compared to sulfate based salts used in the coagulation-flocculation process.





*Figure 13. Effect on pH on the removal efficiency of coagulants*

#### 4.1.3. Effect of MP size

At all dosages, the coagulants consistently eliminated a higher fraction of the MP size (0.3-1.18 mm). For bigger MP sizes, the average mean efficiency was  $55.78\% \pm 22.59\%$ , while for smaller particles, it was  $44.92\% \pm 22.98\%$ . The findings are consistent with other studies' inquiries. Larger PET particles (0.4–0.5 mm) were more effectively eliminated than smaller ones (0.1–0.4 mm and less than 0.1 mm), which is usually attributed to the MPs' polymer type. Because they are denser than water, larger particles of these MPs have a higher clearance rate (Acarer et al., 2024, Ma et al., 2019).

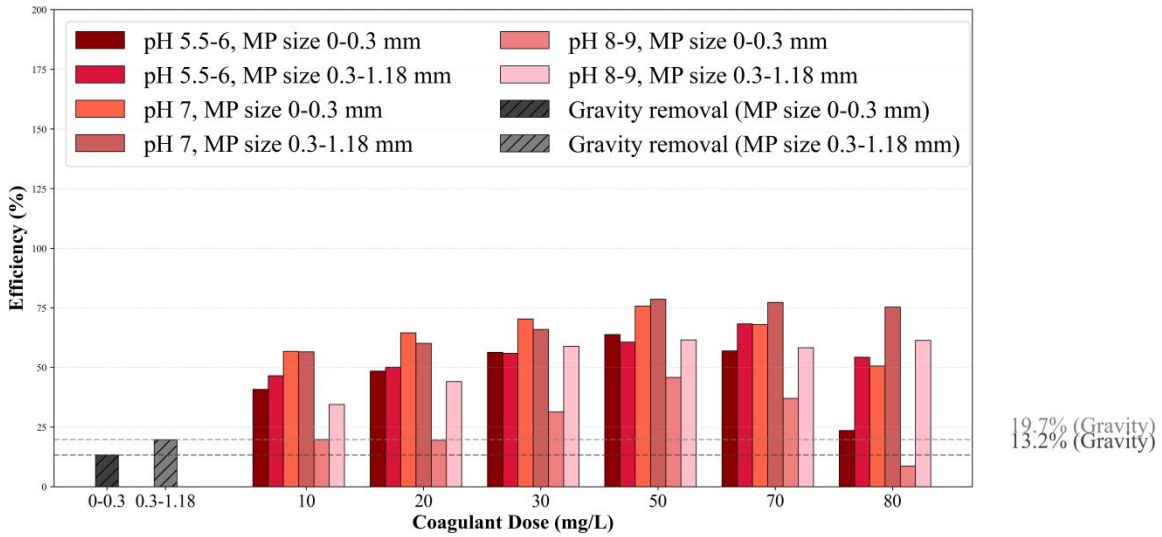
#### 4.1.4. Effect of gravity

Without coagulants, a certain amount of microplastic clearance was seen, which was explained by natural settling. To ensure uniformity in the outcome, environmental conditions and water quality were maintained in each instance. The removal effectiveness was 19.7% for the larger fraction (0.3–1.18 mm) and 13.2% for the finer fraction (0–0.3 mm). Because of their relatively high density, about 30% of PET particles sank on their own (Zhang et al., 2021).

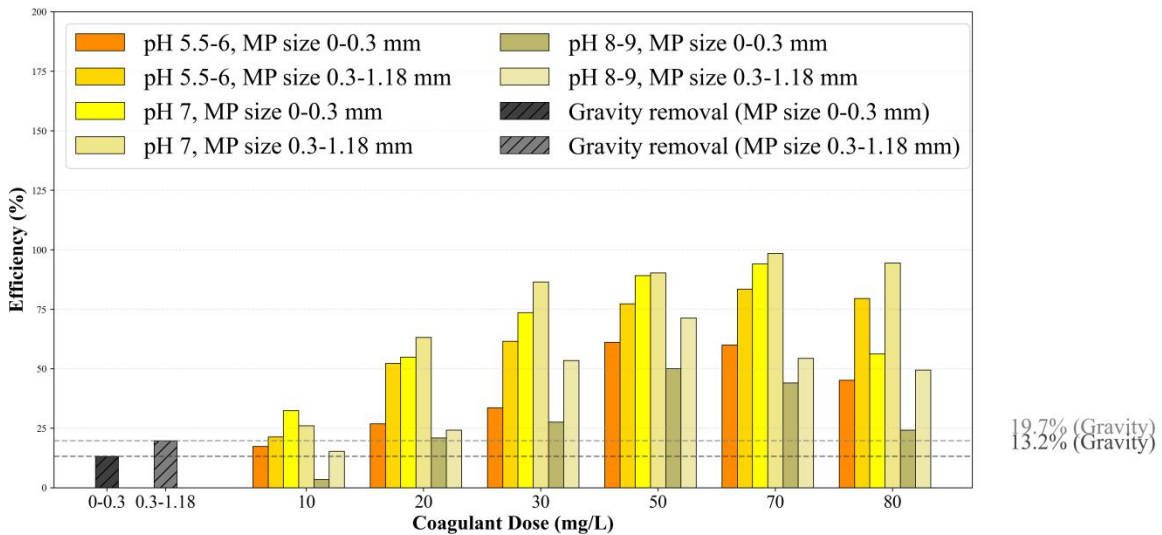
These values demonstrate the baseline removal potential that is present in the system before pharmacologic intervention, even though they are insufficient for treatment. A comparison of

removal percentages by natural settling and coagulation–flocculation for all four coagulants is presented in the figures below.

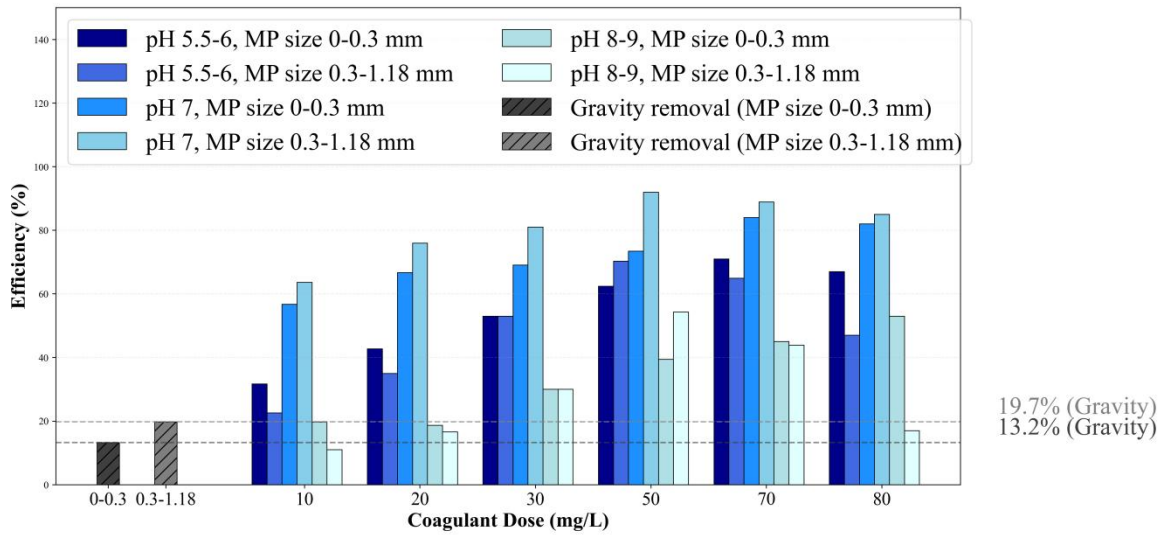
### Removal efficiency of PET MPs by Ferric chloride



### Removal efficiency of PET MPs by PAC



### Removal efficiency of PET MPs by Ferrous sulfate



### Removal efficiency of PET MPs by Alum

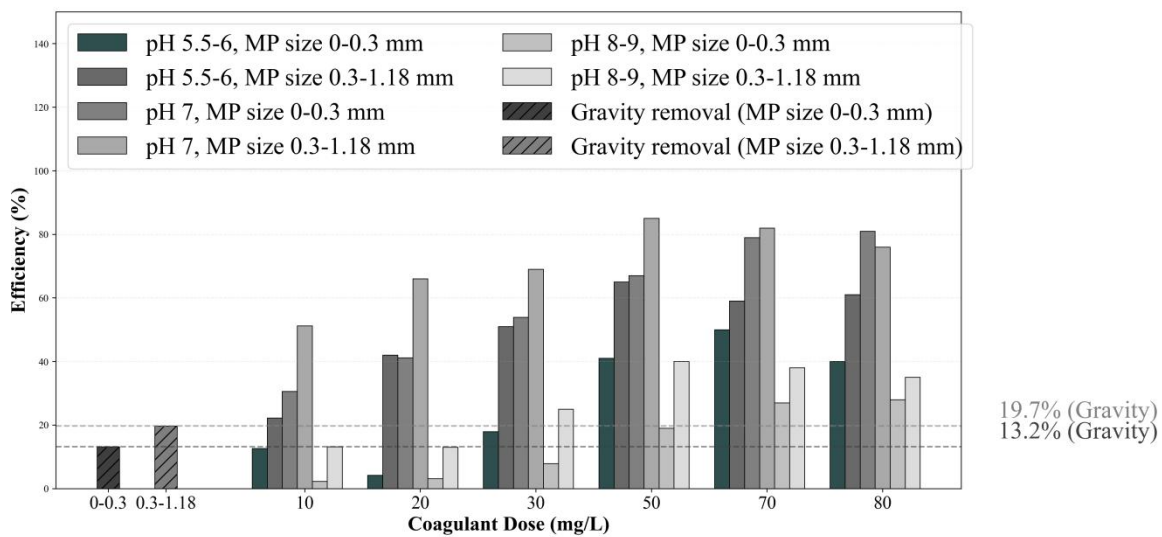
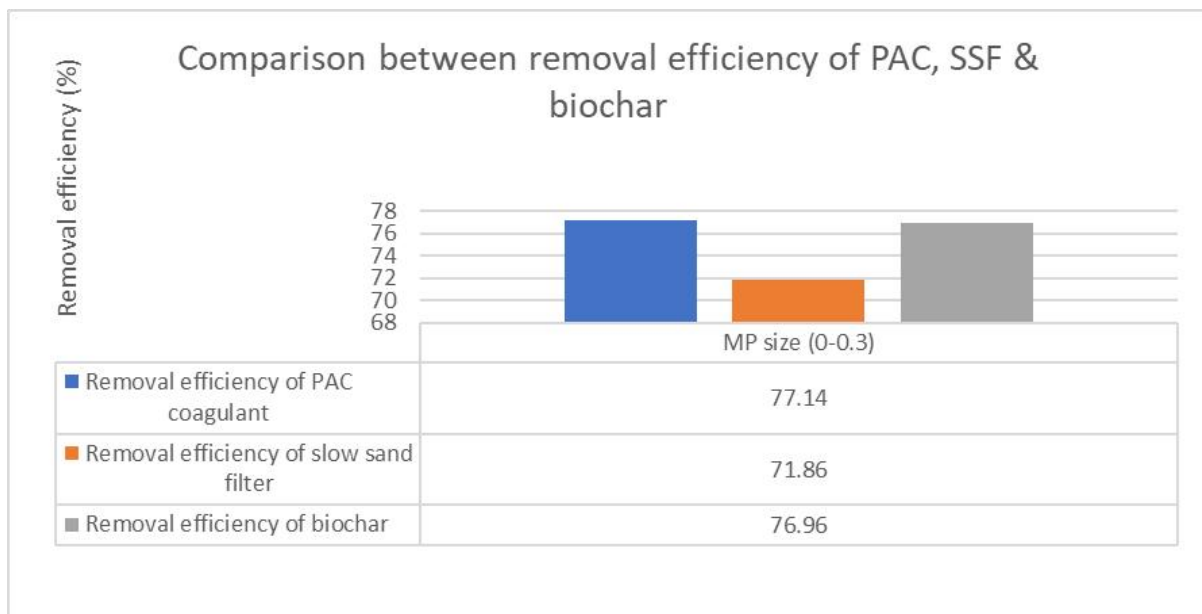


Figure 14. Removal efficiency of PET MPs by coagulants

## 4.2. Filtration result analysis for different sizes

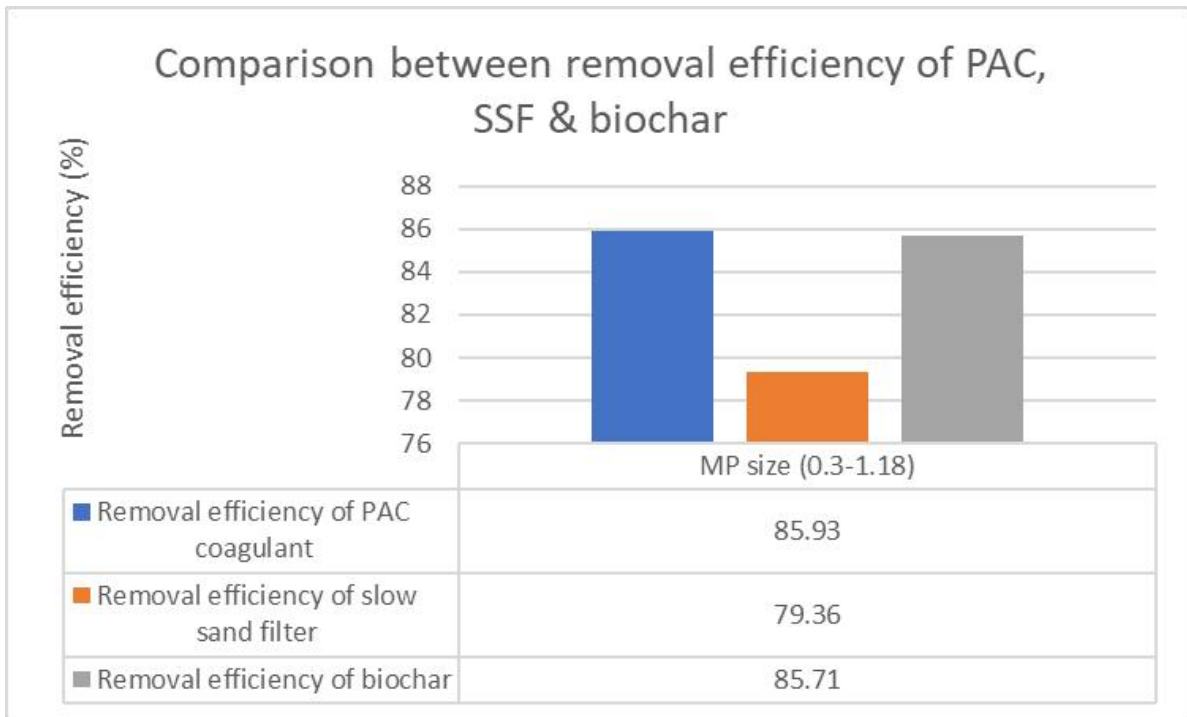
The comparison of removal efficiencies for microplastics (MPs) sized 0–0.3 mm shows that PAC coagulant achieved the highest efficiency at 77.14%, followed closely by biochar at 76.96%, while the slow sand filter (SSF) was the least effective at 71.86%. The high performance of PAC is likely due to its strong coagulation and flocculation properties, effectively aggregating MPs for removal. Biochar's comparable efficiency can be attributed to its porous structure and high surface area, making it a promising low-cost and sustainable alternative. Although SSF demonstrated the lowest efficiency, it remains a viable low-tech option, particularly in resource-limited settings. Overall, both PAC and biochar show strong potential for effective MP removal, with biochar offering added environmental and economic benefits. The graphical analysis is given below.



**Figure 15. Comparison between removal efficiency of PAC, SSF & biochar in MP size 0-0.3 mm**

For microplastics sized 0.3–1.18 mm, the removal efficiency was highest with PAC coagulant at 85.93%, followed closely by biochar at 85.71%, while the slow sand filter (SSF) showed a significantly lower efficiency of 79.36%. The results indicate that both PAC and biochar are highly effective in removing larger MPs, likely due to enhanced particle capture through

coagulation (in the case of PAC) and surface adsorption (in the case of biochar). The minimal difference between PAC and biochar suggests that biochar can serve as a sustainable alternative without major trade-offs in performance. On the other hand, SSF, though less effective, still offers moderate removal and may be suitable as a complementary or pre-treatment step, particularly in low-resource settings. These findings reinforce the suitability of both PAC and biochar for efficient MP removal, especially for particles in the larger size range. The graphical analysis is given below.



**Figure 16. Comparison between removal efficiency of PAC, SSF & biochar in MP size 0.3-1.18 mm**

## CHAPTER 5: CONCLUSIONS

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### 5.1. Findings of the study

Ferric chloride, PAC, ferrous sulfate, and alum were the four coagulants that were employed in this study's coagulation-flocculation procedure. The greatest percentage of MPs were successfully removed from the microplastic solutions by PAC, outperforming all other coagulants (84% of 0-0.3 mm PET MPs and 88.4% of 0.3-1.18 mm PET MPs). For smaller MPs, the average efficiency was 45.26%, whereas for larger MPs, it was 61.24%. With a mean efficiency of 45.56% for smaller MPs and 59.34% for bigger MPs, ferric chloride came next, demonstrating constant efficiency across all pH and dosage levels.

Aluminum-based coagulants outperformed iron-based coagulants in terms of clearance rates, while chloride-based coagulants performed better than sulfate-based coagulants. The ideal dosage for PAC was found to be between 58.7 and 61.4 mg/L using statistical analysis and machine learning techniques, and it functions best in slightly acidic to neutral environments. The two most important influencing factors were pH and coagulant dosage; coagulant type and MP size had very little bearing on these factors. This leads to the conclusion that high removal efficiency can be achieved under treatment conditions as long as pH and coagulant dose are optimally maintained, regardless of the coagulant type and MP size.

For two distinct MP sizes, this study went one step further and passed the PAC treated water separately through a slow sand filter and biochar. In both sizes (0-0.3 mm and 0.3-1.18 mm), biochar outperforms slow sand filters in terms of removal efficiency.

### 5.2. Limitations of the study

The impact of population density on microplastic (MP) abundance could not be clearly determined due to the rainy season in Bangladesh. Because of the high dilution during this period, the concentration of MPs in surface water was too low to perform count-based analysis. Handling such low MP concentrations also posed a risk of overdosing. Additionally, the laboratory lacked some essential equipment. There was a time gap between the coagulation-flocculation and filtration stages while setting up the filtration unit, during which residual MPs in

the treated water might have settled naturally. Furthermore, during filtration, some sand and biochar particles may have mixed with the final treated water.

### **5.3. Future scope of the study**

This study aimed to enhance the removal of microplastics through the use of different coagulants, yet there are numerous avenues for further exploration. Future research should also look into how microplastics interact with other contaminants such heavy metals, organic pollutants, and nutrients that are frequently found in wastewater and environmental settings. Given that microplastics both absorb and transmit contaminants, comprehending these combined effects may highlight more useful problems with treatment procedures. Additionally, research might be expanded to examine the effects of aging and the formation of biofilms on microplastics on their adsorption capacity and removal efficacy. To find out if coagulants can effectively remove both the particles and the absorbed contaminants, as well as to comprehend how the removal effectiveness fluctuates under various water quality situations, microplastics contaminated with pollutants can be examined during coagulation-flocculation processes.

This study can include an additional unit for the filtration process that will experiment with a sand and biochar unit in a single cylinder. From there, it can be determined the precise height of the biochar and sand by trial and error method where the unit will operate at its highest efficiency rate.

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