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Characterization and Removal/Treatment of PP Microplastics from Huangpu River

Hanqiu Yang[1*], Jiawei Lu[2], Zhipei Huang[3]

[1]*Washington University in St. Louis, St. Louis, USA*
[2]*Concordia International School Shanghai, Shanghai, China*
[3]*Chongqing BI Academy, Chongqing, China*
**Correponding Author. Email:Hailey.y@wustl.edu*

Abstract. Global plastic production has surpassed 400 million tons, yet only a little is being effectively recycled, leading to environment contamination. Among all the different types of plastics, polypropylene (PP) is one of the most abundant and severe in aquatic ecosystems due to its low density and other behaviors. This study focuses on PP microplastic pollution in the Huangpu River, a main water source for Shanghai, where concentrations of PP is 13-50% of detected microplastics in waters. With comparative analysis with other major rivers around the world, the Huangpu River is one of the most polluted river systems among all. To solve this problem, our study evaluated coagulation water treatment, specifically polyaluminum chloride (PAC) and polyacrylamide (PAM). Findings show that particle size, coagulant dosage and the pH level affected the removal efficiency, with PAC and PAM achieving up to 90% PP removal. Showing coagulation as a applicable method to decrease PP microplastic pollution in rivers.

Keywords: Huangpu River, Polypropylene, Chemical Coagulation

1. Introduction

The current global annual plastic production has exceeded 400 million tons and is expected to gradually increase along with industrial and consumer demands [1]. However, only 9% of the plastic produced globally is effectively recycled [2]. The persistent presence of plastic waste in ecosystems has led to widespread plastic pollution worldwide.

There are more than 5 trillion plastic particles floating in the ocean [3]. According to research statistics, the plastic recycling rates vary greatly in different regions around the world. In the European Union, due to the implementation of policies such as the EU Circular Economy Plastic Strategy, the plastic recycling rate is close to 30% [4]. In China, the plastic recycling rate is approximately 23% [5]. In the United States, only 5-6% of plastic is effectively recycled [6]. Plastics that have not been effectively recycled and reused mainly decompose into microplastics (synthetic polymer particles smaller than 5 millimeters) through weathering and mechanical degradation and are often released into rivers and surface water and eventually flow into the ocean, such as the Huangpu River [7].

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The main microplastic pollutants in rivers worldwide generally include polyethylene (PE), polypropylene (PP), polyvinyl chloride (PVC), etc [8]. As a thermoplastic resin with a high melting point and strong chemical resistance, PP is widely used in packaging, containers, medical tools, and household products, contributing to its environmental prevalence [9].

PP has unique ecological toxicity. Firstly, due to the relatively low density of PP (0.9g/cm³), it is more easily ingested by aquatic animals living in surface water [10]. PP can cause intestinal obstruction and gill damage in aquatic animals and eventually reach human consumers after accumulating through the food chain [11]. As PP is not biodegradable, it usually has more severe liver toxicity and poses a risk of triggering inflammatory responses and potential carcinogenicity [10, 12].

Since PP can have ecological risks, understanding its presence in water ecosystems is crucial----- especially in rivers, which act as a main pathway for microplastics to enter the ocean. Rivers not only support diverse aquatic life but also provide drinking water for people. One such example is te Huangpu River. The Huangpu River, a 113km long river that runs eastward through the heart of Shanghai, separating the city into the districts of Puxi(west) and Pudong(east) [13]. It flows from Dianshan Lake, which is part of the Taihu Lake Basin, and flows north into the Yangtze River delta and eventually into the East China Sea (Figure 1) [13]. The river averages 300-700m in width and drains a basin of approximately 24,000km^2, with an average discharge of 180m^3/s [14]. The Huangpu River has long served as Shanghai's "mother river", due to its importance in transportation, water supply and urban development. It includes the Jingze Reservoir and supplies the majority of Shanghai's drinking water— up to 70-80% of Shanghai's water intake— serving a population of roughly 6.7 million [15]. The river's water also sustains a variety of organisms, a recent environmental DNA survey identified 51 fish species in the Huangpu River [16]. Microplastic pollution is especially concerning: recent surveys report concentrations on the order of 1.8-2.4 microplastic particles per liter in Huangpu River water [17]—roughly double the levels observed in adjacent estuarine waters—and have detected microplastics in nearly 60% of sampled fish [18].

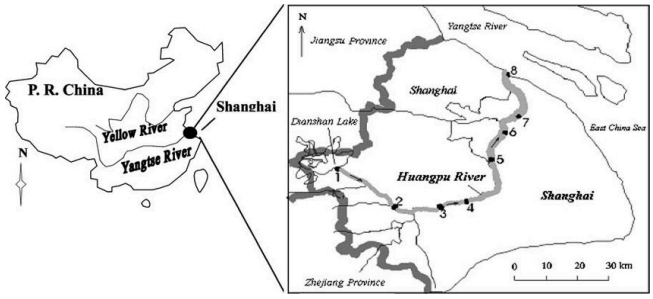


Figure 1. Map of the Huangpu River [19]

From being used as one of the most popular plastic materials, the inappropriate disposal of used PP can result in the river and other water sources in the form of microplastics. In the surface water of the upstream of Huangpu River, which is connected to Taipu River, Lanlu Gang River, and Jinze Reservoir, many types of microplastics are found in both seasons in all these rivers and reservoir that would feed into Huangpu River. From Figure 2, PP is one of the dominant microplastics found in all sites of the other rivers and the reservoir that shows 13% -50% abundance on the surface water [20].

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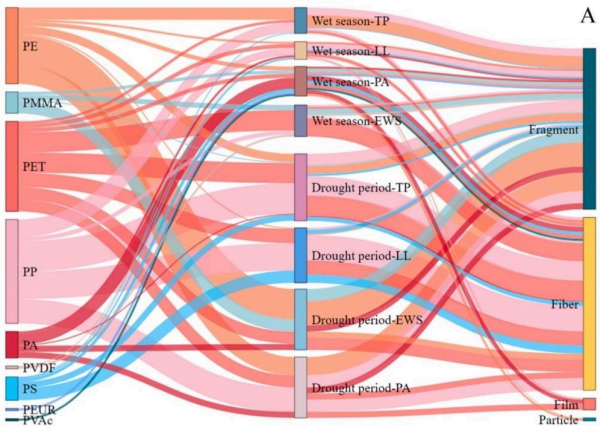


Figure 2. Types of microplastics captured on the surface water of the water sources at the upstream Huangpu River [20]

Microplastics, with polypropylene (PP) as a widespread and recalcitrant subtype, have permeated aquatic ecosystems globally, threatening biota and human health via water cycles [21]. While policy interventions (e.g., plastic bans, waste management regulations) are foundational for long - term pollution prevention, their efficacy is constrained by geopolitical complexities, slow implementation timelines, and inconsistent enforcement [22]. In contrast, treatment technologies offer immediate, site - adaptable solutions to intercept and mitigate microplastic loads in water systems—filling critical gaps where policies alone fall short.

A spectrum of treatment technologies shows promise: membrane filtration (e.g., ultrafiltration, nanofiltration) physically excludes microplastics based on pore size [23] and advanced oxidation processes (AOPs, e.g., ozonation, photocatalysis) degrade polymers via reactive species [23].

There are many studies conducted on plastic pollution in rivers and streams, but only a few research articles have found focusing on plastic pollution in the Huangpu River, also the current papers reveal the problem but left it unsolved by not mentioning and suggesting a suitable solution. While noticing the present micro-plastic issues in the Huangpu River, a workable water treatment solution targeting polypropylene in the river needs to be mentioned and discussed. Furthermore, with scarce discussions targeting the differences of MPs removal efficiency through different coagulants in the coagulation water treatment system, it is also important on providing more insights into the extinctions of PP removal efficiency by applying different coagulants. In order to address the research gaps on both the MPs in the Huangpu River and the PP removal efficiency through coagulation, this study focuses on two core criteria—removal efficiency for PP microplastics (quantifying mass/volume reduction) and cost - effectiveness (capital, operational, and lifecycle costs)—supplemented by resilience (performance under variable water matrices, e.g., salinity, turbidity) and scalability (bench - to pilot - scale feasibility).

2. Morphological characteristics of PP

Polypropylene, abbreviated as PP, is a polymer made from propylene monomers through addition polymerization. It is non-toxic, odorless, transparent in appearance and light in texture. Its density is 0.89 to 0.92 g/cm³, making it the thermoplastic resin with the lowest density [24]. Temperature has a significant impact on its impact strength. The impact strength is relatively high above room temperature, while the impact resistance is poor at low temperatures. Moreover, due to the presence of many tertiary carbon atoms with methyl groups on the main chain of PP [25], its weather

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resistance and aging resistance are poor, making it more likely to appear in rivers in the form of microplastics [25, 26].

There are two ecological risks to the microplastic pollution of PP in rivers: The low density of PP makes it more likely to exist in surface water rather than in river sediments [24, 27], which increases the contact time between PP and river organisms [28]. The molecular structure of PP indicates its high brittleness and makes it more prone to disintegrate into microplastic particles [25, 26], thereby increasing the difficulty of treatment [29].

In conclusion, our research should take PP fibers as the main research object [26, 30], and the microplastic treatment plan for the Huangpu River water area should focus on the surface water [27, 29]. But the specific data of PP is insufficient [31]. Existing studies mostly focus on PE and PS, and the proportion of PP morphology needs to be analyzed more precisely. Therefore, we also hope that there will be more research papers on water pollution problems led by PP in the future [31].

3. Overview of Huangpu River

3.1. PP abundance and behavior in Huangpu River

Polypropylene (PP) is one of the most commonly found microplastics globally. A meta-analysis of 126 estuaries worldwide found PP were the most frequently detected polymers, especially in Asia, where they dominated over 55% of sites [32]. This global trend is shown in the Huangpu River, where PP shows a relative abundance from 13% to 50% (Figure 3). PP occurs both as fragments and fiber forms and is used widely in commodities such as packaging materials, furniture, and car parts. In the Huangpu River, the relative abundance of PP was particularly significant when there was a slow flow of water. Because PP has a lower density than water, so it floats on water and will not be pushed downstream or mixed into the water mass as easily. This allows PP particles to float on the surface for prolonged periods, giving them the ability to accumulate and concentrate in surface water [20]. A recent study has identified the Human Development Index (HDI) as a dominant global factor influencing microplastic abundance. HDI index shows the combined impacts of economic development and living standards on microplastic abundance [33]. In regions like Shanghai, it has low HDI and higher concentrations due to rapid industrialization, urban runoff, and limited waste recycling. If the HDI value increase, there will also be a decrease in the abundance of microplastics being found. Asia has the world's largest microplastic abundance. This highlights the necessity of focused pollution control strategies in highly industrialized but economically developing areas like the Huangpu River basin.

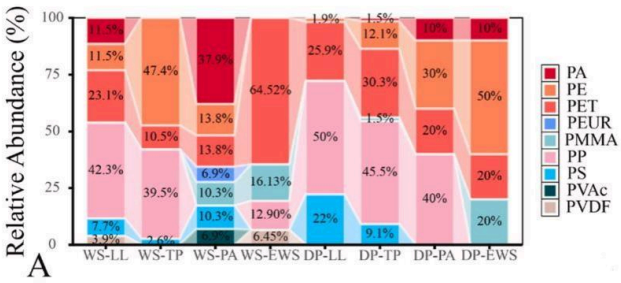


Figure 3. Polymer composition at different regions (LL, TP, PA, and EWS) of the Huangpu River during the wet season (WS) and drought period (DP) [20]

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3.2. Evaluating the Huangpu River in relation to other rivers

When comparing the abundance of microplastics across major river systems, the Huangpu River emerges as one of the most severely polluted areas. The concentration of microplastics in the lower reaches of the Yangtze River, which includes the Huangpu River, ranges from 1.36 x 10^5 to

9.03 x 10^7 items/m^3. This level is marked higher than the other major rivers worldwide: the Mississippi River in the United States (2.69 x 10^4 — 2.49 x 10^5 items/m^3), the Seine River in France (3.67 x 10^3 — 1.43 x 10^5 items/m^3), the Antua River in Portugal (4.15 x 10^4 — 2.49 x 10^5 items/m^3), and the Rhine River in Germany (5.83 x 10^2 — 9.68 x 10^4 items/ m^3). The most frequently reported microplastic is PP (Figure 4) [34]. These findings indicate that the Huangpu River contains one of the highest known microplastic abundances among global freshwater systems. Moreover, social factors are also a key in causing microplastic pollutions. This shows a need for targeted pollution control methods.

Detailed tests taken on the Changjiang system shows microplastic abundance generally decreases from upstream (12.70 ± 24.51 MP/L) through middle reaches (1.53 ± 1.15 MP/L), lower reaches (1.36 ± 0.61 MP/L), and into the estuary (1.71 ± 3.12 MP/L), before entering in the East China Sea (0.22 ± 0.27 MP/L).

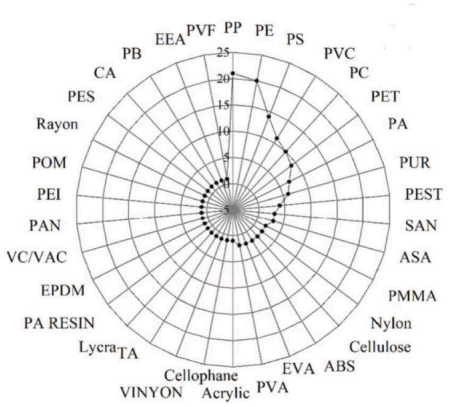


Figure 4. Polymer types and abundance [34]

4. Chemical coagulation

4.1. Mechanism of chemical coagulation

Chemical coagulation is defined as the process of adding chemicals to effluents to remove suspended solid wastes by neutralizing the repulsive electrical charges on particles, allowing them to aggregate into larger floccules for easier gravitational settling (Chemical Coagulation).

And it can be explained in four stages: charge neutralization, absorption bridging, sweeping flocculation, and sedimentation settling, that each stage is under the order of the whole coagulation processing (Figure 5) [35]. Charge neutralization happens when coagulants neutralize the MPs particles and the coagulant itself. Coagulants are the agents used for destabilizing the colloids and prompted on flocculation, and the most common coagulants are either aluminum sulfate or iron sulfate, meaning that they are based on either aluminum or iron [36]. So, in the charge neutralization, the positively charged aluminum ions on the coagulants bind with the negatively charged MPs to reach neutralized stages for both ends of the reaction, the process has reduced the

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electrostatic repulsion between the MPs, enabling them to aggregate better and form larger flocs in the later steps. Absorption bridging leads the coagulants to attach onto the surface of the MPs in the solution that connect and aggregate as much MPs as possible and ensuring the cohesion in forming flocs. After having the flocs formed from the MPs, sweeping flocculation collects the small left-over MPs on the way in water when coagulant attaches onto them to create larger and denser flocs. At the end of coagulation, the flocs settle to the bottle of the container and physically trapped and removed [35].

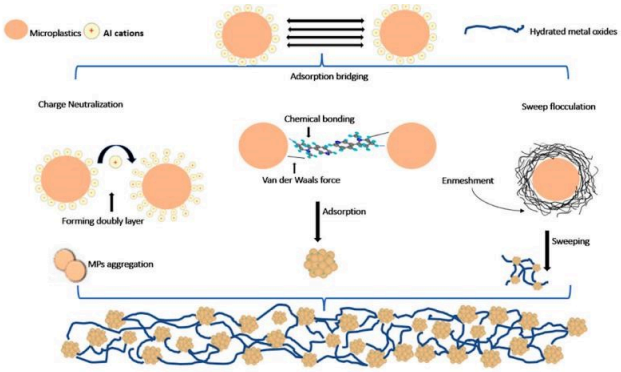


Figure 5. Mechanism of chemical coagulation [35]

PP as one of the highly used plastics in the world for people daily life usage has become one of the dominant MP in the river from the household trash [9], so the attention on the removal efficiency of PP through coagulation is needed throughout the research. The initial size of the

MPs shows significant different removal efficiency for the four MPs: PE, PS, PP, PET, and PVC.

4.2. Particle size effect on removal efficiency

From Figure 6, each MPs must be at least 25 μm to reach at least 50% removal efficiency, also for PP, the size of its initial condition is better to be bigger than 25 μm for a more efficient coagulation removal [37].

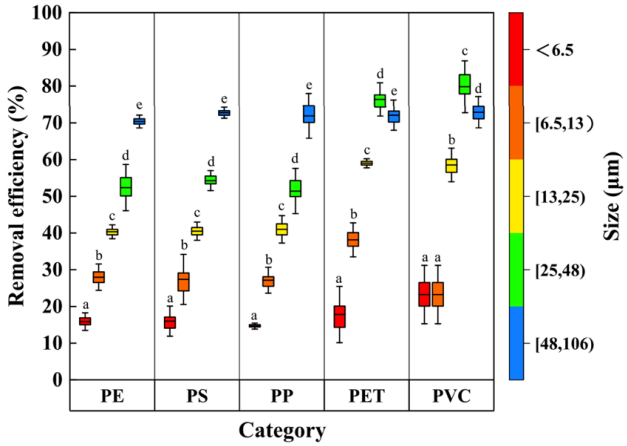


Figure 6. Removal efficiency of different sized MPs [37]

The more precise calculation of size on removal efficiency is shown in Figure 7. The removal efficiency of MPs with size <6.5 μm, [25,48) μm and [48,106) μm were 16.17 ± 1.17 %,50.33 ±

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0.60 % and 71.67 ± 0.17 % respectively. In the coagulation process, the size play an important role on the MP removal performances.

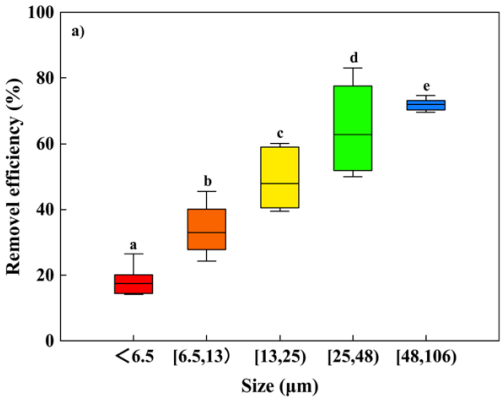


Figure 7. Average removal efficiency of different MP size [37]

4.3. Coagulant

There are many coagulants available for application in every coagulation process; therefore, choosing the most effective one is crucial. And from what is presented in Figure 8 by comparing

Polyferric Sulfate (PFS), Poly Aluminum Chloride (PAC), and the two combinations with Polyacrylamide (PAM) shows the best MPs removal efficiency under the application of the company of PAC and PAM. However, it is noticeable for all of them resulting in the same turbidity removal efficiency (Lee et al., 2024). Turbidity is calculated photochemically by measuring the scattered or absorbed light at a given intensity, which includes any impurity particles in the solution [38].

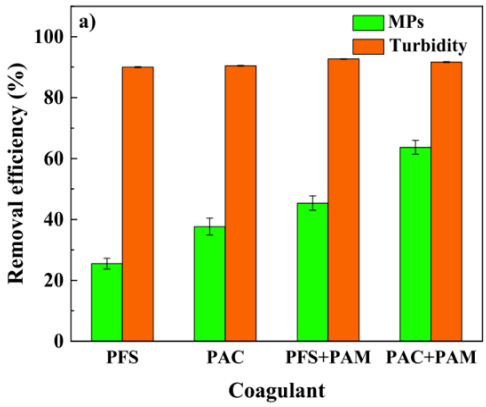


Figure 8. Differences in MPs and turbidity removal efficiency of different coagulants [37]

Since PAC+PAM shows the best presentation on MP removal, knowing how each has performed on PP provides more accurate data to be discussed. Aluminum-based coagulants have already shown a superior efficiency on removing MPs than iron-based coagulants, which PAC also shows a terrific job on the MPs removal that it can achieve up to a rate of over 90% MP removal on PP and PE.

The coagulant dosage plays a crucial role on affecting the results for coagulation. When testing from 10 mg/L to 300 mg/L concentration of PAC, there's a decrease on turbidity when coagulant increase from 50 to 100 mg/L with increasing turbidity removal efficiency and increasing MPs removal efficiency Figure 9a. But an overdose happens at 200 to 300 mg/L PAC doses, giving

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negative turbidity removal efficiency and an occurrence of re-stabilization. 150 mg/L PAC dose is the peak performance on 87% microplastic removal rate and 40% turbidity removal efficiency [35].

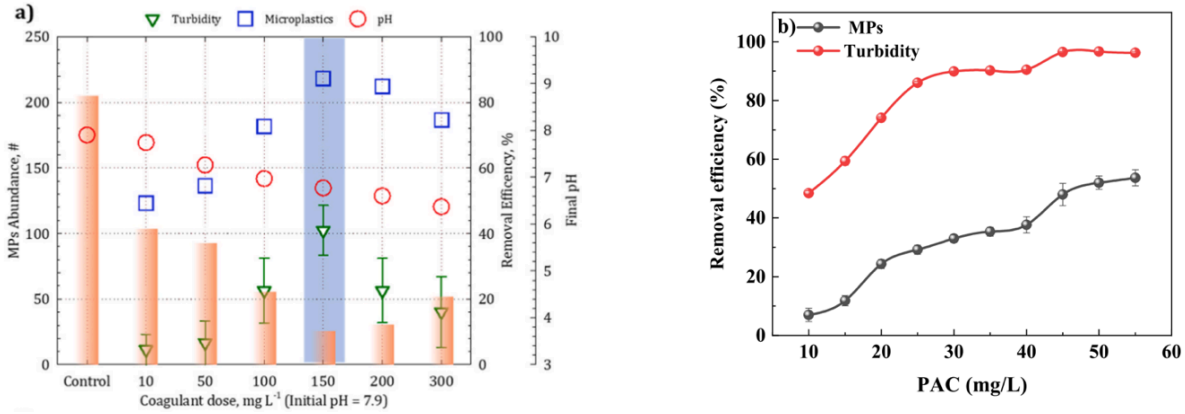


Figure 9. MPs and Turbidity removal efficiency of varies PAC coagulant dosage concentration [35, 37]

Meanwhile, in Figure 9b, the dosage range of PAC for a high MPs removal efficiency shows an agreement with each other. When the dosage of PAC was <20.00 mg/L, the removal efficiency of MPs was <20 %; when PAC was 20.00–40.00 mg/L, the removal efficiency increased slowly and lower than 40 %; when PAC was >40.00 mg/L, the removal efficiency reached >50 %, which that a greater than 40 mg/L is needed for reaching a higher removal efficiency [37].

Even with the correct coagulant dose, the initial pH can affect the process on coagulant hydrolysis mode, surface charge of the MPs, floc size, and other related factors of the process.

In Figure 10, pH 9 is presented as the best pH for reach the lowest 0.29 NTU turbidity and a greater than 90% MP removal efficiency rate.

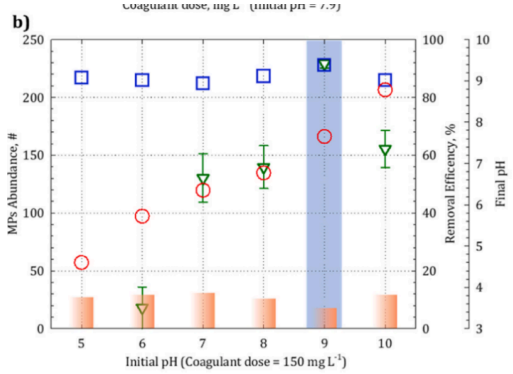


Figure 10. MPs and Turbidity removal efficiency of varies initial pH using PAC coagulant [35]

Under coagulant dose of 150 mg/L and pH 9 the tested PP removal efficiency is averaged around 90%, which is considered a very excellent job on separating the MPs, and the average size of the 50% of the remaining MP in the solution is in between 25 to 45μm, which applies into the concept that the size of the MP affects their removal from using coagulation [35].

Similar to PAC, PAM coagulant presents as high as 65% of MP removal efficiency [37]. According to the high MP removal efficiency, PAM has proven with excellent job on flocculation process throughout the coagulation treatment on polyethylene (PE). Comparison on the flocculation

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index is needed to find the most efficient PAM coagulant. While there are anionic PAM, cationic PAM, nonionic PAM, and amphoteric PAM that all combined with magnesium ions, the flocculation index varies through time [39]. From Figure 11a, anionic PAM shows the highest FI with the maximum of 7.2, which exceeds the maximum FI of the other PAMs that average between 4.6 to 4.8. Anionic PAM also shows the highest removal percentage of the highest floc size among all the other PAMs (Figure 11b). It can produce the highest 57.19 μm floc size with the peaked removal volume. Even though the other three PAMs can form floc sizes bigger than that of anionic PAM given by the graph, but the removal volume is really poor that anionic PAM still outshine all the other PAMs in the comparison by its ability to most efficiently removing the PE with a relatively big floccules in the process [39].

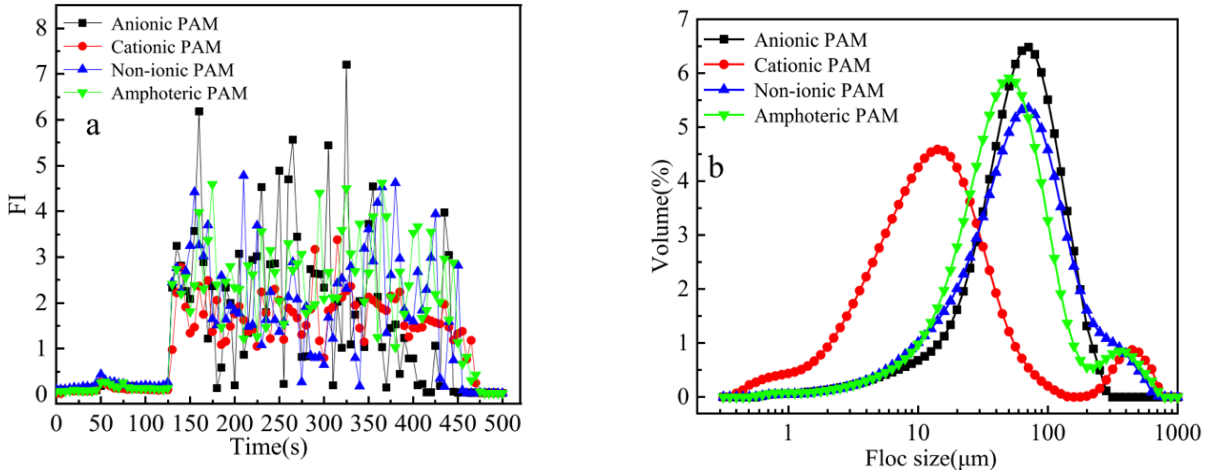


Figure 11. Flocculation index (FI) and percentage of different floc sizes based on different PAMs through time [39]

Having PAM as one of the dominant efficient coagulants to be applied in the process of coagulation on MP removal, the suitable dosage concentration is measured in [37] and [39]. Figure 12a focused on the correlation of PE removal efficiency within the dosage of 1-6 mg/L anionic PAM and concluded that the optimal dosage of PAM by looking at the removal efficiency is 5 mg/L, which results in the highest 84.9% ± 3% removal efficiency. The similar range of optimal dosage of PAM is also shown in Figure 12b that MPs removal efficiency increased slowly after 15.00 mg/L with some decrease in the removal efficiency of turbidity, so the outstanding dosage under the testing from 1-25 mg/L dosage is 15 mg/L. Indeed, Figure 12b also shows an increasing MP removal efficiency tendency from 1-6 mg/L that supports the testing in Figure 12a.

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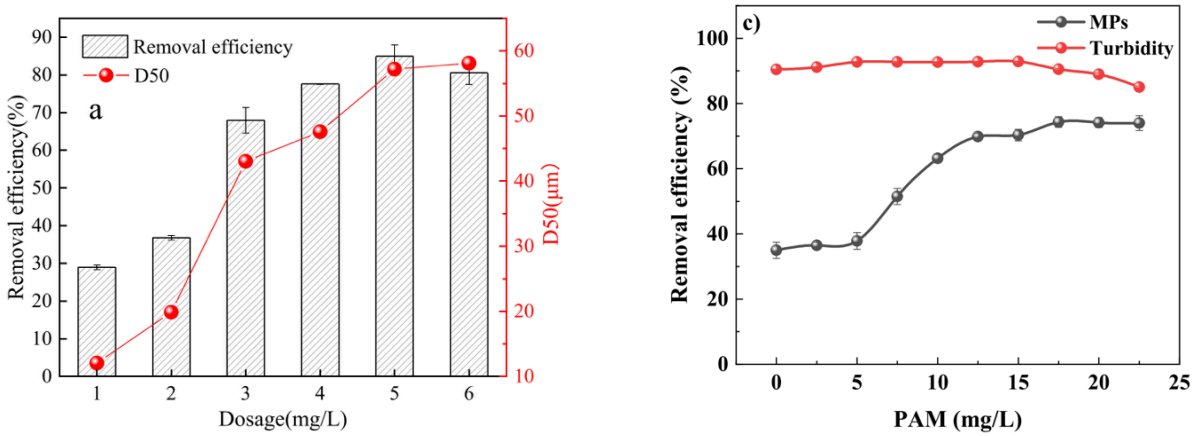


Figure 12. Removal efficiency percentage on different PAM dosage concentration [37, 39]

From many papers, PAC and PAM have shown magnificent work on MP removing through the process of water coagulation with their ability to form large floccules and successfully trap up to 90% of PP and other MP lastly, which also shows good job on clearing the turbidity of the water solutions throughout the experiments. According to the research, PAC and PAM are then the optimal choices for separating and empty the loaded MPs, especially PP, found in the Huangpu River nowadays using the mechanism of coagulation.

5. Conclusion

This study shows that polypropylene microplastics is a major pollutant in the Huangpu River, with concentrations higher than other global river systems. PP is persistence, low density and toxic, its presence has serious risks to organisms and to the safety of Shanghai. Through analysis of coagulation treatment, polyaluminum chloride (PAC) and polyacrylamide (PAM) are the most effective of removing PP's, approaching 90% under optimal dosage and pH conditions. These results show coagulation as a practical and cost effective method to reduce PP microplastic in water systems. Future research should expand deeply into the seasonal monitoring and integration with different treatment technologies to even more enhance the removal efficiency.

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