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Full Tiltle:

The Use of an Alum-Based Coagulant "Bucochem" for the Cleaning of Natural Water from Styrene/Divinylbenzene Microplastics

Short Title:

"Bucochem" for the Cleaning of Natural Water from Microplastics

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Abstract

The efficiency of an alum-based coagulant BUCOCHEM in removing styrene/divinylbenzene microplastic particles sized between 400 and 500 µm from water has been investigated. It was found that the coagulant promotes better sedimentation and compaction of the plastic particles, ensuring the formation of a dense, more stable, and more easily removable sediment layer. 0.1 wt % of the coagulant leads to a decrease in the height of the polymer sediment layer by 14% after 48 hours, as compared to the coagulant-free sedimentation. Furthermore, the former sediment appears more compact and stable.

Additionally, the coagulant led to a faster initial sedimentation of microplastic particles. Although the rate of sedimentation decreased when the coagulant was added, this effect was not crucial for the efficiency of cleaning.

The optimal content of BUCOCHEM was found to be 0.05-0.075 wt%. At this concentration, three-dimensional coagulant flocs can form, adsorb microplastic particles, and trap them in a compact and stable precipitate layer, which effectively resists secondary resuspension.

Keywords: microplastic particles; decontamination of water, coagulation; alum-based coagulants; sediment compaction

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Introduction

Plastic particles are quite stable and persistent in the environment, and their natural decomposition in water lasts from several months to decades. It should also be mentioned that once a plastic pollutant enters water, it often breaks down into fragmented microplastic particles, which increases its environmental harmfulness (Evangelos, 2020; Lapoint, 2020; Aziz, 2023).

Since "microplastics" are artificial materials with particles sized between 1 μm and 5 mm, they can actively adsorb other pollutants on the surface, which increases their negative environmental impact. It should be understood that microplastics can enter the environment in the form of small particles originating from various additions to consumer goods (granules, fibers, etc. added to cosmetics, housekeeping chemistry, and other items) or it can appear as a result of partial decomposition of bigger plastic items like plastic bags, other packaging, details of various machines and mechanisms, etc.

Microplastic (MP) pollution in the environment has numerous adverse effects and has been detected in all aquatic environments, including seas, oceans, rivers, lakes, and even groundwater, as well as in water sources used for the production of drinking and technical water (Pan, 2019; Di, 2018; Panno, 2019, Xiong, 2018).

Various classical water cleaning technologies can be applied to remove MP particles, including filtration/sedimentation alone, coagulation/flocculation followed by filtration/sedimentation/floatation, and others. However, their cleaning effectiveness critically depends on the size of the particles to be eliminated, and it rapidly deteriorates as the particle size decreases. Therefore, aggregation of MP particles seems reasonable in the context of improving their removal from water.

The use of various alum, PAC, and ferric-based coagulants – either alone or combined with flocculants – significantly enhances the efficiency of removal of microplastic, particularly for weathered plastic particles. Commonly, the removal of smaller and weathered particles is better than that of greater and intact particles, while in the context of coagulants' composition,

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alum/PAC/$Al_2(SO_4)_3$-based coagulants show a higher performance than the ferric-based agents (Lapionte, 2020; Aziz, 2023; Tang, 2022; Zhou, 2021]. As reported by Lapointe (2020), alum and PAC coagulants demonstrate similar performance in removing various pristine MP particles. Its efficiency ranged between 65 and 82%, depending on MP composition. In the case of weathered MP, it increased, for some types of MP, up to 98-99%. Aziz et al (2023) also reported the highest coagulation efficiency of alum and aluminum sulfate-based agents, which reached 100 % for some types of polyethylene MP particles. Ferric-based coagulants can also ensure such performance, but at a sufficiently higher dosage. As found by Tang et al (2022) and Zhou et al (2021), removal performance for polystyrene-based MP was lower than that for polyethylene particles, while PAC was still more effective than ferric, and the removal of smaller particles was more complete than in the case of larger MPs.

In this context, it seemed interesting to investigate and compare the coagulation dynamics and efficiency of the locally-made coagulant BUCOCHEM in removing MP particles from water.

Materials and Experimental Methods

This investigation was conducted on a model disperse system made of the ground particles of Copolymer-8B (a copolymer of styrene and divinylbenzene, PS-DVB) and distilled water. BUCOCHEM by LLC “Modern Environmental Technologies” (Ukraine), produced in 2023, lot number 09102023, was used as a coagulant. The technical specifications of the polymer and coagulant are given in Tables 1 and 2.

Table 1. Technical specification of Copolymer-8B.

Parameter	Value
Appearance	Inert spherical colorless grains
Granulometric composition, μm	400÷800

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Mass fraction of the polymer, %	> 95
Bulk weight, g/cm^3	0.55 – 0.7
Genuine density, g/cm^3	1.05 – 1.07
Water content, %	< 1.0

84 Table 2. Technical specification of BUCOCHEM.

Parameter	Value
Appearance	Colorless or light yellowish-greenish liquid
Mass content of Al, %	7.47 – 8.48
Mass content of Al_2O_3, %	14.1 – 16.0
Relative basicity, %	56 – 75
Insoluble residue, wt%	< 0.1
Density, g/cm^3	1.15 – 1.39
Mass content of Fe, %	< 0.05
Mass content of Cl^-, %	8- 22
pH	1.5 – 4.0
Viscosity at 20 ^oC, mPa*s	10 – 65

85

86 Sieving the MP fraction, evaluation of the size and shape of single and aggregated 87 particles.

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A 400-500 μm fraction of Copolymer-8B has been sieved out and separated for further investigation. The size, shape, and configuration of the particles and/or their aggregates were evaluated visually using an MBS-9 microscope.

Sedimentation and compacting of MP particles.

The jar test was conducted to compare the initial settling rate and to observe formation, hydrophilization, and further compacting of the sediment layer. A 5 g sample of the polymer was poured into a glass beaker and mixed with 10 mL of distilled water. The mixture was stirred for approximately 1 minute, until it appeared visually uniform, and then transferred to a narrow and tall graduated glass cylinder up to the zero mark.

The dispersion phase of a just-prepared mixture consisted of a single granulometric fraction sized 400-500 μm, without coagulated flocs, which require some time to form. That is why, a distinct visible margin between the sediment layer and the transparent liquid formed within 10-20 seconds. Then, this margin descended until the primary stabilization of the sediment layer occurred.

The rate of sedimentation was determined as

$$W = \frac{h}{\tau},$$

where h is the height of the clarified liquid layer above the sediment (mm), measured over time τ, s. To minimize individual reading errors, the values of h was determined by five independent observers, and then their readings were averaged.

After 2-3 minutes of initial settling, the suspension separated clearly into a lower sediment layer and an upper transparent liquid layer. In all experiments, the initial height of the sediment layer was 6.9 cm at 20 °C.

Determination of hydrophilization and compacting of the polymer suspension.

After initial settling, the MP suspension layer underwent hydrophilization and secondary compaction resulting in changes in its structure and volume/height. These changes were

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evaluated at 0.5, 6, 24, and 48 hours after initial settling. All experiments were repeated 7-10 times and then they results were averaged.

Sampling the polymer particles for microscopic examination.

When needed, a thin glass microprobe was used to take a sample of the polymer suspension from the middle of its phase. Then, a sample was placed on the microscope slide, covered, and examined visually.

Results and Discussion

Even without a coagulant, the surface of MP particles is getting slightly hydrophilized, forming a hydrate layer surrounding each particle. This "false hydrophilization" of a totally hydrophobic surface occurs due to the residual surfactants/emulsifiers stuck in the bulk of the polymer during its synthesis. As these residual compounds are mostly ionic, they facilitate some secondary hydrophilization of the plastic surface (Mallegol, 2002).

Such hydrophilized particles can aggregate, forming globular ensembles that capture some water in the interparticle space, resulting in some swelling of the sediment layer. This process is rather slow, as the amount of the residual surfactants/emulsifiers is low.

The thin, translucent hydrate layer and the globular, aggregated MP ensembles were observed microscopically in the samples taken from the sediment layer. Over time, such aggregated particles are getting compacted, reducing the interparticle distance and forcing the trapped water out of the interparticle spaces, which results in an overall decrease in the height and volume of the sediment layer.

It should also be mentioned that not all particles are getting hydrophilized. Perhaps, those consisting of a very low amount of the residual surfactants/emulsifier in the surface layer remain hydrophobic. As a result, they do not coagulate and settle individually.

Adding a coagulant to the system intensifies all these processes, as this agent promotes better hydrophilization of the particles. As a result, more intense and rapid hydrophilization, and

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a subsequent deeper compacting of the sediment layer occur. These processes are represented in Fig. 1.

As reported by Waldschläger K. and Schüttrumpf H (2019), loose and linear aggregates of plastic particles compact more slowly than either non-aggregated individual particles or denser, globular aggregates. This finding agrees with our results, which demonstrate that aggregated MP ensembles shift from loose and linear to denser and more globular forms (see further results and discussion below). This structural rearrangement promotes more compact packing of the MP ensembles in the sediment layer, resulting in a decrease in its height and volume. Faster and more efficient sedimentation of globular, dense aggregates with higher fractal dimensions has also been observed by Zheng et al (2011). Similar processes of sediment compaction and regrowth have also been reported by Li et al (2021) for low-density polystyrene MP beads.

The rate of settling also depends on the amount of coagulant added. The density of MP particles is only slightly higher than that of water (see Table 1). When a secondary hydration layer forms around a plastic particle, the density of this hydrophilized object decreases further, approaching that of water and slowing the settling. Furthermore, when loose and large flocs are formed, they encounter greater hydrodynamic resistance as they settle, leading to additional slowing of the process.

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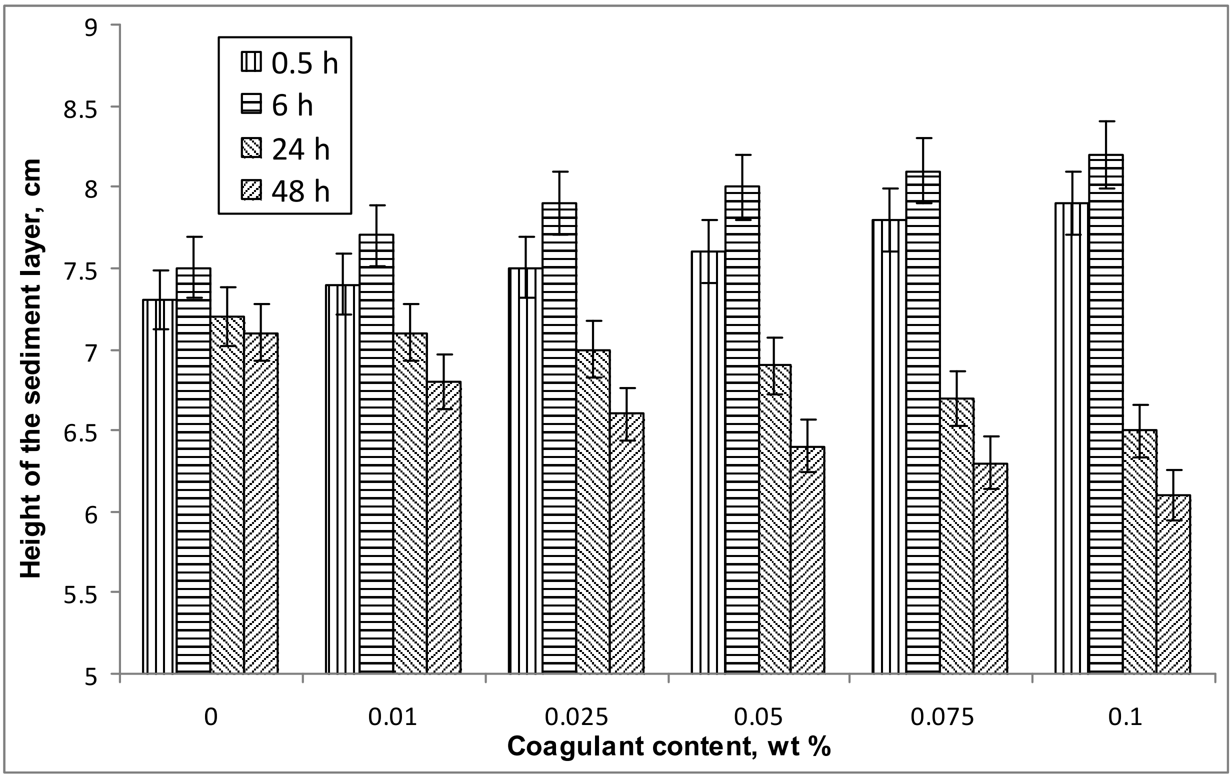

Figure 1. Heights of the polymer sediment layer without/with a coagulant admixture after 0.5, 6, 24, and 48 hours. The relative error of the sediment layer height determination was 2.5%.

As shown in Fig. 2, the settling rate decreased as the coagulant content increased. It should also be noted that without a coagulant, the resulting sediment was rather dense and appeared to contain a minimal amount of immobilized water within. Also, agitation caused the sediment to disperse, but it settled rapidly after the agitation ceased. An initial height/volume of the sediment layer restored within 5 min after agitation; however, the layer remained unstable, causing the system to become turbid even after minor shaking or disturbance.

Once a coagulant is added, the rate of settling decreases (Fig. 2). On the other hand, in this case, the settlement forms a denser and more compact layer, and the external disturbance does not easily lead to its rising. As mentioned above, it is caused by a larger size of the coagulated flocs and an adhesion between aggregated particles that develops during the settling and formation of the sediment. This process is completed within 24 hours, after which the

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settlement solidifies into a single layer that does not break into separate particles or flocs upon regular stirring or shaking.

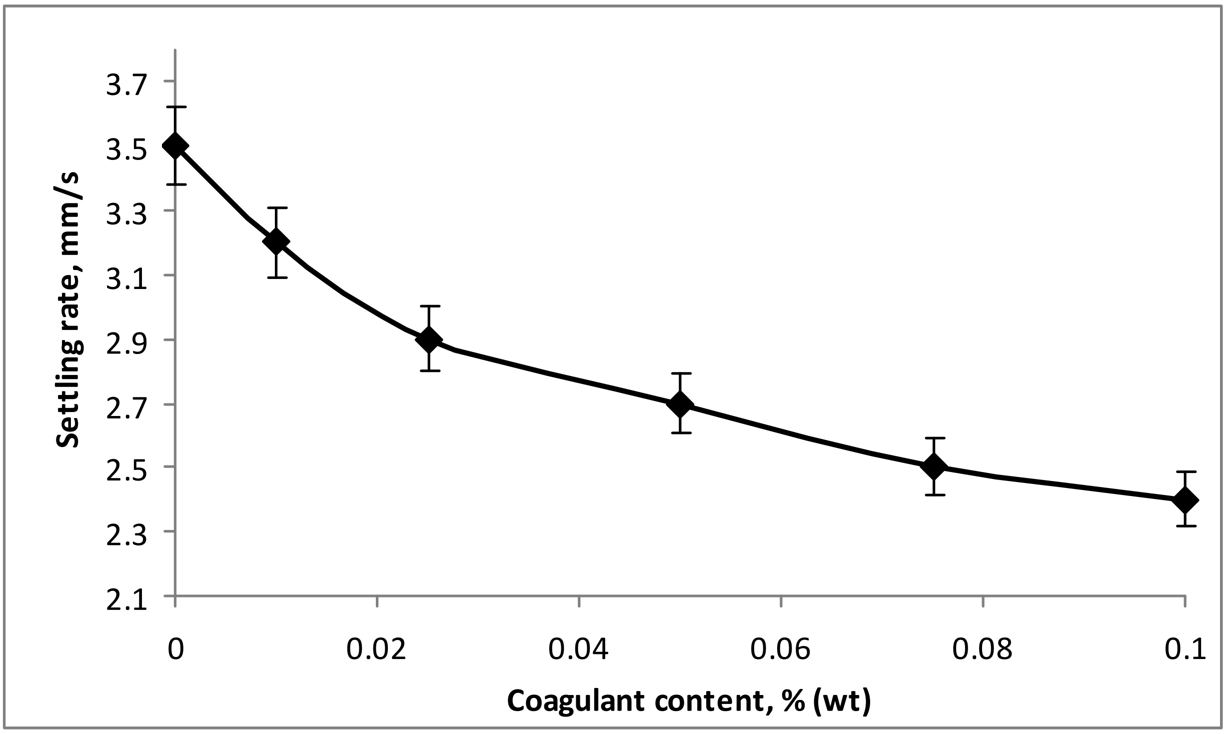

Figure 2. Dependence of the rate of settling of the MP particles on the coagulant content. The relative error of determination was 3.5 %.

Similar results were reported by Nguyen (2021) and Alpergün et al (2025), which observed the deceleration of the settling rate of various MP particles, depending on irregularities in their surface shape and/or aggregation. The more weathered or irregular the particle's surface, or the more aggregated they are, the slower they would sediment. Particular settling rates reported by Nguyen (2021) were quite close to our data. The settling rate reported by Alpergün et al (2025) for polystyrene of a similar size was greater, but this difference could be caused by different polymer expansion grades and differences in the densities of our PS-DVB polymer and pure polystyrene used by Alpergün et al (2025)

It is important to note that the overall time required for nearly complete sedimentation, whether or not a coagulant is used, is relatively short. While our study did not specifically assess

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the completeness of MP removal, Li et al (2021) reported that this can be accomplished within 30 minutes. Therefore, sediment compactness and resistance to secondary resuspension are key factors influencing the efficiency of MP removal from water. In this context, our results are promising, as even a low concentration of BUCOCHEM significantly stabilizes the sediment.

This stabilization occurs as a result of forming a three-dimensional network within the sediment layer. In the absence of a coagulant, the sediment can be easily resuspended even after 24 hours, breaking into individual particles or small aggregates that resettle separately. When a coagulant is used, the sediment remains stable and does not resuspend after shaking, remaining clearly separated from the liquid.

Microscopic observation of the sediment samples proved that the shape and pattern of the flocs changed depending on the coagulant content. As mentioned above, a coagulant promotes better hydrophilization of the surface of MP particles, leading to a more intense interparticle interaction. As a result, the particles can better aggregate and grow into longer, more branched, closely compacted, and more stable ensembles. Indeed, predominantly simple linear ensembles were observed in systems with low concentrations (below 0.02 wt% coagulant) (see Fig. 3, A). As the coagulant content increases, more complex, longer, and branched three-dimensional flocs form in the sediment (Fig. 3, B and C). First, they remain separated (Fig.3, B), but then bind together, forming massive aggregates that extend across the entire sediment layer (Fig. 3, C). This way, the flocs can efficiently interlace and aggregate together, forming a stable sediment that is easily removable and efficiently resists resuspension.

The most efficient concentration of BUCOCHEM was determined to be 0.05-0.075 wt%. At this range, relatively large three-dimensional flocs form and bind together into a stable sediment, which does not resuspend upon stirring. At lower concentrations, the forming flocs are smaller, and the sediment lacks sufficient stability against resuspension. Increasing the coagulant concentration above 0.075% does not provide additional stabilization of the sediment.

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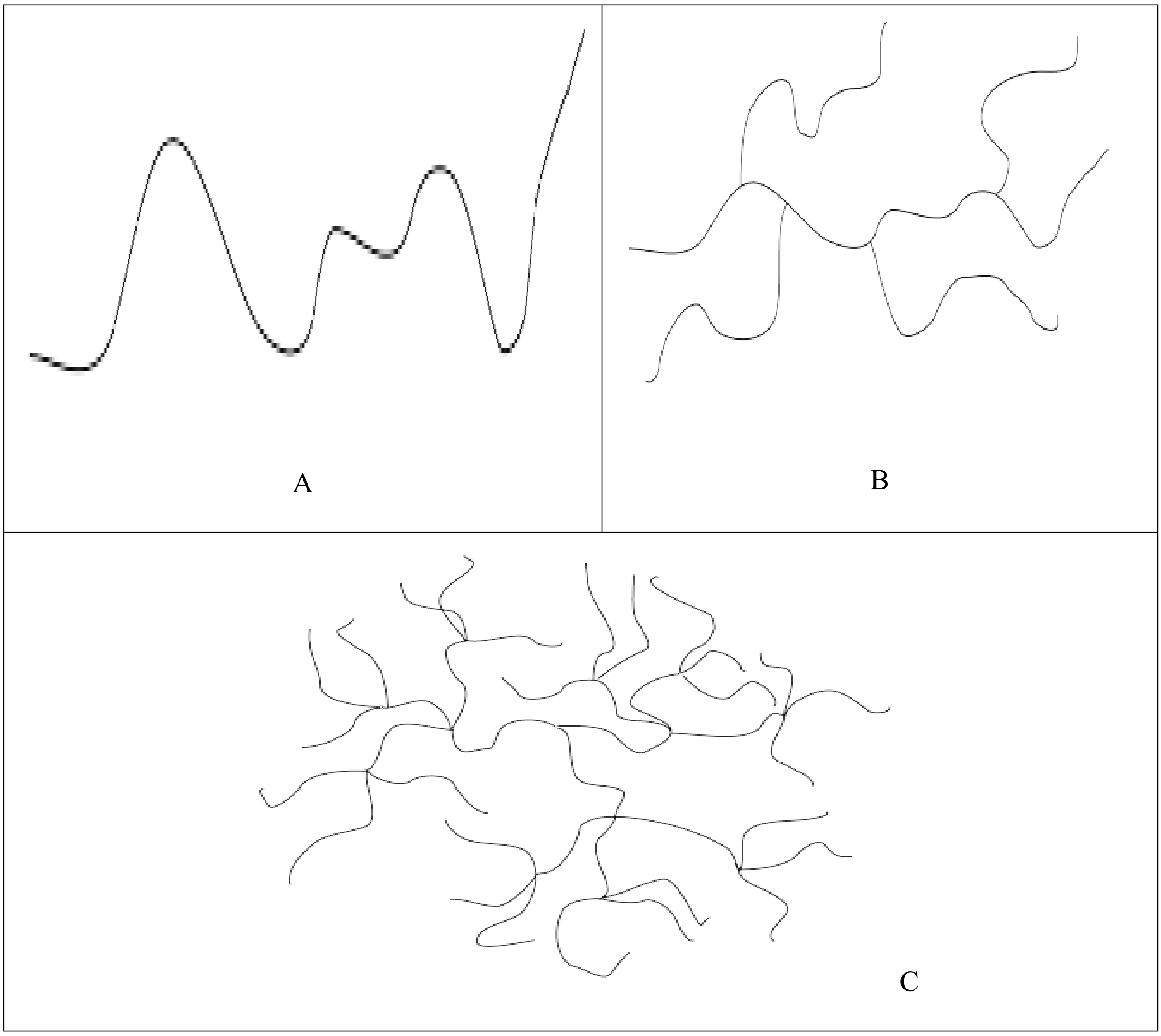

Figure 3. Spatial pattern of the sediment flocs: A – simple and linear (< 0.02% of a coagulant); B – longer linear with initial branching (0.02-0.05%); C – developed branching (>0.05%).

Similar processes are described in a review article (Sun, 2025), where the authors discuss the details of alum-based floc formation, development, and compacting. Due to a combination of aluminum oxo-hydroxides formation, polymerization, and flocculation, the spatial geometry of the flocs changes from linear to planar and then to three-dimensional. The precipitate initially forms as an amorphous, bulky phase, which then undergoes compaction and solidification/crystallization —the same processes have also been observed in our experiments.

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As reported by Zhou et al (2024), branched three-dimensional flocs (like those shown in Fig. 3, C) are highly effective at removing suspended particles. In addition to adsorption mechanisms, these flocs can mechanically capture and trap particles within the "caves" formed inside their bulk structure.

It should also be noted that the most effective water cleaning performance of BUCOCHEM, reached at 0.05-0.075 wt% of the coagulant, is comparatively competitive. Some other alum-based agents used by Sun et al (2025) and Saritha et al (2017) have demonstrated the best cleaning efficiency with respect to natural turbidity of water at concentrations ranging between 0.01 and 0.05 wt%. Since natural turbidity of water is mostly caused by the clay and organic (algae) particles, which are either more hydrophilic and bear higher electric charge (clay) or rather larger (algae), our results featuring 0.05-0.075 wt% as the most optimal content of BUCOCHEM for the removal of lower charged and more hydrophobic MP, seem fair.

Conclusion

If a coagulant is not added to an aqueous PS-DVB suspension, MP particles become hydrophilized, quickly lose sedimentation stability, and form a sediment layer without further solidification. This layer can easily be resuspended by simple stirring or agitation, making the removal of sedimented plastic particles difficult.

If a BUCOCHEM coagulant is added, it causes enlargement of the coagulated flocs, slowing their settling and increasing the volume of the sediment layer. Furthermore, it undergoes secondary self-compaction, forcing out the water that was initially trapped during the sediment formation, and finally solidifies, preventing the secondary resuspension. Hence, this compact sediment can easily be removed during water/wastewater treatment.

The most effective concentration of BUCOCHEM was found to be 0.05 – 0.075 wt%. With such contents, the sediment is compact and stable against secondary resuspension. Its

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formation and solidification are complete within 24 hours, and further increases in the coagulant content do not result in faster sediment formation or improve its stability.

Declarations.

Ethical Approval.

Not applicable.

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Conflict of Interests.

The authors have no competing interests to declare that are relevant to the content of this article.

Availability of Data and Materials.

Not applicable.

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