



Influence of Surfactant Treatment and Ultrasonic Dispersion on the Coagulation–Flocculation and Filterability of LDPE Microplastics [†]

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Abstract

The aggregation behavior of microplastics is often assumed to facilitate their removal during water treatment; however, this assumption has not been systematically evaluated for low-density polyethylene (LDPE) particles. This study aims to experimentally distinguish the effects of aggregation and dispersion on the coagulation–flocculation behavior and filterability of LDPE microplastics in the context of urban water treatment. Surface modification using two non-ionic surfactants (Tween 20 and Tween 80), combined with ultrasonic dispersion, was applied to induce controlled changes in particle aggregation behavior. Optical microscopy was used to characterize aggregation and dispersion behavior. Subsequent jar tests and filtration experiments were conducted to assess how these distinct particle states influence separation performance. Rather than presuming improved removal, the study focuses on identifying the conditions under which aggregation or dispersion governs microplastic breakthrough and filterability. By addressing process-related factors that may influence microplastic passage into treated water, the findings contribute to understanding short-term exposure risks within the urban water and health nexus.

Keywords: microplastics; LDPE (low-density polyethylene); aggregation; dispersion; coagulation–flocculation; filterability

1. Introduction

The widespread presence of microplastics in aquatic environments has emerged as a critical concern within the global water and health nexus [1]. Urban water systems receive microplastics from various sources, like household wastewater, synthetic textiles, tire wear, stormwater runoff, and the fragmentation of plastic debris [2]. Once introduced into bodies of raw water sources, these particles can enter drinking water treatment plants, where their removal efficiency depends on both particle properties and treatment conditions [3]. Given the growing evidence of microplastic contamination in treated drinking water, understanding the mechanisms directing their behaviors during conventional treatment processes has become an urgent research priority.

Among the various polymer types identified in urban waters, low-density polyethylene (LDPE) is of special relevance due to its extensive use in packaging materials and its low density, which promotes buoyancy and extended environmental persistence [4]. During water treatment, physical properties (hydrophobicity, surface charge, and size



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distribution) of LDPE microplastics have a significant impact on how they interact with coagulants, organic matter, and mineral particles [5,6]. Conventional coagulation, flocculation, sedimentation and filtration processes are generally assumed to facilitate microplastic removal, especially when particles aggregate into larger flocs [7,8]. However, this assumption has frequently been extended from general colloidal theory or studies on higher-density polymers and inorganic particles, rather than being systematically validated for buoyant polymers like LDPE [9].

Aggregation is commonly considered useful for removal because larger agglomerates have increased settling velocities and are more easily retained by granular filter media [10]. However, the behavior of microplastics aggregating is complex and may depend on physicochemical conditions including organic matter content, hydrodynamic shear, ionic strength, and surface-active substances [11]. In water systems, surfactants originating from domestic and industrial discharges are generally present and may modify the surface properties of microplastics [12]. By altering hydrophobic interactions and steric stabilization, such compounds can either promote aggregation or activate dispersion. Especially for low-density microplastics, dispersion into smaller, more stable colloidal forms may increase mobility and breakthrough during treatment, potentially counteracting the presumed benefits of aggregation [13].

Despite increasing attention to microplastic removal efficiencies in drinking water treatment, most research report overall removal percentages without differentiating whether observed performance is led by surface modification, floc structure, particle size, or filter retention mechanisms. Furthermore, not enough research has been performed on how controlled dispersion, produced by ultrasonic treatment, affects coagulation behavior and subsequent filterability. This gap is especially relevant for LDPE microplastics, whose density is about equal to that of water, which limits removal by sedimentation and may render filtration processes more effective.

2. Materials and Methods

Commercial LDPE microplastics (Colin Chemical, İstanbul, Turkey) were used in this study. The particles were rounded in morphology and had a nominal size fraction of <100 µm. LDPE was selected due to its low density and environmental significance in urban water systems. LDPE particles were directly added to each 1 L experimental batch at a dose of 0.1 g/L, followed by mixing to ensure homogeneous distribution within the suspension. The microplastic concentration (0.1 g/L) was selected to ensure measurable turbidity and observable particle behavior during laboratory-scale experiments. Similar approaches have been used in previous studies investigating microplastic removal mechanisms in drinking water treatment, where elevated particle concentrations are applied to enable controlled observation of coagulation and filtration processes [14–16]. The same initial microplastic concentration was applied consistently in all coagulation, settling, and filtration experiments to implement comparative evaluation of aggregation dependent behavior under controlled conditions.

To investigate the influence of surface modification on aggregation behavior, two non-ionic surfactants (Tween 20 and Tween 80, Sigma Aldrich, St. Louis, MI, USA) were applied at a concentration of 100 mg/L. Surfactant solutions were added to LDPE suspensions, followed by 15 min of contact under continuous mixing to allow adsorption onto particle surfaces. To induce controlled dispersion and disrupt agglomerates, ultrasonic treatment was applied using a Bandelin Sonoplus (Berlin, Germany) probe-type ultrasonicator. Sonication was conducted for 12 min at 30% amplitude. The specific energy input was recorded as 37,653 kJ for the Tween 20 and 37,545 kJ for the Tween 80 experimental sets. A maximum

temperature threshold of 60 °C was set in order to prevent thermal alteration of polymer properties; however, this temperature was not reached during the experiments.

Four particle conditions were therefore comparatively evaluated: untreated LDPE, surfactant-modified LDPE, ultrasonically dispersed LDPE, and surfactant-modified and ultrasonically dispersed LDPE.

The aggregation and dispersion states of LDPE particles were qualitatively characterized using a simple optical microscope (Optika, Ponteranica, Italy). Observations were conducted at 10× and 40× magnifications.

Coagulation/flocculation experiments were performed using a conventional jar test apparatus under laboratory conditions. Ferric chloride (FeCl₃, Merck, Darmstadt, Germany) was selected as the coagulant due to its widespread application in drinking water treatment. A fixed coagulant dose of 40 mg/L was applied in all experiments. After coagulant addition, rapid mixing was conducted for 1 min to ensure homogeneous dispersion of FeCl₃ throughout the suspension. This was followed by slow mixing for 20 min to promote floc formation and particle incorporation into aggregates. Subsequently, suspensions were allowed to settle for 20 min prior to supernatant sampling.

Filtration performance was evaluated using a lab-scale granular filtration setup packed with drinking water treatment plant filter sand. Representative sand samples were prepared prior to each experimental run using the quartering method to obtain homogeneity of the filtration medium.

Filterability was determined according to the Ives Filterability Test approach. During each filtration run, head loss, filtration rate, and filtrate turbidity were monitored. The Filterability Index (FI), as defined by Ives [17], was calculated as:

$$FI = C/C_0 \times H \times 1/(V.T) \quad (1)$$

where C represents effluent turbidity, C₀ is influent turbidity, H is head loss (m), V is filtration rate (m/h), and T is the duration of the filter run (h).

All experiments were conducted in duplicate and the reported values represent the average of two independent measurements. Due to the limited number of replicates within the scope of this preliminary conference study, detailed statistical analysis was not performed.

3. Results and Discussion

The coagulation, flocculation, and sedimentation results demonstrated the combined influence of surfactant addition and ultrasonication on LDPE dispersion and turbidity behavior (Table 1). In the absence of both surfactant and ultrasonication, LDPE particles remained floating at the surface due to their buoyant nature, contributing very little to bulk turbidity (0.76 NTU). When surfactants were added without ultrasonication, partial mixing of LDPE into the water column was observed, leading to moderate increases in initial turbidity (1.09 NTU, 1.76 NTU). However, full dispersion was not achieved under these conditions.

Table 1. Influence of dispersion conditions (surfactant and ultrasonication) on turbidity behavior during coagulation, flocculation, and sedimentation.

Ultrasonication	Surfactant	Initial NTU	Settled NTU	Turbidity Removal (%)
No	None	0.76	0.52	31.6
No	Tween 20	1.76	1.51	14.2
No	Tween 80	1.09	0.99	9.2
Yes	Tween 20	3.15	1.72	45.4
Yes	Tween 80	2.62	1.69	35.5

The most significant dispersion occurred when surfactant addition was combined with ultrasonication (Table 1). Under these conditions, initial turbidity increased substantially (2.62 NTU, 3.15 NTU), indicating enhanced particle distribution throughout the water column. Despite this increased dispersion, turbidity removal after sedimentation did not follow a simple linear trend. While removal efficiencies of 35–45% were achieved under ultrasonication-assisted conditions, surfactant-only systems exhibited lower removal efficiencies (9%, 14%). According to these results, dispersion improves particle availability for coagulation but does not always indicate better settleability. Rather, sedimentation performance is determined by the interaction between floc formation dynamics and dispersion state.

Ives filterability experiments were conducted for the Tween 20 and Tween 80 conditions at a constant filtration rate of 10 m/h and a run time of 5 min. Although the settled turbidity values entering filtration were similar ($C_0 = 1.72$ NTU), Tween 80 produced a lower filtrate turbidity ($C = 0.48$ NTU) than Tween 20 ($C = 0.60$ NTU), indicating slightly improved particle retention (Table 2). However, head loss was higher with Tween 80 (23 mm) compared to Tween 20 (15 mm), leading to a higher FI (0.00784, 0.00628). Since lower FI values indicate better filterability, the results suggest that the improved effluent quality observed with Tween 80 came at the expense of increased hydraulic resistance (like a greater tendency toward clogging). Overall, retention and head loss development were impacted by surfactant specific dispersion and particle/media interactions, indicating a trade-off between filter run hydraulics and effluent clarity.

Table 2. Ives filterability test results and calculated Filterability Index (FI) for LDPE suspensions treated with Tween 20 and Tween 80.

Surfactant	C_0 Settled (NTU)	C Filtrate (NTU)	Head Loss H (mm)	V (m/h)	T (min)	FI
Tween 20	1.72	0.60	15	10	5	0.00628
Tween 80	1.69	0.48	23	10	5	0.00784

Visual observations made during the filterability experiments showed that although the addition of Tween 20 and Tween 80 enhanced LDPE dispersion, particle adhesion to the inner walls of the filter cones was still observed (Figure 1). This suggests that increased dispersion was not sufficient to prevent microplastic surface interactions under filtration conditions. Due to their buoyancy, LDPE particles were found to stay completely at the water's surface in the absence of any surface modification or ultrasonic treatment, with little to no downward transport into the filtration zone.



Figure 1. Visual comparison of LDPE behavior during Ives filterability tests. The left cone corresponds to the Tween 20 treatment, the middle cone to the Tween 80 treatment, and the right cone to untreated conditions.

Microscopic observations of flocs formed under Tween 80 and ultrasonication conditions revealed compact aggregate structures with heterogeneous internal features (Figure 2). Dark inclusions were observed within the floc matrix at higher magnifications. While these inclusions may correspond to entrapped LDPE particles, definitive identification cannot be confirmed based solely on simple optical microscopy. The images suggest physical incorporation of dispersed particles into the ferric hydroxide floc structure; however, further spectroscopic verification would be required for polymer specific confirmation.

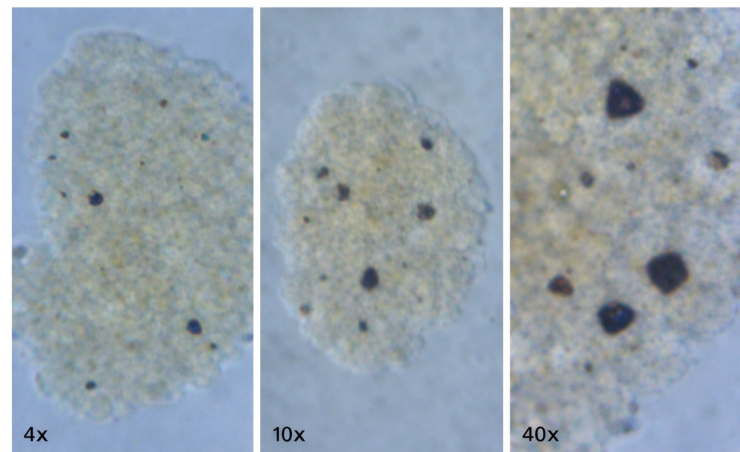


Figure 2. Floc morphology under Tween 80 + ultrasonication condition at different magnifications (4×, 10×, 40×).

4. Conclusions

This study demonstrated that the aggregation and dispersion state of LDPE microplastics significantly influences their behavior during coagulation, flocculation, and filtration processes. Adding surfactant and using ultrasonication to disperse the particles did make them disperse more, but this did not always make them settle better or filter more easily. The findings highlight the complex interaction between particle surface condition, floc formation, and hydraulic behavior within treatment systems. As a preliminary work, this study provides an initial mechanistic insight and indicates the need for further research incorporating advanced particle characterization and replicated experiments to better understand microplastic removal dynamics in coagulation/flocculation and filtration.

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