Effects of Linear Alkylbenzene Sulfonate and Polyoxyethylene Sorbitan Monolaurate Surfactants on Pristine and Aged Microplastic Removal by Electrocoagulation

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ABSTRACT

Various types of pollutants are present in wastewaters, which can combine and form even more toxic components or interfere with the treatments used for purification. Among emerging contaminants are microplastics and surfactants, which coexist in different types of wastewaters. This study aimed to assess the effects of the anionic surfactant linear alkylbenzene sulfonate (LAS) and the nonionic surfactant polyoxyethylene sorbitan monolaurate (Tween 20) on the removal of microplastics from pristine and aged glitter PVC surfaces using electrocoagulation with aluminum electrodes. To avoid interference from other substances, a benchtop reactor operating in batch mode with particles suspended in ultrapure water was developed for the experiments. The analysis methods employed included counting with the aid of a magnifying glass, gravimetry, zeta potential measurements, and scanning electron microscopy. The results revealed that the addition of surfactants led to a reduction in the removal efficiency of plastic microparticles. The lowest removal percentages were observed at a concentration of 100 ppm, and the inclusion of Tween 20 resulted in a decrease of 23% for pristine microplastics and 45% for aged microplastics. In contrast, the addition of LAS led to a decrease of 6% for pristine microplastics and 24% for aged microplastics. Therefore, the decrease in removal efficiency was more pronounced for degraded microplastics in both the Tween 20 and LAS experiments. Comparing the reduction in removal efficiency between the two types of surfactants, it can be observed that the nonionic surfactant (Tween 20) had a greater impact on the removal of microplastics by electrocoagulation.

Keywords: surfactants, microplastic, glitter PVC, LAS, tween, electrocoagulation.

INTRODUCTION

Various types of contaminants known as emerging pollutants have been increasingly detected in the environment. Due to their recent emergence, little is known about their effects on the environment, and many of them do not yet have their maximum values regulated by environmental legislation. Among them, plastics were developed in the early 20th century and their versatility led to widespread use in the manufacturing of various objects. However, the extensive use of plastics has created a serious problem, as a significant portion of the waste generated by humanity consists of plastic materials. These plastics degrade slowly in nature, resulting in an increasing accumulation of plastic waste in the environment [1]. Microplastics (MP) have arisen as a significant environmental concern, both through their manufacturing in small dimensions and their formation from the fragmentation of larger plastic objects and debris. These tiny waste pieces, measuring less than 5 mm in diameter, are considered emerging pollutants [2]. While studies have primarily focused on the presence of microplastics in marine environments, it is important to recognize that rivers and lakes are also heavily impacted by this issue.

Certain rivers receive mine tailings or treated sewage, which, even in their raw form, carry fragments of plastic materials. As a result, these rivers become potential vectors for the transport of macro and microplastic particles. Moreover, domestic wastewater systems serve as significant sources

of microplastics. Everyday activities such as clothes washing release a considerable amount of synthetic fibers into the water, and the presence of cosmetic and pharmaceutical products further contributes to the microplastic contamination [3, 4].

The detrimental effects of microplastics extend beyond environmental implications. Researchers have already discovered microplastics in the bodies of 220 aquatic animal species, raising concerns about their potential hazards. Ingestion of microplastics by aquatic organisms has been linked to various adverse effects, including growth deficiencies, histological variations in the intestine, and metabolic and behavioral alterations. These findings highlight the potential consequences of microplastic ingestion on the overall health and well-being of aquatic ecosystems [5].

Moreover, recent studies have shed light on the presence of microplastics in human tissues, emphasizing the potential risks to human health. Researchers have identified microplastics in lung tissue of deceased individuals [6], placenta [7], blood [8] and even in human heart [9]. These findings suggest that microplastics can enter the human body through various pathways and have prompted concerns regarding their potential impacts on human physiology and health.

In summary, microplastics pose a significant threat to both aquatic ecosystems and human well-being. Their widespread presence in rivers, lakes, and marine environments, as well as their potential to bioaccumulate in organisms, raises the need for comprehensive research and effective strategies to mitigate and prevent further microplastic pollution. It is essential to address the root causes of microplastic generation, improve waste management practices, and promote sustainable alternatives to plastic materials to safeguard our environment and human health.

Sewage contains various components, including nanomaterials and surfactants, making it crucial to evaluate the interactions among these constituents. The addition of surfactants, such as anionic sodium dodecyl sulfate (SDS) and nonionic nonylphenol nonoxylate (NPEO, Tergitol NP-9), into environmental water samples has been found to delay the aggregation and sedimentation of TiO_2 and ZnO nanoparticles. Furthermore, it was observed that the first type of surfactant exhibited poorer performance, resulting in a more substantial reduction compared to the second type [5, 10]. Coagulation/flocculation technique is commonly used for the removal of MP from aqueous matrix.

Several studies done with this purpose have been reported with successful results. However, few of them have focused in MP that has suffered the consequences of weathering along the time of exposure, known as aged microplastic. This phenomenon changes substantially the surface characteristics of MP, enhancing its adsorption properties [11]. In this way, when MP coexist with surfactants it is expected that their effect should be more severe in terms of charges adsorption and neutralization [11]. Stealth effects of nonionic surfactants should be enhanced as well [12].

Electrocoagulation involves the generation of coagulants through the application of an electric current, leading to the formation of metal hydroxide complexes. These complexes act as coagulants and facilitate the aggregation and subsequent removal of particles from the solution. In conjunction with flotation, which utilizes gas bubbles to lift the coagulated particles to the surface, electrocoagulation offers a promising approach to efficiently remove microplastics.

While previous studies have examined the effectiveness of electrocoagulation and coagulation with metal salts for microplastic removal, the focus has primarily been on pristine microplastics (PMP) without considering the impact of aging or the presence of surfactants [13–15]. Aged microplastics (AMP) may undergo physical and chemical changes over time, potentially affecting their behavior during the electrocoagulation process. Additionally, surfactants, commonly found in aquatic environments, can influence the properties and interactions of microplastics, potentially altering their removal efficiency.

Therefore, there is a research gap regarding the comparison of electrocoagulation-based removal of both pristine and aged microplastics in the presence of surfactants. Investigating the behavior and removal efficiency of microplastics under these conditions is crucial for better understanding the applicability and effectiveness of electrocoagulation as a potential treatment method for microplastic pollution. Deepening research on this issue could contribute valuable insights towards developing more comprehensive and efficient strategies for mitigating microplastic contamination in various environmental settings.

This study aims to investigate the effects of anionic surfactant LAS and nonionic surfactant Tween 20 on the removal of plastic microparticles, specifically glitter, in both pristine and aged forms, using the electrocoagulation method with

aluminum electrodes. Various concentrations of surfactants were added to examine their impact on the removal efficiency of microplastics.

MATERIALS AND METHODS

Materials and reagents

The plastic material utilized in the experiment was aged and pristine PVC glitter particles (Honey Ind. Ltd.), that has its occurrence in sea water as reported previously [16]. Glitter particles had an average size of 0.5 mm. The reactor, depicted in Figure 1, was constructed from transparent glass and had an effective volume of 16×14×15 cm³. Four aluminum plates measuring 5×10 cm² and 0.1 cm in thickness were used as electrodes.

For the electrocoagulation process, voltage was applied using an adjustable current source (HIKARI, HF-3003S). A magnetic stirrer (TE-089, TECNAL) was employed, with the rotation fixed in 20 rpm. As reported elsewhere [13, 17], the agitator remained operational throughout the entire duration of the reactor operation. For scanning electron microscopy, a Jeol JSM-6610 scanning microscope was used and zeta potential measurements were made using Zetasizer Nano ZS90 from Malvern. All chemical reactants were analytical grade and purchased from Neon chemical co. (Brazil). The water used in this study was ultrapure from a Gehaka instrument co. equipment. Figure 1 shows the schematic representation of the system.

Methods

Preparation of MP suspension

As previously documented [11], the microplastic aging process was achieved by the application of UV radiation during 15 d. A wooden chamber internally covered with reflective paper, measuring 50 cm in width, 50 cm in length, and 70 cm in height, was used for this purpose. The chamber contained two 15 W lamps that emitted UV radiation with a peak of 254 nm. This setup aimed to simulate the degradation of microplastics over time and exposure to sunlight.

The suspension was prepared using a concentration of MP particles of 200 mg/L[1] [14] in ultrapure water. In the beginning of the experiments, 10 mg/L of SDBS surfactant were added to ensure wettability and dispersion of the particles. To
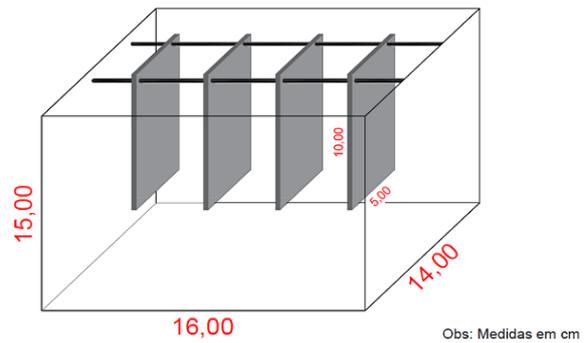

Figure 1. Schematic representation of the constructed reactor

enable current conduction, NaCl was added to the solution as an electrolyte and the pH was adjusted by adding HCl.

Coagulation experiments

The coagulation study was conducted in two stages. In the first stage of the experiments, the removal of microplastics was assessed according to earlier reports [2, 13, 15] that used a stereoscopic magnifying glass with trinocular zoom for counting glitter. Samples were collected using a 20 mL syringe and placed in Petri dishes for scanning from left to right during the reading process [2]. Two samples were collected in each experiment, one before and another after the electrocoagulation process after 5 min of flotation [13]. The percentage of microplastic removal was determined using Equation 1.

$$R = ((C_i - C_f)/C_i) \times 100 \qquad (1)$$

where: R – represents the microplastic removal as a percentage, C_i – the count of microplastics in the sample before treatment, C_f – the count of microplastics in the sample after treatment and 5 min of flotation.

In the preliminary phase, the alteration in mass of the aluminum plates was gauged for currents of 0.6 A and 2 A. The aluminum plates underwent a cleansing procedure employing hydrochloric acid and distilled water. Post-cleansing, they were subjected to a drying process within an oven for a duration of 2 h, followed by a cooling period of 20 min, after which their weights were measured. This stage aimed to ascertain the most favorable parameters for the removal of MP, thereby giving base to the subsequent investigation of the impacts of surfactants on the electrocoagulation process. In the second phase

of the study, the addition of surfactants at different concentrations of pristine and aged microplastics was initiated. Gravimetry was employed for the analysis in this phase. The samples were filtered and dried in a drying oven, after which they were weighed. Qualitative filter papers with a diameter of 15 cm (Qualy) were dried in an oven for 2 h and then weighed to prepare the tests. The glitter from the bottom of the reactor after treatment and 5 min of flotation was collected. The filters with the microplastics were taken to the oven for 2 h and then weighed. The removal of microplastics in each experiment was determined using Equation 2.

$$R(\%) = \frac{P_i - P_f}{P_i} \times 100 \qquad (2)$$

The difference between the weight of the filter with the glitter *Pi* and the weight of the filter alone *Pf* represents the initial amount of glitter placed in the experiment, which was fixed at 0.2 g/L, equivalent to 0.4 g since 2 L of distilled water were used in each experiment. R represents the microplastics removed during the electrocoagulation process. In the second phase of the experiments, additional analyses were conducted using scanning electron microscopy and zeta potential. Surfactant concentrations of 0, 10, 30, 50, and 100 ppm were examined.

Stage 1

To determine the basic parameters for the electrocoagulation process, a simple experimental design with two levels, three factors, and two central points ($2^3 + 2$) was employed, resulting in a total of 10 duplicate experiments. The selected parameters were reactor operating time, pH, and electric current. The two levels of time were set at 10 and 30 min [18], pH levels were 3 and 5 [9], and electric current levels were 0.6 and 2 A. The values for the electric current were determined based on the analysis of electrical conductivity. The choice of a lower pH was made to minimize precipitate formation, considering the solubility of aluminum in an aqueous solution [19].

For the experiments, a volume of 2 L was used. As the microplastic removal efficiency showed negligible variance in the range of 100 mg/L to 1000 mg/L, a glitter concentration of 200 mg/L was chosen [19]. The electrodes were connected in pairs by an iron bar that was not submerged. Two plates functioned as the positive pole, and two plates functioned as the negative pole. These plates were interspersed, following the monopolar model in parallel connection [19]. The distance between the electrodes was maintained at 2 cm [20, 21].

Stage 2

After determining the fixed values for pH, current, and operating time in the reactor during the first step, the addition of different concentrations of nonionic and anionic surfactants was initiated. The surfactant dosages used were 0, 10, 30, 50, and 100 ppm. In this stage, experiments were conducted using both pristine and aged PVC glitters.

RESULTS AND DISCUSSION

Stage 1

In the initial stage, the experiments were performed in duplicate, and the results were recorded in Excel. The variance, standard deviation, and coefficient of variation were calculated to assess the data dispersion. As the coefficient of variation for all assays was below 10%, the results exhibited low dispersion and could be considered homogeneous. Table 1 shows the visualization of the conditions of the experiments and the results, presenting the initial and final pH as well as the microplastic removal.

The removal efficiency was lowest with a current of 0.6 A and 10 min of operation, reaching a maximum efficiency of 60%. However, when the operation time was extended to 30 min, the removal percentage increased to approximately 85%. With a current of 2 A, the results were closer, ranging between 70% and 90%. The combination of parameters that yielded the best result was a pH of 5, 30 minutes of operation, and a current of 2 A, resulting in a removal efficiency of 90%. This outcome was expected since higher current and longer operation time lead to greater coagulant release in the treated solution.

Regarding the weight of the plates, only the extreme points were compared, as the operating time and pH were the same. With an electric current of 0.6 A, the average mass loss was 0.013 g/min, whereas with a current of 2 A, the reduction was 0.034 g/min. There was a considerable increase in the loss of aluminum with an increasing current, amounting to approximately 165%. After analyzing the results, the parameters for the second phase were set at a pH of 3, an operating

Table 1. Average final pH results and microplastic removal for the duplicate experiments

Exp.	pH	t. (min)	I (A)	pH final	Removal (%)
1	3	10	0.6	4.7	59.2
2	5	10	0.6	8.0	52.1
3	3	30	0.6	5.2	86.8
4	5	30	0.6	8.5	84.3
5	3	10	2	7.5	87.6
6	5	10	2	8.5	73.7
7	3	30	2	8.3	81.5
8	5	30	2	8.5	90.3
9	4	20	1.3	8.3	86.1
10	4	20	1.3	8.4	86.0

time of 10 min, and an electric current of 0.6 A. Despite achieving the highest microplastic removal with a pH of 5, 30 min of operation, and 2 A of current, these values were not used due to the ongoing scanning process, causing the pH to increase beyond 7.

Stage 2 electrocoagulation with pristine microplastic

After confirming the homogeneity of the data, Figure 2 was generated to compare the average percentage removal of microplastics while varying the amount and type of surfactant present in the reactor. The addition of Tween 20 to the reactor resulted in a decrease in microplastic removal through electrocoagulation flotation. The removal percentage decreased when using 10 and 30 ppm concentrations. However, at a concentration of 50 ppm, there was an increase in the removal percentage, although it did not surpass the treatment without any surfactant. As Tween 20 is a nonionic surfactant, it impedes coagulation through steric repulsion. The hydrophobic tail of the surfactant attaches to the hydrophobic microplastic, leaving its hydrophilic head exposed, creating a shield around the PVC and preventing aggregation. However, at higher surfactant concentrations, this protective layer may become less effective as surfactant molecules begin to aggregate, allowing microplastics to coagulate freely. The removal percentage decreased again when using 100 ppm, reaching the lowest percentage observed. This improvement at 50 ppm and worsening at 100 ppm could be attributed to an inflection point in the efficiency of the steric repulsion layer. There was a decrease of approximately 6.5% at 50 ppm and 23.1% at 100 ppm.

When using LAS, there was an increase in microplastic removal at a concentration of 10 ppm, but from 30 ppm onwards, the removal percentage was lower compared to the absence of surfactant. The lowest removal value was obtained at a concentration of 100 ppm. The increase observed was approximately 12.7%, while the largest decrease was approximately 6.4%. This increase can be attributed, to some extent, to previous studies indicating improved microplastic removal due to the addition of surfactants, which create a more uniform suspension of water and microplastics,
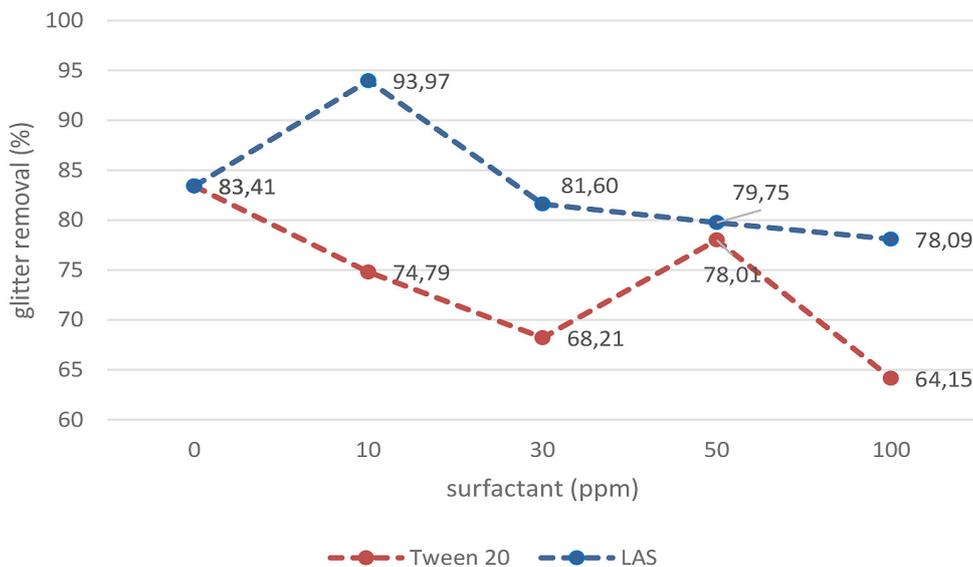

Figure 2. Comparison of pristine microplastic removal as a function of the amount of Tween 20 and LAS

facilitating the coagulation process and glitter counting with the coagulant [20].

Comparing the effects of Tween 20 and LAS, it is evident that the former exhibits decreased efficiency from the minimum surfactant dosage of 10 ppm, whereas LAS shows improvement in the treatment. With higher dosages, both surfactants impair the microplastic removal, and a concentration of 100 ppm yields the poorest results for both. However, the drop observed with Tween 20 is more significant than that with LAS, aligning with findings from [12], who reported a greater negative influence of Tween 20 on microplastic removal through chemical coagulation compared to LAS.

Stage 2 electrocoagulation with aged microplastic

After confirming the homogeneity of the data, a graph was generated to compare the average percentage removal of microplastics when varying the amount and type of surfactant present in the reactor (Figure 3).

The removal of degraded microplastics in the presence of Tween 20 at a concentration of 10 ppm decreases by approximately 8% compared to the experiment without surfactant. At 30 ppm, there is a decrease of nearly 14%. However, there is a slight improvement in removal at a concentration of 50 ppm, which exhibits a 13% decrease compared to 0 ppm concentration. However, at 100 ppm, the removal drops significantly by 26.2%. Similarly, with LAS surfactant, microplastic

removal also decreases. For a concentration of 10 ppm, there is a decrease of 3.4% compared to the treatment without surfactant, while at 30 ppm, there is a decrease of 8.4%. However, at a concentration of 50 ppm, there is an improvement in removal, although it remains below the percentage observed with 0 ppm, with a decrease of 3.5% compared to the procedure without surfactant. At 100 ppm, there was a decrease of 14% in removal.

Comparing the removal of aged microplastics in the presence of Tween 20 and LAS reveals a similar curve pattern; however, the decrease in removal with the nonionic surfactant is greater than that with the anionic surfactant. The difference in curvature between the graphs lies mainly in the variation of the percentage between 30 ppm and 50 ppm concentrations, where there is a larger increase in removal with LAS compared to Tween 20. The poorest removal results for both types of surfactants were observed at 100 ppm, with LAS achieving a removal of 44% and Tween 20 reaching 32.3%, representing a difference of nearly 12%. These findings align with studies by Xia [12], which indicated that nonionic surfactants had a more detrimental effect on the chemical coagulation process than ionic surfactants. Analyzing the graph, it is evident that the higher the surfactant concentration, the greater the difference in microplastic removal between Tween 20 and LAS. For example, at 10 ppm, the variation is less than 5%, while at the highest concentration, the difference exceeds 10%.
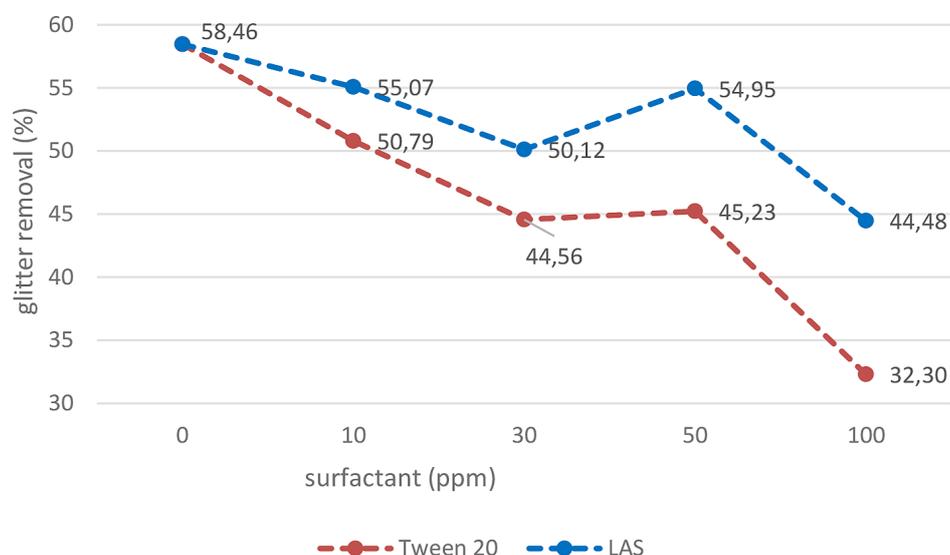

Figure 3. Comparison of aged microplastic removal percentage for degraded microplastics as a function of the amount of Tween 20 and LAS

Comparison of Tween 20 and LAS curves in pristine and aged microplastic

A graph was generated with four curves representing the experiments to facilitate the comparison of results (Figure 4). The removal of microplastics that have undergone UV radiation is impaired not only in the presence of both types of surfactants but also without any surfactant. It can also be observed that the curves become similar as the removal of plastic microparticles decreases. For example, the curve with the highest efficiency is that of pristine microplastics in the presence of LAS, which shows an increase in removal with 10 ppm of surfactant. The other curves follow a similar pattern, decreasing with 10 and 30 ppm concentrations, showing a slight increase at 50 ppm without exceeding the removal without surfactant, and decreasing again at 100 ppm. Regarding the increase in removal at a concentration of 50 ppm, it is observed that as the removal of microplastics worsens (lower on the graph), the increase experienced becomes smaller. In the last curve, which represents the lowest removal on the graph, the difference between 30 ppm and 50 ppm is very small, almost forming a straight line without inclination.

The literature documents the efficacy of alum coagulation-settling for removing pristine polyethylene and polystyrene microplastics (MPs), highlighting the stronger influence of LAS electrostatic repulsion over Tween 20 steric resistance. This observation aligns with our findings from electrocoagulation of pristine MPs. The reported removal efficiency in [12] exceeds our own, likely attributed to the ionic interaction between PVC glitter and the ionic charges of LAS, as well as the monomers of Tween 20. Additionally, we must consider differences in removal mechanisms, particularly the flotation (counter-gravity) observed in our study versus the settling (gravity-assisted) reported in literature [12]. Given the similar densities of the three MPs examined, settling is presumed to be the more efficient mechanism

Scanning electron microscopy analysis

To compare the surface modifications of intact microplastics degraded by UV radiation, SEM images were taken side by side with an approximate magnification of 5000 times, without the use of surfactants in the electrocoagulation process. Figure 5 illustrates the comparison of the surface of pristine and aged microplastics without surfactant.

The surface of the microplastics becomes rougher after degradation by UV radiation, which is consistent with the findings of [11], who observed the formation of cracks and color changes on the previously smooth surface of microplastics exposed to UV rays. Similar surface modifications were observed in the glitters used in this study, as shown in Figure 6.

Figure 7 presents the comparison between pristine microplastics in the presence of 100 ppm of the anionic surfactant LAS and the non-ionic surfactant Tween 20, magnified 150 times. Figure 8 shows the same comparison for aged
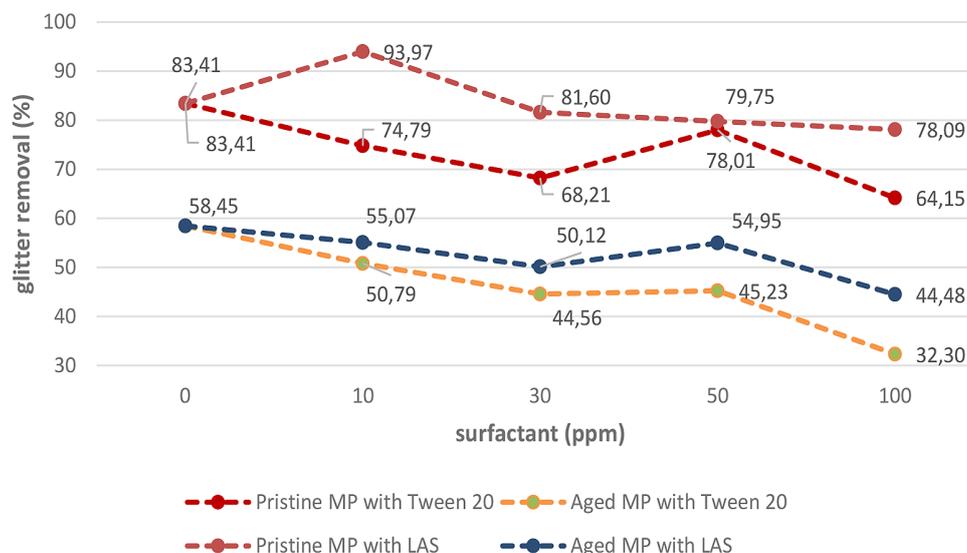
Figure 4. Comparison of microplastic removal in the presence of Tween 20 and LAS for both intact and degraded microplastics
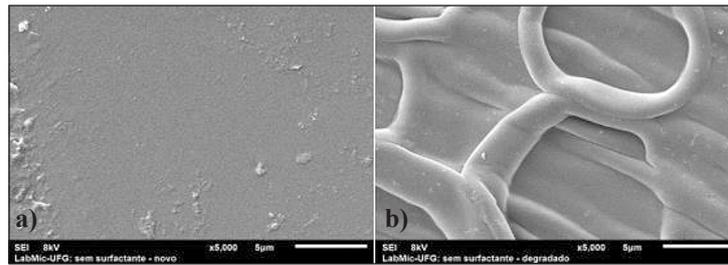
Figure 5. SEM comparison of the surface of pristine (a) and aged (b) microplastics without the addition of surfactant
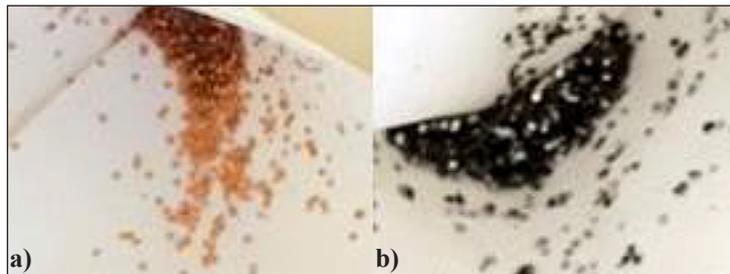

Figure 6. Comparison of pristine (a) and aged (b) glitters exposed to UV radiation

microplastics. The surface of pristine and aged glitters in the presence of Tween 20 appears relatively clean, whereas the surface of microplastics in the presence of LAS exhibits a layer with a foamy appearance. For aged microplastics, the layer of dirt is smaller in the presence of LAS compared to pristine microplastics. This can be explained by the fact that PVC microplastics carry a negative charge and are attracted to the positive ions of aluminum, forming a positive layer around the plastic. As the anionic surfactant LAS carries a negative charge, it is possible that the glitters attract the surfactant, which does not occur with Tween 20 as it is nonionic and has no charge. This finding is consistent with [22], who observed that the presence of an ionic surfactant significantly increased the adsorption capacity of PVC microplastics for pollutants with opposite
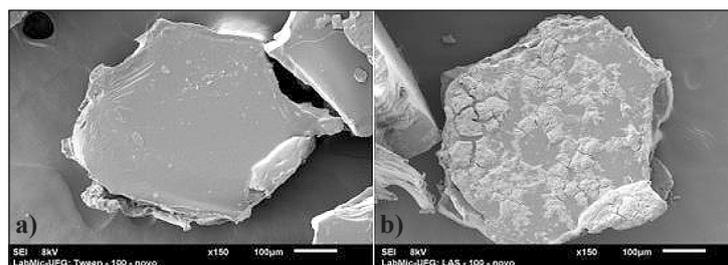

Figure 7. Comparison between pristine microplastics in the presence of Tween 20 (a) and LAS (b)
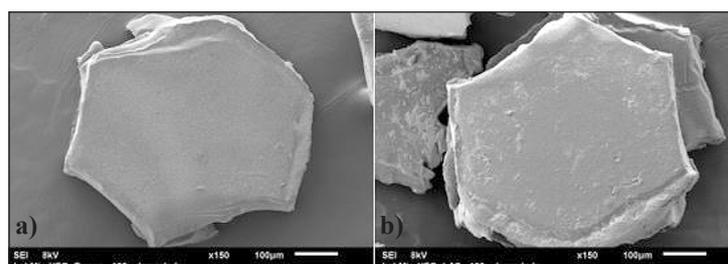

Figure 8. Comparison between aged microplastics in the presence of Tween 20 (a) and LAS (b)

charges. On the other hand, nonionic surfactants prevented the adsorption of pollutants with positive and negative charges due to steric hindrance caused by the hydrophilic polyethylene glycol chains. Additionally, for aged microplastics, the layer of dirt is smaller than that observed for pristine microplastics in the presence of LAS, which can be attributed to the decrease in zeta potential of microplastics when aged by UV radiation [11].

Zeta potential analysis in conjunction with microplastic removal

Figures 9, 10, 11, and 12 illustrate the removal and zeta potential in the presence of Tween 20 for pristine microplastics, with LAS for pristine microplastics, with Tween 20 for degraded microplastics, and with LAS for degraded microplastics, respectively. Figure 9 shows the removal curve of pristine glitter in the presence of Tween 20 and the corresponding zeta potential values. As a nonionic surfactant, Tween 20 functions through steric stabilization. In this case, the hydrophilic group attaches itself to the outer layer of the particle, attracting water and creating a protective barrier that prevents coagulation [23].

With a low concentration of Tween 20, this effect was not as pronounced, resulting in a slightly increased zeta potential of the glitter. However, with a higher concentration of the nonionic surfactant, the surface charge of the glitter became increasingly negative, likely due to the enhanced steric stabilization effect on the surface. This explains the decrease in glitter removal, as this protective layer impedes particle aggregation.

In Figure 10, the glitter without the presence of surfactant exhibits a positive zeta potential due to surface aggregation. Upon the addition of LAS, the charge on the glitter is neutralized as this surfactant is anionic. Initially, at 10 ppm, there is an improvement in removal, attributed to the closer proximity of the zeta potential to zero. However, with higher concentrations of LAS, the zeta potential remains relatively unchanged, while the removal of microplastics decreases. This decrease in removal may be attributed to the adsorption of the surfactant, which is more abundant at higher concentrations, promoting steric repulsion and creating a barrier that hinders particle contact and adhesion. Another possible reason for the reduced removal of glitter could be the diminished van der Waals forces between plastic
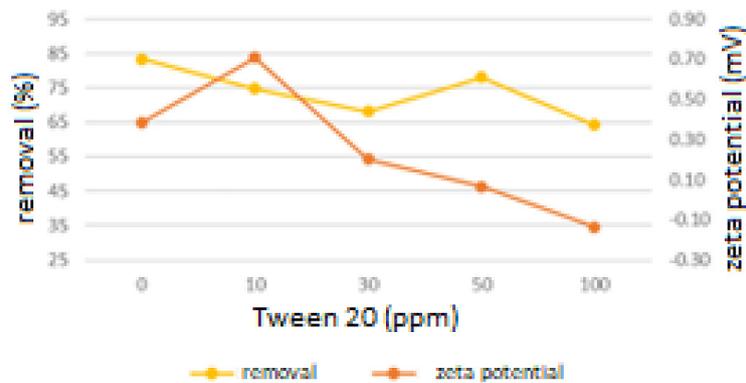

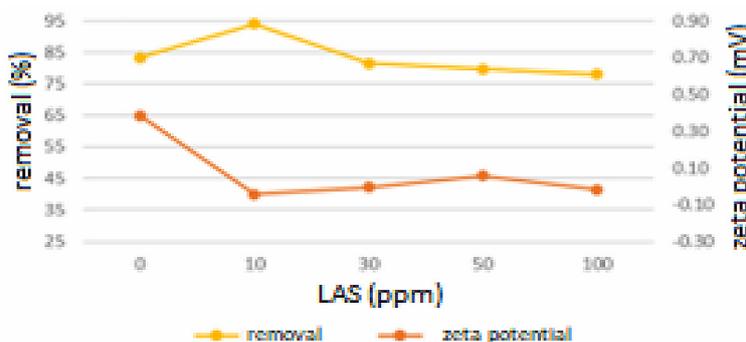**Figure 9.** Removal and zeta potential in the presence of Tween 20 for pristine microplastics

Figure 10. Removal and zeta potential in the presence of LAS for pristine microplastics
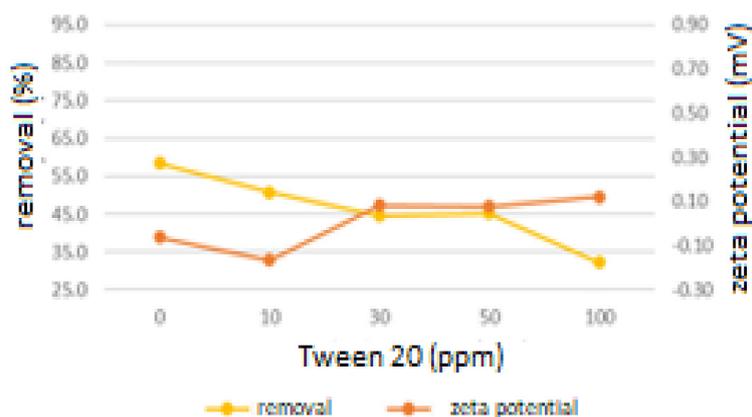
Figure 11. Removal and zeta potential in the presence of Tween 20 for aged microplastics
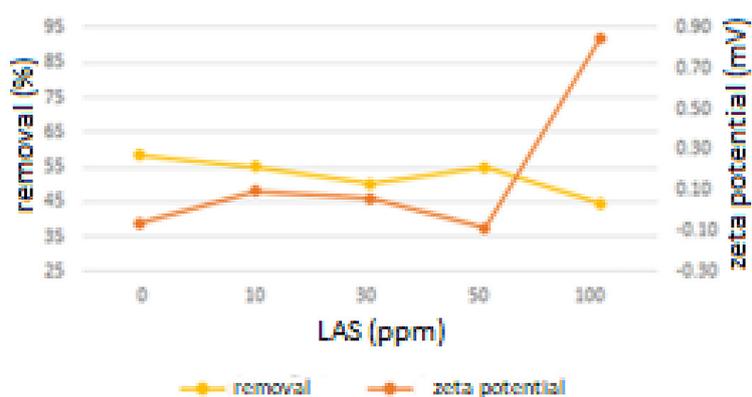

Figure 12. Removal and zeta potential in the presence of LAS for aged PM

particles caused by the adsorbed surfactant layer, leading to coagulation or aggregation. Figure 11 demonstrates that with 10 ppm of surfactant, there is a slight decrease in the zeta potential and consequently a reduction in the removal of microplastics. However, with higher concentrations of Tween 20, the zeta potential is neutralized and reaches a value similar to the modulus of the zeta potential at the 10 ppm concentration. Nonetheless, the removal of microplastics continues to decrease, attributed to the formation of a steric protective layer around the glitter. The hydrophobic tail of Tween 20 adheres to the hydrophobic PVC microplastics, resulting in a larger adsorption area on the aged microplastics, which leads to greater steric protection and less aggregation between plastic particles. This disparity in removal percentage between pristine and aged microplastics, as observed in Figure 11, is due to the larger adsorption area on the surface of UV-aged microplastics, allowing for enhanced steric protection through increased surfactant adsorption. In Figure 12, the addition of LAS results in a decrease in removal, despite the zeta potential being close to zero. This phenomenon can be attributed to the hydrophobic adsorption of LAS, which prevents particle aggregation. The elevation of the glitter charge at a concentration of 100 ppm is due to the formation of a more intense layer of negatively charged hydrophilic heads surrounding the glitter, attracting ions. Both aged and pristine glitter in the presence of LAS exhibit a zeta potential close to zero, but the removal of the aged glitter is smaller than that of the pristine glitter. This difference can be explained by the larger adsorption area of the aged glitter, allowing for greater steric protection through increased surfactant adsorption on its surface.

CONCLUSION

In this study, we examined the impact of the anionic surfactant dodecyl benzene sodium sulfonate and the nonionic surfactant polysorbate 20 on the removal of microplastics from pristine

PVC and PVC aged through the electrocoagulation method. The percentage decrease in removal between experiments without surfactant and those with 100 ppm of active surfactant was 23% and 45% for pristine and aged glitter, respectively, when Tween 20 was used, and 6% and 24% when LAS was used. The presence of both types of surfactants negatively affected the agglomeration of both types of glitters, with a greater impact observed on the plastic microparticles degraded by UV radiation. Furthermore, there was a difference in the decrease in removal between the two surfactants, with Tween 20 causing greater damage compared to LAS, for both pristine and aged microplastics. Among all the conducted assays, only one resulted in an improvement in removal: the addition of 10 ppm LAS to the electrocoagulation process, which led to a 12% increase compared to the experiment without any surfactant

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