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Application of Iron-Activated Persulfate for Cosmetic Wastewater Treatment: TOC Reduction and Biodegradability Improvement

Zastosowanie nadsiarczanu aktywowanego żelazem w oczyszczaniu ścieków kosmetycznych: redukcja TOC i poprawa biodegradowalności

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Keywords: *Industrial wastewater, Advanced Oxidation Processes, metallic iron, persulfates*

Abstract
Industrial wastewater treatment must be carried out in order to reduce the impact on both living organisms and non-living environments. Cosmetic wastewater was chosen for this study due to the rapid growth of the cosmetic sector and the complexity of its effluents. Wastewater from a cosmetic industry was collected, and analyses were carried out which involved application of the $Fe^0/S_2O_8^{2-}$ process for cosmetic wastewater treatment. The purpose of the study is to understand the correlation between pollutants concentration, metallic iron dosage, persulfate dosage, as well as the duration of contact and their combined effects. The experiment was carried out with different dosages of iron and persulfate, 1 to 4 g/L, and contact times (0 to 120 minutes). It was shown that Total Organic Carbon (TOC) decreased from 613.3 mg/L to 530.3 mg/L after treatment. Five day biochemical oxygen demand (BOD_5) increased from 114 mg/L to 138 mg/L which, combined with the general decrease in the content of organic compounds expressed as TOC, indicates an increase in the susceptibility of wastewater to biological treatment. The comprehensive analysis indicates improvements in wastewater quality. This study demonstrated that advanced oxidation procedures utilizing metallic iron and persulfate are promising as wastewater technology.

Słowa kluczowe: *ścieki przemysłowe, procesy pogłębionego utleniania, żelazo metaliczne, nadsiarczan*

Streszczenie
Oczyszczanie ścieków przemysłowych musi być prowadzone w celu ograniczenia ich wpływu zarówno na organizmy żywe, jak i na środowisko nieożywione. Do badań wybrano ścieki z przemysłu kosmetycznego, ze względu na szybki rozwój sektora kosmetycznego oraz złożoność i zmienność ścieków. Pobierano ścieki z zakładu przemysłu kosmetycznego i przeprowadzono badania obejmujące zastosowanie procesu $Fe^0/S_2O_8^{2-}$ do ich oczyszczania. Celem badań było określenie zależności pomiędzy stężeniem zanieczyszczeń, dawką żelaza metalicznego, dawką nadsiarczanu, a także czasem kontaktu oraz ich łącznym wpływem. Eksperyment przeprowadzono z użyciem różnych dawek żelaza i nadsiarczanu (1–4 g/L) oraz czasów kontaktu (0–120 minut). Wykazano, że zawartość ogólnego węgla organicznego (OWO) zmniejszyła się po procesie z 613,3 mg/L do 530,3 mg/L. Pięciodobowe biochemiczne zapotrzebowanie tlenu (BZT_5) wzrosło ze 114 mg/L do 138 mg/L, co w połączeniu z ogólnym spadkiem zawartości związków organicznych wyrażonych jako OWO, wskazuje na wzrost podatności ścieków na oczyszczanie biologiczne. Przeprowadzona analiza potwierdza poprawę jakości ścieków. Badania wykazały, że procesy pogłębionego utleniania wykorzystujące żelazo metaliczne i nadsiarczan są obiecującą technologią oczyszczania ścieków.

Introduction

The cosmetics industry is among the quickest growing consumer segments; it produced EUR 474.2 billion worldwide in 2019. Industry revenues were impacted in 2020 as coronavirus was at its peak at the time. There was a slight drop of 1.2%, bringing it down to EUR 468.3 billion [5]. Apart from the manufacturing chain, this industry has a major environmental footprint because of the huge amounts of wastewater released, sometimes in nature. packed with synthetic organic chemicals, oils, preservatives, perfumes, surfactants, and dyes. Recent advances in dye removal and reprocessing technologies have expanded options for treating high-strength industrial effluents [2]. It is difficult and requires a lot of time to treat these wastewater, therefore more advance solution is needed than the usual biological, chemical, or physical methods. The process of treating wastewater is an important step in the maintenance of water sources that are clean, and it is also a prerequisite for the sustainable use of natural resources. Common wastewater treatment methods may reduce the amount of pollutants, however, these methods may not be able to entirely eliminate persistent organic pollutants (POPs). Many cosmetic wastewater pollutants are biodegradation resistant, therefore typical secondary treatments fall short. Conventional secondary biological processes are

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limited in treating many persistent organic pollutants [17]. Advanced Oxidation Processes (AOPs) have therefore been widely explored as possible substitutes and played an important role historically in hazardous waste treatment [8]. They produce extremely reactive radical species that can break down complicated organic compounds. Persulfate-based oxidation has become more popular among several AOPs. Heterogeneous photocatalysis has also been proposed as an effective AOP for some industrial effluents [4]. Persulfates, when they are activated, create radicals ($SO_4^{\bullet-}$) which are very powerful oxidizers with high redox potential similar to hydroxyl radicals but with superior selectivity and longer half-lives. Mechanistic studies have shown how phenolic moieties can directly activate persulfate and affect radical pathways [3]. Persulfate activated by ferrous ions has been effective in removing endocrine-disrupting compounds such as bisphenol A [9]. They are appealing for industrial wastewater treatment because they work well against a wide variety of organic pollutants [10]. Ferrous-activated persulfate has been reported to remove species such as arsenic(III) and diuron, demonstrating the approach's applicability [24]. Presence of POPs in soil and groundwater poses a significant threat to human health. Groundwater management and salinization risks illustrate the broader environmental drivers for effective contaminant remediation [15]. Industrial activities are the major causes of this, which makes it difficult for conventional remediation methods to address. These pollutants pose a significant threat to water resources globally and human health. Sulfate radicals ($SO_4^{\bullet-}$) are very effective at breaking down pollutants found in wastewater, and it includes POPs, industrial chemicals, Pharmaceuticals and Personal Care Products (PPCPs). Persulfate is versatile for in situ uses, affordable, and stable during storage and transportation. Iron is a good activator because it is cheap and not very dangerous, heat, alkaline environments, or transition metals can all activate. Iron-catalyzed persulfate reduces the requirement for powerful oxidants and has been shown to quickly break down challenging molecules [10]. Challenges consist of possible metal leaching, pH dependency, and rivalry among Fe^{2+} and target organics for radicals [21]. Research keeps improving activation techniques to maximize efficiency and reduce negative side effects. Worldwide, chlorinated solvents, fuels, phenols, Polycyclic Aromatic Hydrocarbons (PAHs), Polychlorinated Biphenyls (PCBs), and groundwater and soil contamination with these compounds is being dealt with. Recent reviews have summarized the pathway from bench studies to field application of persulfate activation for groundwater remediation [13]. Pesticides and explosives have made the water problem worse [15]. Billions of people around the world suffer from bad hygiene. Therefore, very important is in situ chemical oxidation (ISCO) employing oxidizers including permanganate, hydrogen peroxide, ozone, and persulfate [1]. ISCO approaches using persulfate and permanganate have been reported for a range of subsurface contaminants. [16]. Every oxidant has unique stability, activation criteria, and radical species [17] [15] [25].

Table 1 shows the key features of each one. Persulfate is special because it is very stable and produces a lot of radical species. Though treatment effectiveness relies on variables including pH, temperature, mineralizing a broad spectrum of pollutants of concern and producing sulfate radicals. Many studies have looked at how persulfates might be used to treat wastewater. Fe^{2+} /persulfate employed for petrochemical wastewater and documented notable TOC decreases were treated with zero-valent iron-activated persulfate degrading chlorinated solvents [22] [23]. But cosmetic wastewater has not been studied much. Traditional methods like Fenton oxidation have been tested for cosmetic wastewater, but they have flaws like persulfate-based treatments minimize sludge and preserve excellent pollutant breakdown efficiency [14]. Persulfate oxidation caused varying reactions in textile wastewater, pretreated wastewater became more biodegradable. A 2017 study demonstrated that pharmaceutical wastewater showed moderate improvements after treatment. However, the researchers cautioned that without additional treatment procedures, the effectiveness of the process remains limited [19]. These evaluations highlight the necessity of further research on different wastewater streams. Using $Fe^0/S_2O_8^{2-}$ for cosmetic wastewater treatment is examined in this study together with dosage and contact time-related pollutant removal. This study concentrates on the cosmetics industry, unlike earlier research on petrochemical or textile wastewater. Its innovation is demonstrating that $Fe^0/S_2O_8^{2-}$ not only lowers TOC but also boosts BOD_5, so enhancing wastewater's suitability for biological treatment. The research investigates $Fe^0/S_2O_8^{2-}$ process ability to treat cosmetic wastewater. Through careful study of their impacts, the study aims to provide a fresh perspective on the efficacy of persulfate dosage, metallic iron dosage, and contact time. This mechanism speeds up the rate at which things decay.

Materials and Methods

Wastewater samples were obtained from a cosmetic plant in Warsaw, Poland, and stored at 4 °C prior to analysis. The plant produces a variety of cosmetic products. Wastewater parameters including COD, BOD_5, TSS, pH, surfactants, and TOC were determined in accordance with EN and ISO standards. TOC was determined using a TOC-L analyzer (Shimadzu, Kyoto, Japan) with an OCT-L8-port sampler, following EN 1484:1999. Reaction vessels comprised 250 mL glass beakers used in every experiment. To guarantee uniform reagent mixing, the beakers were kept on a magnetic stirrer and the stirring speed (about 300 rpm) was kept constant during the trials. Under laboratory settings, the reactions were conducted at room temperature (22 ± 2 °C). The wastewater was adjusted to pH 3.0 with analytical grade sulfuric acid (H_2SO_4) prior to every run as acidic conditions are conducive to persulfate activation. A calibrated digital pH meter was used to track the pH. Ammonium persulfate and metallic iron (Fe^0) powder with purity ≥ 98%, particle size < 100 µm) were used. Reagents were $Na_2S_2O_8$ (purity > 98%). At the start of each experiment, these were precisely weighed on an analytical balance and added to the beakers. For Fe^0 and persulfate, the concentrations investigated were 1, 2, and 4 g/L. The durations of contact for each trial were 0, 15, 30, 60, and 120 minutes. Before analysis, they were filtered through 0.45 µm cellulose nitrate membranes to get rid of

Table 1 Characteristics of chemical oxidants used for destruction of organic contaminants (adapted from Huling and Pivetz, 2006)

Tabela 1. Charakterystyka utleniaczy chemicznych stosowanych do degradacji zanieczyszczeń organicznych (opracowano na podstawie Huling i Pivetz, 2006)

Oxidant	Oxidant chemical	Commercial form	Activator	Reactive species
Permanganate	$KMnO_4$ or $NaMnO_4$	Powder, liquid	None	MnO_4^-
Hydrogen peroxide	H_2O_2	Liquid	None, Fe(II), Fe(III)	$OH^{\bullet}$, $O_2^{\bullet-}$, $HO_2^{\bullet}$, HO_2^-
Ozone	O_3 in air	Gas	None	O_3, $OH^{\bullet}$
Persulfate	$Na_2S_2O_8$	Powder	None, Fe(II), Fe(III), heat, H_2O_2, high pH	$S_2O_8^{2-}$, $SO_4^{\bullet-}$
Peroxone	H_2O_2 plus O_3 (in air)	Liquid, gas	O_3	O_3, $OH^{\bullet}$
Percarbonate	$Na_2CO_3{\cdot}1.5H_2O_2$	Powder	Fe(II)	$OH^{\bullet}$
Calcium peroxide	CaO_2	Powder	None	H_2O_2, HO_2^-

suspended solids. To ensure repeatability, duplicate all tests were performed. All runs had the same temperature, stirring speed, and reagent conditions. This design guaranteed dependable comparison of how well Fe^0 dosage, persulphate dosage, and reaction time affected the efficiency of pollutant elimination. Following EN 1484:1999, the Total Organic Carbon (TOC) was assessed using a TOC-L analyser (Shimadzu, Kyoto, Japan) fitted with an OCT-L8-port autosampler. A one-factor-at-a-time approach was applied to assess TOC. The effects of pH adjustment (to 3.0), iron and ammonium persulfate dosage (1–4 g/L), hematite-to-persulfate ratio, and contact time (0–120 minutes) were systematically investigated. Prior to each test, wastewater was homogenized by thorough mixing. Treatments were applied under controlled pH conditions with addition of ammonium persulfate and iron. Experimental data were subjected to statistical analysis to evaluate the significance of treatment effects and identify optimal conditions for maximizing TOC removal and improving biodegradability [3] [20].

Results

The cosmetic wastewater samples showed a high level of pollution, characterized by significant organic and chemical loads. The raw samples contained 613.3 mg/L of total organic carbon (TOC) which decreased to 530.3 mg/L after filtration because most of the organic matter existed as suspended particles. The COD values showed a decrease from 1644 mg/L to 1437 mg/L after filtration which confirmed that suspended solids made up a large portion of the total pollution. The analysis showed that wastewater contained dissolved pollutants together with particulate matter which formed a major part of the effluent composition. Basic wastewater characteristics and measured parameters are summarized in Table 2. The treatment methods need to evolve because standard processes do not achieve sufficient removal of both fractions. These results support the requirement of sophisticated treatment methods, including $Fe^0/S_2O_8^{2-}$ oxidation, to help to lower organics, surfactants, and nutrients while also improving biodegradability.

Table 2 Analysis of Wastewater characteristics and Treatment

Tabela 2. Analiza charakterystyki ścieków oraz procesu ich oczyszczania

Parameter	Value	Unit
TOC	613.3	mg/L
TOC filtered	530.3	mg/L
BOD_5	114	mg/L
TSS	35	mg/L
COD	1644	mg/L
COD filtered	1437	mg/L
Anionic Surfactants	800	mg/L
Total phosphorus	11	mg/L
Conductivity	1.462	mg/L

Metallic Iron/Persulfate Process

The results of treatment processes are shown in figures 1 – 3.

Figures 1–3 present a summary of the treatment outcomes. At baseline, every condition registered TOC of 613.2 mg/L. TOC decreased with 1 g/L Fe^0. At 1 g/L persulfate, quickly dropped to 532.1 mg/L in 15 minutes, then stabilized around 517.4 mg/L at 120 minutes. Higher persulfate concentrations (2–4 g/L) produced a faster decrease to 532.1 mg/L in 15 minutes followed by stabilization near 517.4 mg/L at 120 minutes. Higher persulfate concentrations (2–4 g/L) produced a faster decrease to 532.1 mg/L in 15 minutes, then stabilization near 517.4 mg/L at 120 minutes. With 4 g/L reaching the lowest TOC (501 mg/L) at 120 minutes, g/L) showed more gradual

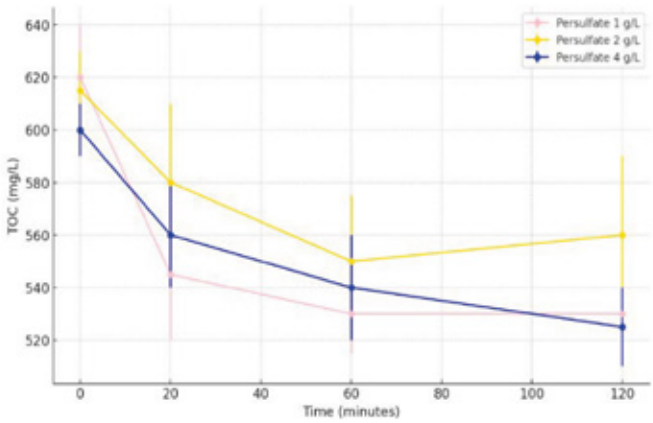

Fig. 1 Cosmetic Wastewater TOC [mg/L] against Time (minutes) at Selected Fe Dose (1 g/L)

Rys. 1. Zawartość ogólnego węgla organicznego (TOC) w ściekach kosmetycznych w funkcji czasu (minuty) przy wybranej dawce żelaza metalicznego (Fe = 1 g/L)

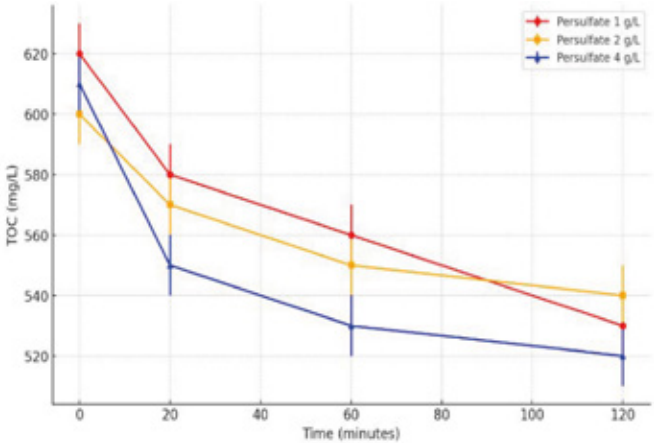

Fig. 2 Cosmetic Wastewater TOC [mg/L] against Time (minutes) at Selected Fe Dose (2 g/L)

Rys. 2. Zawartość ogólnego węgla organicznego (TOC) w ściekach kosmetycznych w funkcji czasu (minuty) przy wybranej dawce żelaza metalicznego (Fe = 2 g/L)

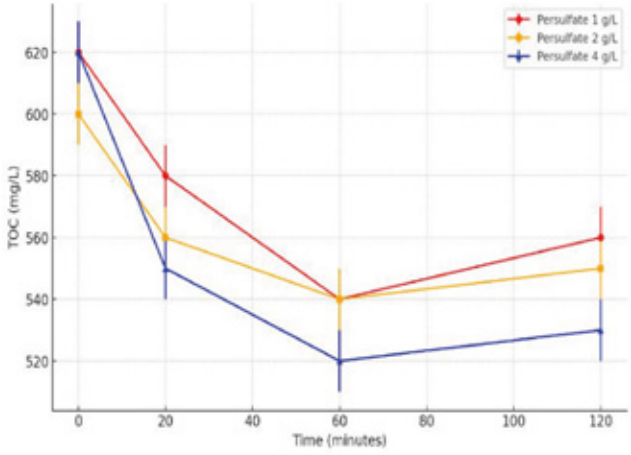

Fig. 3 Cosmetic Wastewater TOC [mg/L] against Time (minutes) at Selected Fe Dose (4g/L)

Rys. 3. Zawartość ogólnego węgla organicznego (TOC) w ściekach kosmetycznych w funkcji czasu (minuty) przy wybranej dawce żelaza metalicznego (Fe = 4g/L)

but sustained decreases. At 2 g/L Fe^0, first elimination was slower, with 559.3 mg/L at 15 minutes for 1 g/L persulfate and more marked decreases at higher persulfate concentrations. By 120 minutes, TOC fell to 512 mg/L under 4 g/L persulfate, which suggests increased efficiency. The greatest performance was seen at 4 g/L Fe^0, after 15

minutes with 4 g/L persulfate, TOC dropped to 540.1 mg/L, then progressively declined to about 520 mg/L at 120 minutes. These findings support the conclusion that, particularly with high iron dosage, greater persulfate levels improve pollutant removal. TOC removal efficiency rises with persulfate concentration and contact. time. The 4 g/L Fe^0 and 4 g/L persulfate condition saw rapid initial degradation within the first 15 minutes, then stabilization between 60–120 minutes. Showcased ideal circumstances for advanced oxidation in cosmetic wastewater treatment by showing the most consistent and substantial TOC decrease.

Effect of Iron Dosage on TOC Removal Efficiency in the Fe /Persulfate Process

The initial TOC of cosmetic wastewater was 613.2 mg/L, the TOC of was evaluated at three Fe^0 dosages (1, 2, and 4 g/L) for 1 g/L Fe^0, TOC dropped to 517.4 mg/L, corresponding to a removal efficiency of 15.6%. At 2 g/L Fe^0, TOC was reduced to 553.4 mg/L, equivalent to 9.8% removal. TOC dropped to 501.0 mg/L at the highest dosage of 4 g/L Fe^0, which resulted in the highest removal efficiency of 18.3%. These findings indicate that increasing Fe^0 dosage improved TOC reduction, the most successful performance was found at 4 g/L. However, the increase in efficiency was not exactly related to iron dosage, which implies that persulfate activation efficiency and radical consumption dynamics might also constrain general process performance [3] [20].

Discussion

The $Fe^0/S_2O_8^{2-}$ system showed great efficiency in lowering organic load in cosmetic wastewater, with a TOC elimination of up to 18.3% and a rise in biodegradability as shown by the BOD_5/TOC ratio. These findings support the possibility of treating complicated industrial wastewater with persulfate-based oxidation. Understanding why these results were obtained, what elements affected efficiency, and how they relate to other studies offers crucial background for the relevance and originality of this effort.

Treatment Mechanism

The observed TOC decrease is mostly caused by metallic iron's persulfate activation, which generates extremely reactive sulfate radicals ($SO_4^{\bullet-}$). These radicals are known with their longer half-life and better selectivity than hydroxyl radicals ($^{\bullet}OH$), they are ideal for breaking down complicated organic molecules often found in cosmetic wastewater. Although the presence of surfactants and emulsifiers in the effluent presented a problem, the great oxidizing power of sulfate radicals helped to partially dissolve these recalcitrant species. Effectiveness was also influenced by the dual function of metallic iron. Studies have detailed the removal mechanisms, and the role of iron chelates in improving persulfate activation and pollutant removal [20]. Apart from activating persulfate, Fe^0 also facilitated adsorption and coagulation processes, and this synergy aligns with the conclusions of a 2010 study, which found that iron-based activation enhances treatment performance [18]. Comparable rapid reaction phases have been reported in a 2018 study, where substantial trichloroethene (TCE) degradation occurred during the initial stage of persulfate oxidation in groundwater [6]. This consistency implies that persulfate systems always perform well in the early stages, independent of the kind of pollutant [3] [15] [20].

Factors Affecting Efficiency

Persulfate dosage: TOC removal increased consistently with higher persulfate concentrations. The 4 g/L dosage achieved the best performance, confirming that oxidant availability directly influences radical production. This trend is consistent with a 2020 study, which demonstrated that increasing persulfate doses enhanced the degradation of phenolic compounds but also resulted in diminishing returns due to radical scavenging at excessively high concentrations [11]. In our case, the absence of radical quenching at 4 g/L indicates that this concentration was still within an optimal range for cosmetic wastewater.

Iron dosage: Increasing iron concentration improved TOC removal, though the effect was less pronounced than persulfate dosage. The best performance was observed at 4 g/L Fe^0, supporting the role of iron as both an activator and coagulant. However, excessive iron can introduce secondary concerns such as sludge generation and radical scavenging, as noted by [21]. Our results indicate that optimization of iron dosage is critical to balance activation efficiency with byproduct management.

Reaction time: The bulk of TOC removal occurred within the first 60 minutes, with limited gains observed thereafter. This plateau effect suggests that the majority of reactive radicals were consumed early, and subsequent oxidation was hindered by the accumulation of intermediate byproducts. A similar pattern was reported in a 2019 study, where pharmaceutical wastewater pollutants underwent rapid initial degradation before reaching a stabilization phase attributed to radical depletion and the generation of refractory intermediates [7].

Features of wastewater: The process' efficiency was probably influenced by the high amounts of phosphorus (11 mg/L) and surfactants (800 mg/L). Phosphorus helps to drive radical competition, while surfactants can scavenge sulfate radicals thereby lowering their availability for TOC oxidation. These matrix effects may partly explain why TOC removal in this study was lower than that reported for simpler water matrices such as chlorinated solvents or dye effluents [2] [12]. Several similarities and differences can be drawn when using other advanced oxidation studies as a benchmark. A 2018 study reported that persulfate oxidation removed more than 80% of trichloroethene (TCE) from groundwater, a result that greatly exceeds the 18.3% total organic carbon (TOC) removal observed in this study [6]. The reason for the large difference is likely due to the specifics of the pollutants present. TCE is a chlorinated solvent and has simpler degradation pathways than a complex wastewater that has different surfactant rich compounds that are more resistant to mineralization. Both studies share similar characteristics in that both experiences rapid reduction in pollutants during the initial treatment phase, demonstrating the remarkable kinetic performance of persulfate activation. A 2014 study [12] reported chemical oxygen demand (COD) removals exceeding 40% in dye wastewater treated with persulfate, a finding further supported by a 2015 study [2]. The removal that we obtained in our study is less than those studies, however, it reflects the complexity of the pollutant load in cosmetic effluent; wastewater composition has a considerable effect on the efficacy of persulfate oxidation. These studies suggest persulfate is broadly applicable, but the efficiency is reliant on effluent type. A 2017 study reported on pharmaceutical wastewater showing improved biodegradability after treatment with persulfate, mirroring our findings of improved BOD_5/TOC ratio [7]. This similarity further confirms that persulfate processes can be effectively used as pretreatment steps that alter resistant compounds to a more biodegradable form rather than achieving total mineralization of organic pollution. In addition, 2010 study emphasized the dual role of iron in persulfate activation, enhancing both radical generation and coagulation [18]. This observation is perfectly in line with our results showing that Fe^0 enhanced pollutant removal in cosmetic wastewater. Our study further confirms this by demonstrating that the iron-activated persulfate system is also effective in surfactant- and phosphorus-rich effluents. Finally, the necessity of combining advanced oxidation processes with biological treatments to achieve improved degradation performance was highlighted in a 2018 study [4]. Our findings are a pillar for this method: the pre-

treatment with persulfate not only turned cosmetic wastewater into a biodegradable source, but it also made the biological treatment stage potentially more efficient. Moreover, iron had a double function in persulfate activation, whereby both radical generation and coagulation were facilitated [18]. This observation is perfectly in line with our results showing that Fe^0 enhanced pollutant removal in cosmetic wastewater. Our study further confirms this by demonstrating that the iron-activated persulfate system is also effective in surfactant- and phosphorus-rich effluents. [15]

Conclusion

An evaluation study took place for in situ chemical oxidation (ISO), where persulfate activation occurs through metallic iron-activated persulfates. The cosmetic industry wastewater under study contained high organic loads (TOC 613.3 mg/L, COD 1644 mg/L), high anionic surfactants (800 mg/L), and total phosphorus (11 mg/L). The introduction of Fe^0 into the persulfate system was found to be an effective treatment for refractory pollutant degradation and thus, worthy of further development, whereas the dissolution dynamics were governed strongly by factors such as persulfate dosage and contact time. TOC removal increased with persulfate concentration, where the 4 g/L Fe^0/4 g/L persulfate condition has shown the highest degradation efficiency. Pollutants were significantly removed in the first 15 min and then leveled off, corresponding well with the rapid yet terminating nature of radical oxidation. Interesting to note was that the approach made the effluents more biodegradable, authenticated through the increase of the BOD_5/TOC ratio. This observation clearly shows that iron-activated persulfate process is not apt for use on a stand-alone basis but rather as a pretreatment method for conversion of non-biodegradable compounds into intermediates. Thus, coupling with downstream biological processes may have a major effect on the opposed remediation efficiency, an idea corroborated by recent studies on coupled advanced oxidation–biological treatment processes. The results also highlighted limitations such as a diminished role of iron dosage as an independent parameter or increased radical scavenging at higher pollutant loads constraining complete mineralization. On the contrary, these results proved pollutant removal under actual complex cosmetic wastewater conditions that broaden the application of persulfate-based ISCO far beyond simpler contaminant matrices such as chlorinated solvents or dye wastewaters [2]. Choosing persulfate-based ISCO, wherein metallic iron serves as the activator, seems to provide a viable means of cosmetic wastewater remediation, especially for hybrid treatment trains. Several critical areas need to be addressed in future research, to help move this technology into practice for the treatment of industrial wastewater. First, under real operating conditions, the oxidant-to-catalyst ratios should be optimized in terms of efficiency, cost, and any secondary impacts, including iron leaching. Second, both persulfate oxidation and biological treatment should be subjected to further investigation. Persulfate-based ISCO systems would achieve better pollutant elimination and reduced oxidant consumption through their combination with adsorption methods and membrane separation techniques. The solution to these obstacles will help persulfate-based ISCO become a core sustainable industrial wastewater management system which fights persistent organic pollutants in water systems for environmental protection [3] [20].

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