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# Removal of microplastics by electrocoagulation: A brief review and bibliometric analysis

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***Abstract – This study aims to conduct a bibliometric analysis and a brief review of scientific documents addressing the removal of microplastics (PMs) from liquid effluents using electrocoagulation (EC) technology. The search strategy identified 89 papers in Scopus and 61 in WoS. The bibliometric analysis used 105 documents, while the review included 11 articles. The findings indicate a growing interest among researchers in the application of EC for PMs removal, as evidenced by the increasing number of publications in recent years. Many studies focus on the analysis of synthetic samples, identifying current density, pH, salt concentration, electrode spacing, and electrode material as the most influential parameters affecting both efficiency and process costs. Reported operational costs position EC as a competitive technology. However, further studies incorporating maintenance costs and waste management considerations are necessary to assess its economic viability fully. Future research should focus on optimizing operational parameters, investigating the interaction of PMs with other contaminants, scaling up EC systems, and integrating EC with other treatment technologies.***

***Keywords-- microplastic removal, electrocoagulation, bibliometrics, emerging pollutants, water treatment.***

## I. INTRODUCTION

Plastic exhibits remarkable versatility in its physical and chemical properties. Combined with its low production cost, plastic has become one of the most widely used materials across various industries [1]. However, a significant proportion of this material is improperly disposed of, causing detrimental effects on numerous ecosystems. By 2025, more than 250 million metric tons of plastic will be discharged into the oceans [2].

Plastics degrade naturally or artificially into smaller particles. When these particles range from 0.1 µm to 5 mm, they are classified as microplastics (MPs). It is estimated that between 60% and 80% of plastic discharged into water bodies consists of microplastics [3]. The sources of microplastics are diverse, with wastewater treatment plants being one of the primary contributors [4]. Each wastewater treatment plant (WWTP) is estimated to release over 4 million microplastic particles daily [5], [6]. This is largely because the WWTP is not designed to eliminate microcontaminants and no regulations currently govern these emerging pollutants. Consequently, it is crucial to develop efficient techniques for controlling and removing microplastics [7]. Among the available alternatives, electrocoagulation stands out as a technology that is easy to operate, highly efficient, and cost-effective [8].

There is a noticeable scarcity of reviews addressing the application of electrocoagulation (EC) to remove microplastics. However, some preliminary studies have been conducted, such as a review of the use of electrochemical technologies for identifying and eliminating microplastics from water [9]. Reference [10] analyzed the principles, operating conditions, and mechanisms of microplastic removal via EC, however, this review does not specify the academic sources consulted or the recency of the articles analyzed.

More general reviews have also been published, evaluating the removal of various emerging pollutants (including microplastics) using EC [8], [11], [12]. Similarly, reviews addressing the presence and removal of microplastics in wastewater using different technologies, including EC, have been published [13]–[20].

Despite these efforts, research on removing microplastics through electrocoagulation remains in its early stages [9]. This is evidenced by the limited number of reviews specifically focusing on the application of electrocoagulation for removing micro- and nanoplastics in wastewater. A bibliometric analysis is needed to identify key advancements reported in the literature and future research perspectives in this field.

Therefore, this study aims to conduct a comprehensive literature review and analyze the key bibliometric indicators related to the application of electrocoagulation for microplastic removal in wastewater. This investigation seeks not only to provide a deeper understanding of the use of this technology for MP removal but also to offer insights for future studies on this topic.

## II. METHODOLOGY

### *A. Database and bibliometric indicators*

The search and retrieval of scientific documents were conducted using the two leading academic databases worldwide: Scopus and Web of Science (WoS) [21]. The Query applied in both databases was: (microplastics OR "microplastics removal") AND electrocoagulation, using TITLE-ABS-KEY for Scopus and Topic for WoS. The retrieved documents included original articles, reviews, conference papers, book chapters, and books. The search results identified 89 documents in Scopus and 61 in WoS (until November 30, 2024).

With the support of RStudio, 45 duplicate documents published in both databases were identified and subsequently removed. The remaining documents were unified into a dataset comprising 105 entries and then analyzed using Bibliometrix. Bibliometrix is a comprehensive mapping analysis tool designed for use within the R software environment [22], [23]. The primary bibliometric indicators analyzed include annual production, leading authors, most-cited documents, and the most frequently occurring keywords.

As criteria for inclusion and exclusion, only original articles were considered for this review, excluding reviews, book chapters, and books. This filtering process identified 41 documents in SCOPUS and 53 documents in WoS. The identification and selection of scientific articles were conducted following the PRISMA methodology (see Fig. 1), frequently applied in review studies [24], [25]. This approach allowed the identification of 11 scientific articles present in both academic databases.

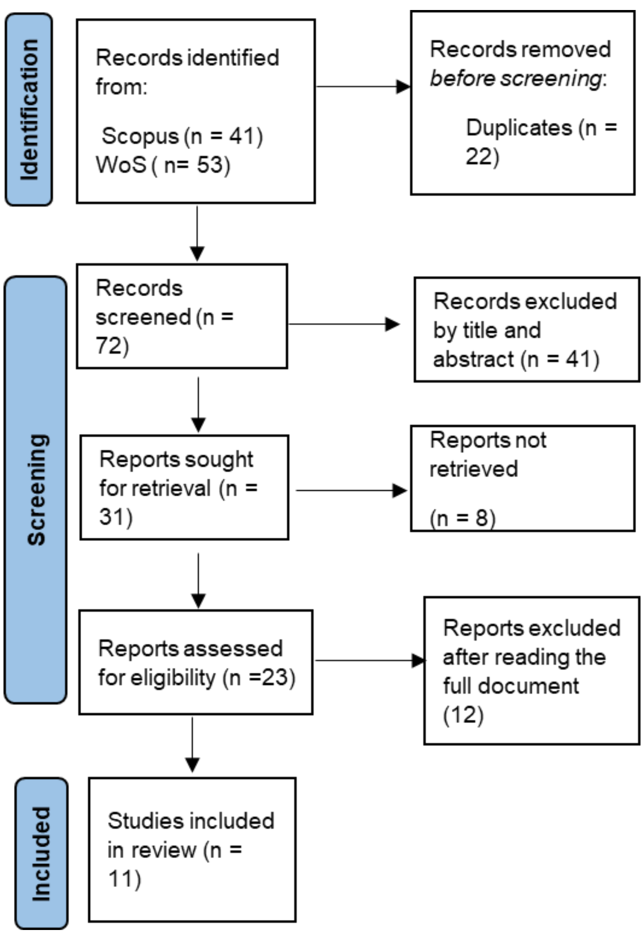


Fig. 1 PRISMA Diagram describing the selection of relevant articles for the systematic review.

## III. Results and Discussion

### A. *Main bibliometric indicators*

The annual scientific production, presented in Fig. 2, highlights the growing interest of the scientific community in this subject. Notably, the number of publications in this field began with three in 2020 and rose to 47 by 2024. This exponential growth (98.95% annual growth rate) reflects increasing attention to microplastic removal, particularly through electrocoagulation. This trend is attributed to the unique advantages of electrocoagulation, including high efficiency, versatility in removing various contaminants, low maintenance costs, and compatibility with other technologies [26].

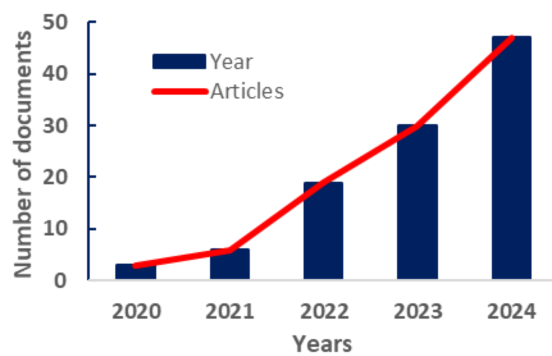


Fig. 2 Annual scientific production in Scopus and WoS.

### B. *Most cited papers*

Identifying and reviewing the most-cited scientific documents is a crucial initial step when delving into a specific research topic. Table I lists the 09 most-cited documents, including the first author, year of publication, and DOI. All the listed documents have been cited over 100 times. Water Research, Chemosphere, and Environmental Chemistry Letters published the three most-cited documents (with more than 200 citations as of 2023). However, it is important to highlight that in December 2024, Chemosphere was removed from WoS indexing [27].

Among the journals with the highest number of publications in this top 09 list, Chemical Engineering Journal and Science of the Total Environment stand out with two and three publications each. This information is particularly relevant when selecting a journal to submit research related to this topic.

### C. *Most frequent keywords*

Word clouds provide users with terms that highlight the most significant elements of a topic. Words displayed in larger fonts are considered the most important [28]. The analysis of keywords has been a subject of investigation in bibliometrics [29], [30].

TABLE I
MOST CITED SCIENTIFIC DOCUMENTS

| First Author, Year | Journal | DOI | Total Citations |
|---|---|---|---|
| Rajala K, 2020 [31] | Water Research | 10.1016/j.watres.2020.116045 | 250 |
| Shen M, 2020 [18] | Chemosphere | 10.1016/j.chemosphere.2020.126612 | 220 |
| Osman AI, 2023 [20] | Environmental Chemistry Letters | 10.1007/s10311-023-01593-3 | 202 |
| Shen M, 2022 [9] | Chemical Engineering Journal | 10.1016/j.cej.2021.131161 | 174 |
| Sharma S, 2021 [32] | Chemical Engineering Journal | 10.1016/j.cej.2020.127317 | 160 |
| Krishnan RY, 2023 [33] | Science of the Total Environment | 10.1016/j.scitotenv.2022.159681 | 149 |
| Ahmed MB, 2021 [34] | Science of the Total Environment | 10.1016/j.scitotenv.2021.145793 | 128 |
| Xu Q, 2021 [35] | Chemical Engineering Journal | 10.1016/j.cej.2021.129123 | 112 |
| Thacharodi A, 2024 [36] | Journal of Environmental Management | 10.1016/j.jenvman.2023.119433 | 104 |

Fig. 3 illustrates the word cloud of the most frequently used keywords in the 105 analyzed articles. Prominent keywords include "microplastics," "microplastic," and "electrocoagulation," which were reported most often in the scientific literature. These terms are frequently accompanied by related keywords such as "waste-water," "environmental monitoring," "water pollutants," and "removal," which reflect the applications of electrocoagulation technology or the sources containing microplastics.

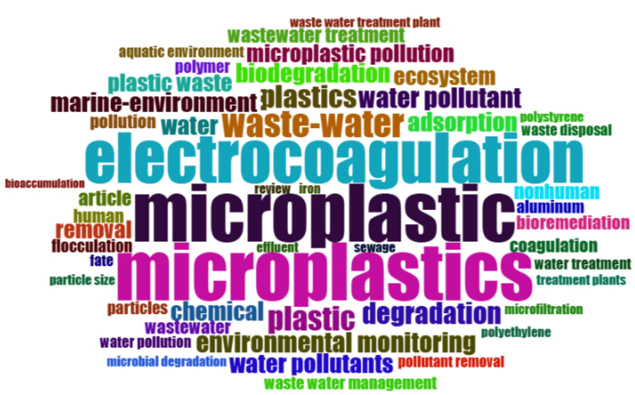


Fig 3. Most popular keywords

Additionally, less frequent keywords, such as "aluminum," "polyethylene," and "particle size," are associated with specific objectives or factors evaluated in certain studies.

## D. *Sample Characteristics*

The studies analyzed alternate between synthetic samples prepared in the laboratory [37]–[40] which simulate real effluents (e.g., laundry wastewater or wastewater from treatment plants), and those that evaluate both synthetic and real effluents [4], [41]–[45]. Table 2 presents the authors, types of samples, and characteristics of the microplastics (MPs) analyzed.

The comparability between different studies is significantly improved by using synthetic wastewater, as it eliminates the inherent variability found in real wastewater. Additionally, synthetic samples allow for more rapid technological development [46], substantial cost and logistical reductions [47], and greater ease of standardization and adaptability [48]. However, the absence of organic and inorganic components typically present in real effluents can alter process efficiency, often resulting in lower removal rates compared to those achieved with synthetic effluents.

Regarding the microplastic particles evaluated, several materials stand out, including commercial polyester [4], polypropylene (PP) [38], [39], [41], [42], polyethylene terephthalate (PET) [38], [39], [42], polyethylene (PE), polyvinyl chloride (PVC) [37], [41], polymethyl methacrylate (PMMA) [41], and polystyrene (PS) [40]. The choice of polymer type for synthetic samples depends on the type of effluent being simulated. For instance, polyester, polypropylene (PP), polyethylene (PE), and PVC are used to simulate wastewater from treatment plants [4], [37], [39]. Meanwhile, PET, PP, LDPE, PA, and PS are commonly used for simulating laundry wastewater [38], [42]. The particle sizes evaluated range from 50 to 5000 µm.

## D. *Operational Parameters of the Electrocoagulation System*

The control of operational parameters has been a focal point in numerous studies addressing this topic. The significance of these parameters lies in their ability to influence both the efficiency of the process and the associated treatment costs and energy consumption [4], [9], [37]. The most frequently studied parameters include:

i) Current Density: It has been demonstrated that an appropriate current density can achieve microplastic removal efficiencies exceeding 80% [4], [9], [37]; ii) pH: A neutral or near-neutral pH has been shown to allow for removal efficiencies of up to 98% [9], [37]; iii) Electrode Material: The anodic material, particularly aluminum, has been proven to be more effective than iron for microplastic removal [9]; iv) Electrolyte Concentration and Voltage: Both factors significantly impact removal efficiency [9] as well as operational costs; v) operating Time: This parameter influences floc formation, with longer times promoting improved floc development. However, excessively long operating times can have adverse effects, not only reducing efficiency but also increasing costs [49].

Table II presents the key characteristics of the electrocoagulation system, including optimal parameters and the achieved efficiencies in the removal of microplastics and other contaminants.

### E. *Cost Estimation*

Electrocoagulation is an effective technique for the removal of microplastics, and cost estimation becomes a critical parameter in its application. Reported operational costs range from \$0.125 to \$0.53 per cubic meter, primarily covering energy consumption and electrode wear. However, some costs, such as maintenance and the treatment/disposal of sludge, are not commonly accounted for in the literature. Among the most influential parameters affecting cost estimation are current density, pH, reaction time, NaCl concentration, and electrode material.

A near-neutral pH and low current densities minimize energy costs [4]. Similarly, aluminum electrodes achieve higher removal efficiency compared to iron electrodes. However, aluminum electrodes are associated with higher costs than their iron counterparts.

### E. *Future Research Directions*

The application of electrocoagulation for microplastic removal remains in its early stages, and an increase in the number of studies is expected in the coming years. Future research should focus on scaling up the technology, evaluating the lifespan of electrodes, and assessing associated costs [44], [50]. Optimizing reactor design is another critical area of interest [4]. Additionally, attention should be given to the fate of microplastics following treatment [42], [45] and the evaluation of the long-term benefits of electrocoagulation [42].

It is also essential to investigate the influence of other parameters on process efficiency, such as dissolved oxygen levels, organic matter content [39], [41], [43], reactor configurations, and the effects of various types of microplastics in diverse real effluents [39], [44]. Moreover, exploring renewable energy sources in electrocoagulation systems is a promising avenue for future research [39].

The evaluation of different microplastics and their interaction with various electrode materials is another important topic [45]. Furthermore, the integration of electrocoagulation with other technologies offers significant potential for enhancing its efficiency and effectiveness [40].

TABLE II
CHARACTERISTICS OF THE ELECTROCOAGULATION SYSTEM, OPTIMUM PARAMETERS AND REMOVALS ACHIEVED

| Author(s) | EC System Characteristics | Optimal Conditions | Removal Efficiency |
|---|---|---|---|
| [4] | Batch system (2.4 L), 1.92–8.07 mA/cm², pH 2–7, 90 min and 5 min (sedimentation). Al (30 cm × 2.54 cm × 0.25 cm; active area: 110 cm²), De = 1 cm, 60 rpm. | pH 4, current density: 2.88 mA/cm², 60 min. | 98.5% microplastics, 92.2% COD, 88.8% thermotolerant coliform. |
| [41] | Electrodes: 7 cm × 6 cm × 0.1 cm, effective area: 84 cm². Reaction time: 60 min, 100 rpm, sedimentation time: 30 min. | Current density: 15 mA/cm², ozone dosage: 66.2 mg/L. | 90% microplastics, 93.9% CODcr, 99.7% turbidity, 99.9% LAS. |
| [42] | Fe anode and stainless-steel cathode, De = 3 cm, 1L reactor (open flow: 1 L/3 min), sedimentation: 10 min, 15 V, 1 A. Polymer type and MP shape effects evaluated. | Higher efficiency was reported in alkaline pH. | 70–93.5% microplastics (synthetic and laundry wastewater), differentiated removal: PET > LDPE > PP > PA. |
| [38] | Al/graphene and Fe/graphene electrodes (25 cm × 2.5 cm × 0.25 cm), monopolar parallel connection, De = 2 cm, NaCl: 0.01–0.1 M, 8–16 V, pH 3–10. | Aluminum/graphene: optimal pH 5.5, 10 V. Iron/graphene: optimal pH 7, 14 V, NaCl: 0.1 M. | Al/graphene: 96% PET and PS. Fe/graphene: 86% microplastics. Fe/graphene >99% Cr. |
| [39] | Sono-electrocoagulation reactor with aluminum electrodes (5 cm × 7 cm × 1.25 mm), De = 1 cm. Voltage: 4.5–11.5 V, 60–120 min, maximum temperature: 45 °C. | 90.35% efficiency with 6343.36 MPs/L, 0.018 mol/L $Na_2SO_4$, 10.03 V, and 62.21 min. | 90.34% microplastic removal, with COD and TSS reduction. |
| [43] | Batch reactors with aluminum electrodes (7 × 3.5 cm, 99.52% purity), De = 5 mm, solution adjusted with 0.5 g/L NaCl | pH 6, current density: 3.81 mA/cm², reaction time: 15 min. | Maximum MPs removal efficiency: 99% under optimal conditions. |
| [44] | Semi-batch system with aluminum electrodes (distance: 5 mm, surface area: 6.42 × $10^{-3}$ m²). Magnetic stirrer: 180 rpm. | Current density: 300 A/m², reaction time: 25 min, pH 7, ambient temperature. | MPs: 97.9%, surfactants: 91.2%, COD: 86.3%, turbidity reduced from 145 ± 10 NTU to 1.2 ± 0.7 NTU. |
| [50] | Batch reactor (2 L) with aluminum electrodes (10 cm × 5 cm), current: 0.6A–2.0A, 10–30 min, pH 3–5. | Current: 2.0A, reaction time: 30 min, initial pH: 4. | 90.3% microplastics |
| [45] | Cylindrical reactor (500 mL) with electrodes: Fe, Al, stainless steel (SS), Ti, graphite (Gr). Current: up to 3 A, voltage: up to 30 V, 300 rpm. | Stainless steel cathode exhibited highest removal efficiency. | COD: 89.6%, surfactants: 99.4%, oil-grease: 99.3%. No specific microplastic removal reported. |

| | | | |
|---|---|---|---|
| [37] | aluminum and iron electrodes (90 mm × 60 mm × 1 mm), De = 2 cm. Current density: 10–20 A/m². | Al-Fe electrode combination, current density: 20 A/m², neutral pH: 7. | 100% removal of both polymers (PE and PVC) with EC. |
| [40] | Al and Fe anodes, cathode: stainless steel. reactor: 0.58 L and 2.00 L. 120 × 40 × 1 mm and 200 × 80 × 2 mm, 100 rpm. | Current density: 16.3 A/m². Higher electrolyte concentrations and smaller µPS sizes | 97% microplastics |

Some emerging technologies have been reported for microplastic removal, such as membrane bioreactors (MBR), although the removal of fibrous microplastics is less efficient and membrane fouling has been reported [51]. Likewise, rapid sand filtration shows efficiencies of 75.49% to 97%, while processes such as dissolved air flotation and electrocoagulation reach around 95% and 99% removal, respectively [52]. While this study includes only eleven articles, which may limit the breadth and variability of research captured, it is important to note that the field of electrocoagulation for microplastic removal is still emerging. Additionally, the lack of access to some non-open-access studies further constrains the scope of the review.

## IV. Conclusions

The application of electrocoagulation for removing microplastics from water has garnered increasing interest among researchers, as evidenced by the exponential growth in publications over the past four years and the high citation counts of the top 09 identified documents. Furthermore, the analysis of the keyword cloud reveals the thematic scope of these studies, highlighting terms such as wastewater, water pollutants, environmental monitoring, and ecosystem, which are associated with the presence of microplastics as an emerging contaminant requiring monitoring and control in various ecosystems, particularly within water treatment systems.

Given that this research area remains in its early stages, most studies have focused on synthetic effluents that simulate real wastewater, particularly those from water treatment plants and laundries. Consequently, further research is needed to evaluate real effluents with diverse compositions. The most critical operational parameters in electrocoagulation include current density, pH, electrode spacing, electrolyte concentration, and anode material. These parameters, along with the type and concentration of microplastics, can significantly impact process efficiency and operational costs, underscoring the need for additional studies.

Cost estimation is a key factor in decision-making for the implementation of any technology. In the case of electrocoagulation, preliminary assessments have reported operational costs ranging from $0.125 to $0.53 per cubic meter. However, future studies should incorporate maintenance expenses, and the costs associated with waste treatment following the process.

The efficiency of electrocoagulation is highly dependent on various operational parameters; further research is essential to optimize the operational parameters of electrocoagulation systems, assess the impact of polymer type and size, and examine their interactions with electrode materials. Additionally, greater emphasis should be placed on investigating the interactions of microplastics with other contaminants, such as dissolved organic matter, heavy metals, and pharmaceuticals. Moreover, studies on the scalability of electrocoagulation technology and its integration with other treatment systems are necessary to advance its practical applications.

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## References

[1] B. Alvim, M. A. Bes-Piá, and J. A. Mendoza-Roca, "Separation and identification of microplastics from primary and secondary effluents and activated sludge from wastewater treatment plants," Chem. Eng. J., vol. 402, p. 126293, 2020, doi: https://doi.org/10.1016/j.cej.2020.126293.

[2] J. R. Jambeck et al., "Plastic waste inputs from land into the ocean," Science, vol. 347, no. 6223, pp. 768–771, Feb. 2015, doi: 10.1126/science.1260352.

[3] Z. D. Taha, R. Md Amin, S. T. Anuar, A. A. A. Nasser, and E. S. Sohaimi, "Microplastics in seawater and zooplankton: A case study from Terengganu estuary and offshore waters, Malaysia," Sci. Total Environ., vol. 786, p. 147466, 2021, doi: https://doi.org/10.1016/j.scitotenv.2021.147466.

[4] D. Elkhatib, V. Oyanedel-Craver, and E. Carissimi, "Electrocoagulation applied for the removal of microplastics from wastewater treatment facilities," Sep. Purif. Technol., vol. 276, p. 118877, 2021, doi: https://doi.org/10.1016/j.seppur.2021.118877.

[5] Z. Zhang and Y. Chen, "Effects of microplastics on wastewater and sewage sludge treatment and their removal: A review," Chem. Eng. J., vol. 382, p. 122955, 2020, doi: https://doi.org/10.1016/j.cej.2019.122955.

[6] S. A. Mason et al., "Microplastic pollution is widely detected in US municipal wastewater treatment plant effluent," Environ. Pollut., vol. 218, pp. 1045–1054, 2016, doi: https://doi.org/10.1016/j.envpol.2016.08.056.

[7] M. Lapointe, J. M. Farner, L. M. Hernandez, and N. Tufenkji, "Understanding and Improving Microplastic Removal during Water Treatment: Impact of Coagulation and Flocculation," Environ. Sci. Technol., vol. 54, no. 14, pp. 8719–8727, Jul. 2020, doi: 10.1021/acs.est.0c00712.

[8] P. V Nidheesh, J. Scaria, D. S. Babu, and M. S. Kumar, "An overview on combined electrocoagulation-degradation processes for the effective treatment of water and wastewater," Chemosphere, vol. 263, p. 127907, 2021, doi: https://doi.org/10.1016/j.chemosphere.2020.127907.

[9] M. Shen et al., "Efficient removal of microplastics from wastewater by an electrocoagulation process," Chem. Eng. J., vol. 428, p. 131161, 2022, doi: https://doi.org/10.1016/j.cej.2021.131161.

[10] F. Liu et al., "A systematic review of electrocoagulation technology applied for microplastics removal in aquatic environment," Chem. Eng. J., vol. 456, p. 141078, 2023, doi: https://doi.org/10.1016/j.cej.2022.141078.

[11] M. Ammar, E. Yousef, M. A. Mahmoud, S. Ashraf, and J. Baltrusaitis, "A Comprehensive Review of the Developments in Electrocoagulation for the Removal of Contaminants from Wastewater," Separations, vol. 10, no. 6. 2023, doi: 10.3390/separations10060337.
[12] Y. Mao, Y. Zhao, and S. Cotterill, "Examining Current and Future Applications of Electrocoagulation in Wastewater Treatment," Water, vol. 15, no. 8. 2023, doi: 10.3390/w15081455.
[13] W. Biao, N. A. Hashim, M. F. Bin Rabuni, O. Lide, and A. Ullah, "Microplastics in aquatic systems: An in-depth review of current and potential water treatment processes," Chemosphere, vol. 361, p. 142546, 2024, doi: https://doi.org/10.1016/j.chemosphere.2024.142546.
[14] Y. Li et al., "Microplastics in Water: A Review of Characterization and Removal Methods," Sustainability, vol. 16, no. 10. 2024, doi: 10.3390/su16104033.
[15] Q. Liu, Y. Chen, Z. Chen, F. Yang, Y. Xie, and W. Yao, "Current status of microplastics and nanoplastics removal methods: Summary, comparison and prospect," Sci. Total Environ., vol. 851, p. 157991, 2022, doi: https://doi.org/10.1016/j.scitotenv.2022.157991.
[16] M. Bodzek, A. Pohl, and C. Rosik-Dulewska, "Microplastics in Wastewater Treatment Plants: Characteristics, Occurrence and Removal Technologies," Water, vol. 16, no. 24. 2024, doi: 10.3390/w16243574.
[17] T. Zhou, S. Song, R. Min, X. Liu, and G. Zhang, "Advances in chemical removal and degradation technologies for microplastics in the aquatic environment: A review," Mar. Pollut. Bull., vol. 201, p. 116202, 2024, doi: https://doi.org/10.1016/j.marpolbul.2024.116202.
[18] M. Shen et al., "Removal of microplastics via drinking water treatment: Current knowledge and future directions," Chemosphere, vol. 251, p. 126612, 2020, doi: https://doi.org/10.1016/j.chemosphere.2020.126612.
[19] B. Cui et al., "Chemical methods to remove microplastics from wastewater: A review," Environ. Res., vol. 249, p. 118416, 2024, doi: https://doi.org/10.1016/j.envres.2024.118416.
[20] A. I. Osman et al., "Microplastic sources, formation, toxicity and remediation: a review," Environ. Chem. Lett., vol. 21, no. 4, pp. 2129–2169, 2023, doi: 10.1007/s10311-023-01593-3.
[21] R. Pranckutė, "Web of Science (WoS) and Scopus: The Titans of Bibliographic Information in Today's Academic World," Publications, vol. 9, no. 1. 2021, doi: 10.3390/publications9010012.
[22] H. Arruda, E. R. Silva, M. Lessa, D. J. Proença, and R. Bartholo, "VOSviewer and Bibliometrix.," J. Med. Libr. Assoc., vol. 110, no. 3, pp. 392–395, Jul. 2022, doi: 10.5195/jmla.2022.1434.
[23] M. Aria and C. Cuccurullo, "bibliometrix: An R-tool for comprehensive science mapping analysis," J. Informetr., vol. 11, no. 4, pp. 959–975, 2017, doi: https://doi.org/10.1016/j.joi.2017.08.007.
[24] F. García-Ávila et al., "Cleaner production and drinking water: Perspectives from a scientometric and systematic analysis for a sustainable performance," South African J. Chem. Eng., vol. 45, pp. 136–148, 2023, doi: https://doi.org/10.1016/j.sajce.2023.05.003.
[25] A. A. Selçuk, "A Guide for Systematic Reviews: PRISMA.," Turkish Arch. Otorhinolaryngol., vol. 57, no. 1, pp. 57–58, Mar. 2019, doi: 10.5152/tao.2019.4058.
[26] P. P. Das, M. Sharma, and M. K. Purkait, "Recent progress on electrocoagulation process for wastewater treatment: A review," Sep. Purif. Technol., vol. 292, p. 121058, 2022, doi: https://doi.org/10.1016/j.seppur.2022.121058.
[27] J. Robinson, "High profile chemistry journal removed from Web of Science index," Royal society of chemistry, 2025. https://www.chemistryworld.com/news/high-profile-chemistry-journal-removed-from-web-of-science-index/4020769.article (accessed Jan. 21, 2025).
[28] B. Tessem, S. Bjørnestad, W. Chen, and L. Nyre, "Word cloud visualisation of locative information," J. Locat. Based Serv., vol. 9, no. 4, pp. 254–272, Oct. 2015, doi: 10.1080/17489725.2015.1118566.
[29] Y. Jin, "Development of Word Cloud Generator Software Based on Python," Procedia Eng., vol. 174, pp. 788–792, 2017, doi: 10.1016/j.proeng.2017.01.223.
[30] M. Wang and L. Chai, "Three new bibliometric indicators/approaches derived from keyword analysis," Scientometrics, vol. 116, no. 2, pp. 721–750, 2018, doi: 10.1007/s11192-018-2768-9.
[31] K. Rajala, O. Grönfors, M. Hesampour, and A. Mikola, "Removal of microplastics from secondary wastewater treatment plant effluent by coagulation/flocculation with iron, aluminum and polyamine-based chemicals.," Water Res., vol. 183, p. 116045, Sep. 2020, doi: 10.1016/j.watres.2020.116045.
[32] S. Sharma, S. Basu, N. P. Shetti, M. N. Nadagouda, and T. M. Aminabhavi, "Microplastics in the environment: Occurrence, perils, and eradication.," Chem. Eng. J., vol. 408, p. 127317, Mar. 2021, doi: 10.1016/j.cej.2020.127317.
[33] R. Y. Krishnan, S. Manikandan, R. Subbaiya, N. Karmegam, W. Kim, and M. Govarthanan, "Recent approaches and advanced wastewater treatment technologies for mitigating emerging microplastics contamination - A critical review.," Sci. Total Environ., vol. 858, no. Pt 1, p. 159681, Feb. 2023, doi: 10.1016/j.scitotenv.2022.159681.
[34] M. B. Ahmed et al., "Microplastic particles in the aquatic environment: A systematic review.," Sci. Total Environ., vol. 775, p. 145793, Jun. 2021, doi: 10.1016/j.scitotenv.2021.145793.
[35] Q. Xu, Q.-S. Huang, T.-Y. Luo, R.-L. Wu, W. Wei, and B.-J. Ni, "Coagulation removal and photocatalytic degradation of microplastics in urban waters," Chem. Eng. J., vol. 416, p. 129123, 2021, doi: https://doi.org/10.1016/j.cej.2021.129123.
[36] A. Thacharodi et al., "Microplastics in the environment: A critical overview on its fate, toxicity, implications, management, and bioremediation strategies," J. Environ. Manage., vol. 349, p. 119433, 2024, doi: https://doi.org/10.1016/j.jenvman.2023.119433.
[37] C. Akarsu, H. Kumbur, and A. E. Kideys, "Removal of microplastics from wastewater through electrocoagulation-electroflotation and membrane filtration processes," Water Sci. Technol., vol. 84, no. 7, pp. 1648–1662, 2021, doi: 10.2166/wst.2021.356.
[38] E. W. Gabisa and C. Ratanatamskul, "Effects of operating conditions on removal of microplastics (PET, PP, PS) from wastewater by electrocoagulation systems and kinetics of chromium removal in the presence of microplastics," J. Water Process Eng., vol. 61, no. April, p. 105313, 2024, doi: 10.1016/j.jwpe.2024.105313.
[39] M. Ghadami et al., "Removal of Microplastics from Synthetic Wastewater via Sono-Electrocoagulation Process: Modeling and Optimization by Central Composite Design," Pollution, vol. 10, no. 2, pp. 754–765, 2024, doi: 10.22059/poll.2024.369522.2179.
[40] S. Mateo, A. Zhang, A. Piedra, A. Ruiz, R. Miranda, and F. Rodríguez, "Electrocoagulation Assessment to Remove Micropolystyrene Particles in Wastewater," ACS ES T Water, vol. 4, no. 7, pp. 3049–3058, 2024, doi: 10.1021/acsestwater.4c00312.
[41] M. Luo et al., "Removal and toxic forecast of microplastics treated by electrocoagulation: Influence of dissolved organic matter," Chemosphere, vol. 308, no. P1, p. 136309, 2022, doi: 10.1016/j.chemosphere.2022.136309.
[42] K. Senathirajah, R. Kandaiah, L. Panneerselvan, C. I. Sathish, and T. Palanisami, "Fate and transformation of microplastics due to electrocoagulation treatment: Impacts of polymer type and shape," Environ. Pollut., vol. 334, no. July, p. 122159, 2023, doi: 10.1016/j.envpol.2023.122159.
[43] M. Sezer, M. Isgoren, S. Veli, E. Topkaya, and A. Arslan, "Removal of microplastics in food packaging industry wastewaters with electrocoagulation process: Optimization by Box-Behnken design," Chemosphere, vol. 352, no. November 2023, p. 141314, 2024, doi: 10.1016/j.chemosphere.2024.141314.
[44] N. A. Yaranal, S. A. Kuchibhotla, S. Subbiah, and K. Mohanty, "Identification, removal of microplastics and surfactants from laundry wastewater using electrocoagulation method," Water Emerg. Contam. Nanoplastics, vol. 3, no. 1, pp. 1–15, 2024, doi: 10.20517/wecn.2023.46.
[45] C. Akarsu, Z. Isik, I. M'barek, R. Bouchareb, and N. Dizge, "Treatment of personal care product wastewater for reuse by integrated electrocoagulation and membrane filtration processes," J. Water Process Eng., vol. 48, no. May, p. 102879, 2022, doi: 10.1016/j.jwpe.2022.102879.
[46] A. E. Uman, R. A. Bair, and D. H. Yeh, "Direct Membrane Filtration of Wastewater: A Comparison between Real and Synthetic Wastewater," Water, vol. 16, no. 3. 2024, doi: 10.3390/w16030405.
[47] A. K. Kargol, S. R. Burrell, I. Chakraborty, and H. L. Gough, "Synthetic wastewater prepared from readily available materials: Characteristics and economics," PLOS Water, vol. 2, no. 9, p. e0000178, Sep. 2023, [Online]. Available: https://doi.org/10.1371/journal.pwat.0000178.

[48] E. O'Flaherty and N. F. Gray, "A comparative analysis of the characteristics of a range of real and synthetic wastewaters," Environ. Sci. Pollut. Res., vol. 20, no. 12, pp. 8813–8830, 2013, doi: 10.1007/s11356-013-1863-y.
[49] M. Nasrullah, L. Singh, S. Krishnan, M. Sakinah, D. M. Mahapatra, and A. W. Zularisam, "Electrocoagulation treatment of raw palm oil mill effluent: Effect of operating parameters on floc growth and structure," J. Water Process Eng., vol. 33, p. 101114, 2020, doi: https://doi.org/10.1016/j.jwpe.2019.101114.
[50] F. J. C. Teran, V. A. A. Mosque, L. R. De Oliveira, and R. M. F. Cuba, "Analysis of the Efficiency of the Electrocoagulation Process in the Removal of Microplastics," Rev. Gest. Soc. e Ambient., vol. 17, no. 3, pp. 1–7, 2023, doi: 10.24857/rgsa.v17n3-027.
[51] J. Bayo, J. López-Castellanos, and S. Olmos, "Membrane bioreactor and rapid sand filtration for the removal of microplastics in an urban wastewater treatment plant," Mar. Pollut. Bull., vol. 156, p. 111211, 2020, doi: https://doi.org/10.1016/j.marpolbul.2020.111211.
[52] M. Bodzek and A. Pohl, "Removal of microplastics in unit processes used in water and wastewater treatment: a review," Arch. Environ. Prot., vol. 48, no. 4, pp. 102–128, 2022, doi: 10.24425/aep.2022.143713.