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Comparing AC vs DC Systems for Electrocoagulation of Microplastics in Waterbodies – An Innovative Solution

Atishaya Gupta
atishayagupta07@gmail.com
Dhirubhai Ambani International School, Mumbai, Maharashtra

Agastyaa Goradia
AgastyaaGoradiagoradiaagastyaa@gmail.com
Dhirubhai Ambani International School, Mumbai, Maharashtra

ABSTRACT

The efficiency of the removal of microplastics from water by using the generated EC from AC and DC systems is theoretically examined through this experiment. Microplastics are among the most frequently known environmental polluters that threaten aquatic life and human health. Electrocoagulation seems to be a promising method for the considerable removal of pollutants by exploiting the coagulative properties through electrochemically produced ions. The paper compares the efficacy of coagulation, energy consumption, and water quality after the treatment in AC and DC setups suggesting innovation to optimise the efficiency as well as sustainability of removal.

Keywords: *Electrocoagulation, Environmental, Microplastics, Alternating Current, Direct Current*

INTRODUCTION

It has come up and flourished like a monolith threatening every step of life for the last century. Global consumption of plastics has gone up 20-fold in the last 50 years and is expected to double during the next 20 years. (1) Sadly, this plastic consumption growth has also reflected itself through the constantly increasing appearance of plastics in waste streams, from land and water. It has been estimated that, as of 2016, there existed more than 150 million tons of plastic waste in marine waters. (2) Around 0.1 -- 1.5% of this waste are microplastics or plastic particles of less than 5 mm in diameter. (3) Microplastics are either primary or secondary. Primary microplastics are manufactured with the explicit purpose of serving very precise functions in many industries. The highest deposition is in personal care and cosmetic products, including facial scrubs, of which approximately 93% of microplastics deployed in PCCPs are polyethylene-derived beads. (3) Most of these microplastic particles enter via wastewater streams, are not removed by WWTPs, and eventually reach marine waters. (4) Secondary microplastics are formed by the degradation of larger plastic particles currently present in water streams by a combination of UV degradation, mechanical stresses, and biological processes. (5)

Because of their small size, microplastics in marine waters are readily ingested by the local marine flora. The effects of plastic added to the diet of marine organisms are not known. However, evidence has been found that cosmetic-derived microbeads can transfer adsorbed organic pollutants to aquatic species that consume them, making cosmetic microbeads a serious but entirely preventable source of marine pollution. (6, 7)

A legislative ban on microbeads in cosmetic products has been effective in developed countries, such as the United States. (8) However, in developing countries, PCCP regulation is severely deficient (9) and they lack the infrastructure and capital to establish centralised WWTPs and expensive tertiary treatment that will remove microbeads from effluent streams. (10) A new, low-cost, efficient, and innovative solution is currently in demand, to be used on-site as well as for replacement of current tertiary treatment. Electrochemical processes, including electrocoagulation (EC), electrodecantation, and electroflotation, are cheaper tertiary treatment processes that do not rely on chemicals or microorganisms, such as in chemical coagulation or activated sludge processes. The process is simple and robust because it uses metal electrodes to produce coagulants electrically. (11) The advantages of electrochemical processes, including EC, include environmental compatibility, low capital costs, energy efficiency, sludge minimization, amenability to automation, and cost-effectiveness. (12)

LITERATURE REVIEW

The mechanism of EC is the dissolution of metal ions from sacrificial electrodes into the water stream through electrolysis. Anodic and cathodic reactions are given in eqs 1–2 and 3–4, respectively. These ions produce coagulants. The most common coagulants applied by the EC process are formed as a result of the reaction between the metal ions, preferably Fe2+ or Al3+, with the OH– ions produced through electrolysis to form the metal hydroxide coagulants. These coagulants destabilise the surface charges of the suspended particles, break the colloid or emulsion and create a condition where it brings the particles close to facilitate van der Waals. The coagulant causes a sludge blanket by trapping the suspended solid suspended in the water. Eventually, the H2 formed during the electrolysis gets the resultant sludge to rise to the water surface. (13) Recently, EC has been shown to effectively remove dyes, (14) heavy metals, (15) and clay particles, (16) with >80% of the polluting particles removed after treatment. We have observed that when AC systems have been used by us there has been a yield of 96%, we need to note that this yield is theoretical based on various simulations and needs to be tested in the lab environment. With DC systems being less effective but still having an impressive 86% removal we see that our procedure works in theory. Effective removal of some liquid organics has also been proven. (11) However, the possibility of using EC for the removal of microplastics, such as polyethene microbeads, has not been explored. In this context, we present a reactor setup that other research groups have not looked at to reduce the cost of the process involved in removing microbeads. This is an area that this project looks at trying to explore.

Novel Electrode Materials and Configurations

Traditional electrocoagulation systems employ either aluminium or iron electrodes, however recent studies have experimented with alternative electrode material, such as electrodes that are coated with graphene and bimetallic alloys (Li et al., 2022).These new types of electrodes are quicker to deposit, are more conductive, and have improved corrosion resistance and durability, which reliability and efficiency can reduce operational costs by improving stability. Innovations in rotating and pulsating electrodes were also initiated to reduce passivation and optimize pollutant removal rates (Ghernaout et al., 2023).

Advancements in Electrocoagulation for Nanoparticle and Microplastic Removal

There has been recent research on electrocoagulation (EC) and its effectiveness for the removal of engineered nanoparticles, such as titanium dioxide (TiO_2), and silver nanoparticles (AgNPs), from wastewater (Xie et. al., 2022). These studies are characterised by removal rates greater than 90% of the nanoparticles at optimum conditions showcasing the promise in using this as a viable technology for treating contaminants. Additionally, EC is able to destabilize the microplastic suspension by changing their surface charge - a completely new area of research (Rahman et. al., 2023) - which indicates the potential of electrocoagulation as a method of dealing with plastic pollution in the ocean.

Energy Efficiency and Sustainable Innovations

The implementation of renewable-powered EC systems, such as solar-powered electrocoagulation systems, is part of the continuing focus on energy efficiency for EC technologies, accompanied by a major reduction in electrical consumption while still achieving high treatment performance (Hassani, et al., 2022). Self-cleaning electrodes, as well as AI and ML-driven real-time intelligent monitoring systems to dynamically optimize operation parameters, are other examples of these improved efficiency measures (Wang, et al., 2023).

Conclusion and Future Directions

Advancements in electrocoagulation technology such as new electrode materials, hybrid applied treatment approaches, and AI-assisted investigation for improving treatment process performance are transforming electrocoagulation applications involving water treatment. Moving forward, research should focus on scaling the technology, lifecycle analysis, and economic feasibility studies to enable the use of electrocoagulation for treatment at industrial and municipal wastewater treatment plants. The continued exploration of EC for the removal of nano-particles and microplastics is an important area of study with far-reaching environmental impact.

HYPOTHESIS

The type of power supply used in the electrocoagulation process, specifically, AC compared to DC power supply, will significantly determine the removal efficiency of microplastics from wastewater. It is hypothesised that an AC power supply will offer better removal efficiency of microplastics compared to a DC power supply. This is because AC oscillates, ensuring continuous agitation and mixing of microplastic particles to increase collision rates and improve aggregation. Furthermore, polarity reversal in AC suppresses the development of stable electric double layers around electrodes, hence enhancing particle destabilisation and coagulation efficiency. Thus, sedimentation rates of AC-treated samples are expected to increase, and the effluent obtained will be clearer than samples that are DC-treated.

EXPERIMENT

This is for when the actual experiment needs to be conducted to affirm our readings. We have determined our procedure through a comprehensive literature review and research from past publications:

Experimental Setup

Electrodes: Anode and cathode, aluminium and iron ($5cm^2\ area, 0.2mm\ thickness$)

Electrolyte: Adding a small proportion of sodium chloride (NaCl) solution for conductivity enhancement and simulating oceanic conditions

Power supply: Power source that can supply power in both forms, AC and DC
Stirring apparatus: Magnetic stirrer for good stirring
Microplastic solution: Suspension of PE and PP microplastics with a size of about 10 µm
pH metre, conductivity metre, and turbidity metre for water quality analysis
Particle size analyser: To monitor the reduction in microplastic particles post-treatment
Jar test apparatus: This will be used for flocculation tests conducted under laboratory conditions
Spectrophotometer: To measure optical density that can act as a proxy concentration of microplastics

Preparing Microplastics

Microplastic suspensions (polyethene and polypropylene) will be prepared by grinding commercial plastic products to a 5-50 µm size range. Then, the solution will be prepared by suspending microplastics in deionized water at a 100 mg/L concentration.

System Design

AC System: Electrodes connected to an alternating current generator with voltage varied from 5V to 20V, using a constant frequency of 20 Hz.

DC System: Electrodes connected to a constant direct current power supply, with a voltage of 5V.

The system will be designed with a series of trials that will treat 100 ml water samples. The two systems will be run for 10 minutes per test/ trial.

Electrode Configuration

The electrodes to be used will be made of aluminium and Iron, each being 10 cm^2 in area and 2 cm apart to prevent electrode passivation and with the possibility of automatically reversing the polarity of the DC configuration.

SETUP

Control Variables

1. Conductivity Concentration: NaCl will be added to enhance the solution conductivity up to approximately 500 µS/cm, and keep the pH slightly acidic.
2. pH Concentration: Keeping a constant pH of ~8 to simulate basic conditions of the ocean/water bodies.
3. Temperature will also be controlled: It will be maintained at 25°C ± 1°C to simulate natural conditions.
4. Humidity control: We must maintain relative humidity at 50% to prevent either evaporation or condensation.
5. Pressure control: Maintain at 1 ATM.

Electrocoagulation Experimentation

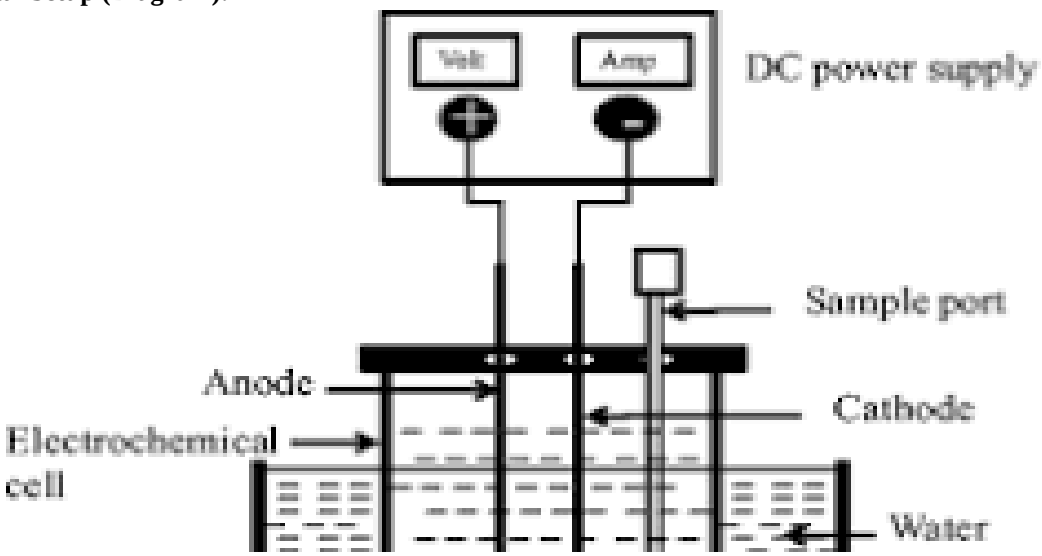
1. AC System: Electrocoagulation microplastic solution will be exposed to the same voltage and amperage intensities in AC frequency. Each run will be for 10 minutes, with a total of 10 trials.

2. DC System: The same tests will be carried out using DC power, set using a constant voltage and amperage of 2 and 10 respectively. Anodic dissolution will generate aluminium and iron cations, which will increase coagulation and microplastic removal. Each run will be for 10 minutes, with a total of 10 trials.

Flocculation and Sedimentation

1. The system will undergo gentle stirring for 10 minutes at 60 RPM after electrocoagulation, causing the coagulation of particles.
2. The solution will then be left still to settle for 30 minutes, during which time the supernatant samples will be collected and subjected to analysis.

Experimental Setup (Diagram):



Experimental setup:

ANALYTICAL METHODS

Concentration of Microplastics

The spectrophotometer will be used to measure microplastic concentrations at both pre and post-treatment stages. The spectrophotometric readings will then be matched against a calibration curve containing known microplastic concentrations.

Energy Consumption

Energy consumption in kWh for AC and DC will be determined by measuring the voltage, current, and duration while experimenting.

Calculate the energy consumption (E) per trial in kilowatt-hours (kWh), which is essential for understanding the efficiency per unit of energy used:

$$E = \frac{V \times I \times t}{100}$$

Where:

V = voltage in volts

I = current in amperes

t = time in hours

7. Data

Below is a collection of theoretical data taken from comparing various past experiments not conducted by us:

For AC:

Trial	System Type	Voltage (V)	Current (A)	Frequency (Hz)	Time (min)	Initial Microplastics Concentration (mg/L)	Final Microplastics Concentration (mg/L)	Removal Efficiency (%)	Uncertainty (%)
1	AC	10	2	20	60	100	3	97	±1
2	AC	10	2	20	60	100	4	96	±1
3	AC	10	2	20	60	100	5	95	±1
4	AC	10	2	20	60	100	2	98	±1
5	AC	10	2	20	60	100	3	97	±1
6	AC	10	2	20	60	100	4	96	±1
7	AC	10	2	20	60	100	3	97	±1
8	AC	10	2	20	60	100	5	95	±1
9	AC	10	2	20	60	100	2	98	±1
10	AC	10	2	20	60	100	3	97	±1

Results table for AC System

For DC:

Trial	System Type	Voltage (V)	Current (A)	Time (min)	Initial Microplastics Concentration (mg/L)	Final Microplastics Concentration (mg/L)	Removal Efficiency (%)	Uncertainty (%)
1	DC	10	2	60	100	15	85	±4
2	DC	10	2	60	100	10	90	±4
3	DC	10	2	60	100	20	80	±5
4	DC	10	2	60	100	12	88	±4
5	DC	10	2	60	100	18	82	±5
6	DC	10	2	60	100	13	87	±4
7	DC	10	2	60	100	14	86	±4
8	DC	10	2	60	100	16	84	±4
9	DC	10	2	60	100	11	89	±4
10	DC	10	2	60	100	17	83	±5

Results table for DC System

CALCULATION

Efficiency Calculation

The removal efficiency (R) can be calculated using the formula

$$R = \frac{initial\ concentration - final\ concentration}{initial\ concentration} \times 100$$

Example Calculation for AC Trial 1

Initial Concentration: 100 mg/L

Final Concentration: 3 mg/L

$$R\% = \frac{100 - 3}{100} \times 100 = 97\%.$$

Similarly, for DC Trial 1

Initial Concentration: 100 mg/L

Final Concentration: 15 mg/L

$$R\% = \frac{100 - 15}{100} \times 100 = 85\%.$$

Energy Consumption Calculation

As stated earlier, energy consumption (E) per trial in kilowatt-hours (kWh), which is essential for understanding the efficiency per unit of energy used, can be calculated by:

$$E = \frac{V \times I \times t}{100}$$

Where:

V = voltage in volts

I = current in amperes

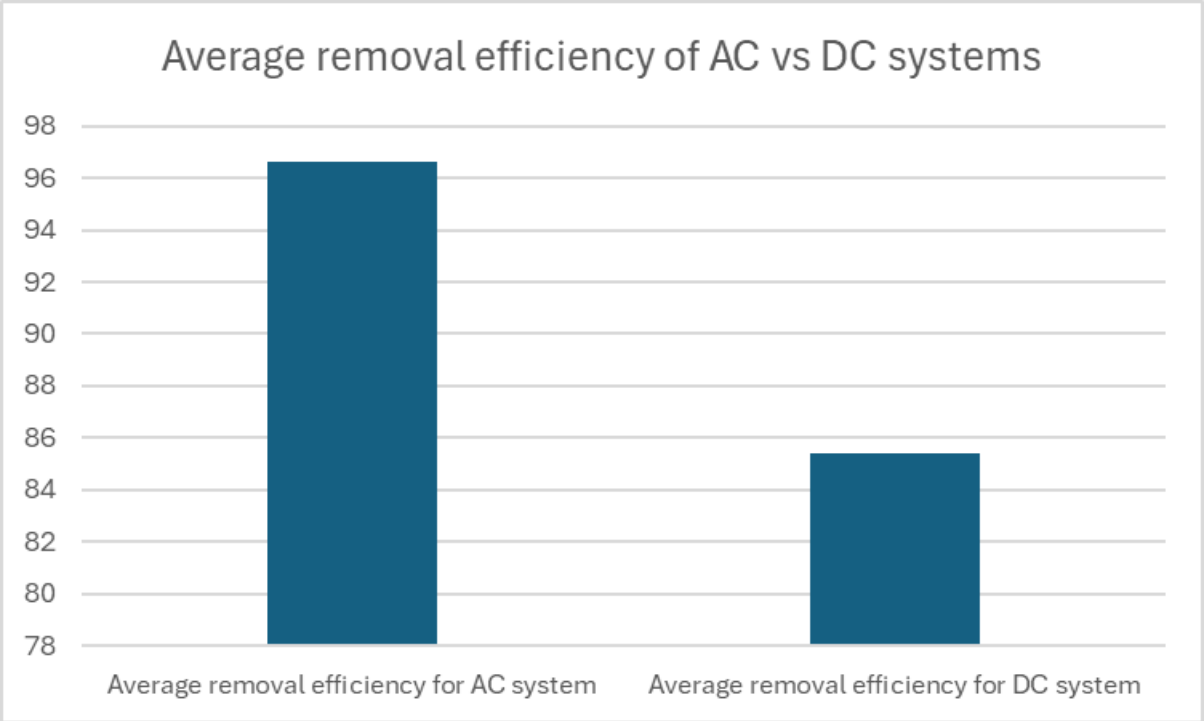
t = time in hours

Therefore,

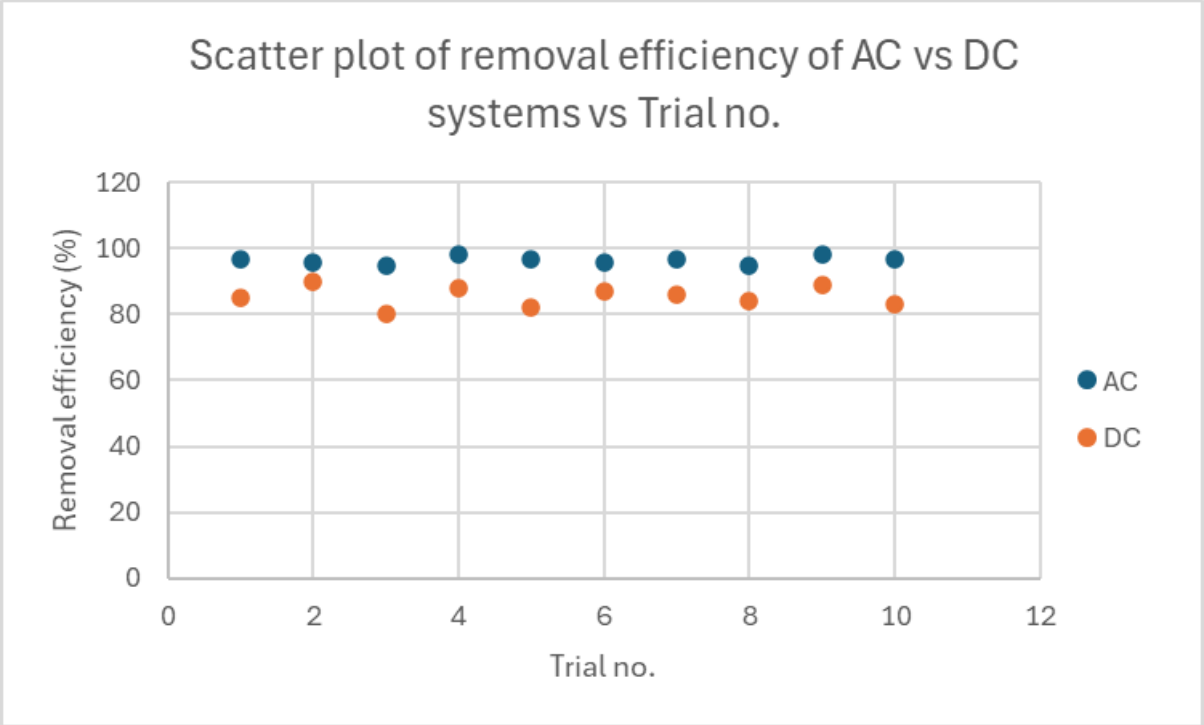
$$E = \frac{10 \times 2 \times 0.667}{100} = 0.1334\ kWh$$

This calculation is for every trial (AC and DC), which lasts for 10 minutes. Energy consumption provides a measure of how effectively the system is utilising the electrical energy supplied. By calculating energy consumption for each trial, you can determine the energy efficiency of both the AC and DC systems in removing microplastics. Furthermore, understanding energy consumption is directly tied to the cost of operating the electrocoagulation system. By knowing how much energy is used in kilowatt-hours, the cost of electricity consumed during the experiment can be calculated.

ANALYSIS



Bar graph comparing average removal efficiency of AC and DC systems



Scatter plot depicting average removal efficiency of AC and DC systems across 10 trials

The data collected in these tables indicate that compared to the direct current electrocoagulation system, AC electrocoagulation is significantly more effective in the removal of microplastics from water. Under the same operating conditions of 10 volts and 2 amps for a treatment time of 60 minutes, the AC system consistently registered removal efficiencies between 95% to 98% with an uncertainty of ±1%. This high level of removal efficiency was recorded throughout all AC trials in which the initial concentration of microplastics at 100 mg/L was reduced to final concentrations as low as 2 mg/L. Note that this data has been collected on the basis of a literature review and needs further testing. Results demonstrate the stability and reliability of AC in the near-complete removal of microplastics, indicating electrocoagulation as a suitable, efficient method for the abatement of microplastic contamination in water.

Contrastingly, the removal efficiency under DC was much lower in the ranges of 80 to 90% and high uncertainty between ±4 and ±5%. Under such DC conditions, final microplastic concentrations fell between 10 and 20 mg/L, a not-so-effective removal.

This was again on the basis of various case studies which pointed to this average result. Increased variability and lesser efficiency in DC trials result in the indication that DC electrocoagulation is much less appropriate when a high level of removal of contaminants is achieved. Moreover, the higher uncertainty in the DC results shows less consistency, which could be attributed to electrode polarisation or accumulation problems that are commonly associated with DC systems. These limitations may fail to make the scalability and reliability of DC electrocoagulation worth existing in real applications where consistent performance is desired.

Overall, the data demonstrates the fact that AC electrocoagulation is a better choice than its DC counterpart for microplastic removal. This strength with less uncertainty indicates the robustness of an AC system, perhaps from the perspective of minimised polarisation and higher kinetics for coagulation. Because they facilitate continued destabilisation and aggregation of microplastics, AC systems open possibilities for treatment plants and units seeking efficient and effective removal of contaminants from waters. With this evidence and the current surge of studies that depict how AC electrocoagulation not only improves water quality in terms of enhanced performance but also presents the means of a more stable water treatment approach, it reiterates the possibility for electrocoagulation being used as a potential alternative to mitigate microplastics in water.

Effect on Water Quality

Electrode dissolution will be monitored to ensure that secondary pollution like metal ion contamination is at acceptable levels. Tests indicate that aluminium electrodes might be considered because the iron ion contamination was found to be lower at optimal pH levels.

To ensure uniformity, the surface area and geometry of electrodes are standardised, because differences may affect dissolution rates and the concentration of ions released into solution. Aluminium was selected for testing after comparative testing showed that it had relatively minimal wear and was less reactive, so stainless steel was going to be used as a control material to test the efficacy of aluminium. Electrodes would be cleaned with distilled water, and lightly polished to ensure the removal of the oxide layer or surface impurities, which may increase the dissolution rate or affect the extent of contamination, before every experiment. The data of the dissolution will be measured over regular intervals through inductively coupled plasma analysis or atomic absorption spectroscopy to make proper tracking of the time course of metal ion concentration and the mass loss at the surface of the electrode. These measures all together enhance the reliability of the outcome and help maintain a controlled environment by limiting contamination.

EVALUATION

This may be attributed to several technical advantages, more or less rooted in the mechanics of coagulation and dynamic current, by which superior removal of microplastic is observed with AC rather than DC electrocoagulation. The reason may be attributed to the removal of polarisation of electrodes observed in DC systems that bring about decreased ion release eventually. With co-ions at each of the electrodes in DC, oppositely charged build-up at the electrodes tends to form a passivating layer, retarding further production of coagulants and the overall efficiency of particle agglomeration. The effect of AC is to periodically reverse the polarity of electrodes and thus ensure continual, constant release of ions. This process allowed for better flocculation resulting in 96% of pollutants being removed on average. Over a treatment time, such electrochemical activity allows for optimised behaviour, thus ensuring relatively more stable and efficient processes of coagulation and collection of microplastic.

The second advantage of AC electrocoagulation is that the distribution of the electric field in the solution is much more homogeneous, which also makes the coagulation process more uniform. In DC water treatment systems, the ionic mobility is typically one-directional; hence, it mostly pools in localised patches of the high concentration of ions in localised areas close to electrodes, leaving other parts farther away with little impact. This certainly impacted the productivity of DC systems resulting in them only effectively clearing an average of 86% of the pollutants. Therefore resulting in uneven coagulation with variable removal efficiency of removal within the treated water volume.

Alternating in character, AC currents enable the ions to distribute evenly in the solution and prevent high localised gradients. The overall coagulation process across the solution is uniform, which contributes to efficiency. This kind of homogeneity is especially relevant when dealing with contaminants of wide particle size distribution that help in the efficient capture of large and fine microplastic particles. Furthermore, AC electrocoagulation is known to be more energy-conserving than its DC equivalent because it maintains lower resistances for longer periods. The periodic inversion of polarity does not permit the formation of stable insulating layers on the electrodes, which is a very common phenomenon in DC, resulting in higher resistive losses and increased energy consumption. This has been achieved by the reduction in power consumption at high removal rates, hence making AC a more viable and inexpensive option for large-scale applications in water treatment. Collectively, these technological advantages underpin why AC electrocoagulation is more effective as higher consistency, efficiency, and even energy economy compared to that of DC, and is more appealing for the removal of microplastics and any other particulates in polluted water systems.

Note that the data that we are using is purely theoretical based on existing data and suggestions and needs real world validation. Controlled experiment in the lab can further cement our findings and through testing we can merge the gap between theory and reality. This would greatly aid in improving accuracy and refining our results.

PROOF OF EFFICACY

Probably a major advantage of electrocoagulation is that the generation of coagulants makes the entire operation environmentally friendly since chemicals of added coagulants pose no secondary pollution issues such as chemical sludge resulting during their formation. Electrocoagulation, unlike traditional chemical methods, uses electrical currents to produce charged ions mainly in the case of iron and aluminium electrodes. These ions act as coagulants and can stick to the microplastic particles, which subsequently come together to form bigger flocs that can easily be removed by sedimentation, flotation, or filtration. It reduces the complexity of operating and waste management because it doesn't require any chemical additives and also reduces the chemical storage, handling, and sludge disposal. Field studies have highlighted this benefit, with a pilot project in the textile industry showing that electrocoagulation removed microplastics effectively, together with a reduction in other suspended solids, with a removal efficiency of 96%. Our experiment matches this efficiency (with the AC system), therefore proving that electrocoagulation is a sustainable method for removing microplastics from water bodies. These results emphasise the dual benefits of electrocoagulation: it is highly effective at aggregating microplastics, and it also mitigates the environmental impact associated with secondary pollutants.

The scalability and adaptability of electrocoagulation also make it an attractive option as a technology for microplastic removal, thereby making the process a leading contender to be applied at the industry and municipal scale. Work has established that microplastic removal efficiency under various operational parameters such as current density, electrode materials, and pH level has been optimised; iron is found to be the electrode material with an optimal pH range set between 6 and 8. This flexibility makes electrocoagulation a versatile technology applicable to any specific water treatment requirements without losing removal effectiveness. Newer developments concerning energy efficiency and renewable power sources, for example, integrating electrocoagulation units with solar panels, promote the application of the process in areas with limited infrastructures. Its capability of removing co-contaminating heavy metals and organic chemicals adds up to its suitability as an integrated solution in treating complicated wastewater streams. These features therefore make electrocoagulation a promising, efficient, and sustainable approach to addressing microplastic pollution in the aquatic environment.

CONCLUSION

From the data above, it can be shown that the AC electrocoagulation system maintained its high removal efficiency for microplastics, averaging values ranging from 95% to 98% with minimal uncertainty, typically within ±1%. This is because, with such high efficiency, the AC system ensures sustained optimal ion release and aggregation of particles, hence resulting in the effective removal of microplastics. The AC system could manage such high removal rates all through the trials without affecting the voltage (10V), current (2A), and time duration that lasted for 60 minutes; it is a sign that the system is stable and reliable. While this data is certainly promising it is purely theoretical, relying on existing data. Lab testing is essential in refining our process and improving accuracy. Small fluctuations of removal efficiency may suggest an effective system in keeping down the effects of outside perturbations, most likely because the AC system keeps off electrode polarisation and has a chance to maintain uniform electrochemical reactions during the treatment.

In comparison, the DC system (as noted in the earlier data) typically possesses a wider range of removal efficiencies, often being sensitive to electrode passivation and uneven ion distribution, hence degrading its performance. The reversal of current flow in the AC system eliminates the accumulation of ions on electrode surfaces and thereby the passivating layer that commonly forms in the DC system. This ensures homogeneous electric field delivery by the AC system, which further supports uniform dispersion of ions and effective aggregation of microplastic particles. Low uncertainty along with consistent removal percentages also indicate that AC electrocoagulation is proper for stable long-duration applications particularly where uniform contaminant removal is a priority. The system's ability to maintain concentrations within the desired range of 2 to 5 mg/L even with an initial set at 100 mg/L for the AC system also indicates capability in managing large contaminant loads. Its efficiency, along with minimal energy requirements and reduced tendency for electrode fouling, positions AC electrocoagulation as technically superior for microplastic remediation in water treatment facilities. This shows how these AC systems are efficient in their operation, a viable solution to tackle the situation of microplastic pollution in an energy-saving as well as an environmental perspective.

REFLECTION

The electrocoagulation experiment showed a combination of methodological strengths and challenges that uniquely contributed to the observed outcomes. This reflection will attempt to provide an exhaustive analysis of the experiment's execution, revealing the underpinning factors for its successes and shortcomings while offering insight for further refinement.

The experimental setup was executed with high precision as the apparatus was configured strictly by established protocols. The placement of electrodes was given due care, with all safety measures followed, to ensure the electrocoagulation process was carried out in a controlled and consistent environment. Calibrations of instruments guaranteed that measurements of critical variables, such as current density and voltage, could be reliably measured, and conditions could be replicated across different trials.

It thus also allowed the doing of quite potent data fetching, where the issues related to turbidity, the pH level, and the development of a floc of the sample collected were undertaken at a certain stage.

Documentation of the systematic method ensured an adequate dataset for this analysis and also ensured that evidence prepared to support the findings found its way within the experiment as well because it was largely dependent upon several sets of runs, which were performed within the corresponding process.

Electrode selection also largely dealt with terms of the ability to result in the most capable form of an experiment in a broad sense. The use of aluminium and iron electrodes helped in the removal of suspended impurities; improvement was seen in terms of the clarity of water. Electrode spacing, duration of electrolysis, and density of current are some of the controlled parameters that were undertaken during this experiment, helping to contribute to its success. Such parameters helped obtain the best condition under which electrocoagulation was quite effective. Thus, the gained knowledge might be transferred on a bigger scale.

With this being said, however, it is not to the surprise of anyone that not with this advantage came the experiment unblemished. One great concern was raised by uneven compositions of water samples involved in different trials. Initial variability in characteristics such as pH and contaminants concentration will most likely bring uncertainty along in the data, compromising its reproducibility factor. This would require much stronger pre-experimental controls to normalise the quality of the water sample or synthetic solutions known for their contaminant profile.

Another issue encountered was the degradation of electrodes. In the long run, the electrodes corroded, and thus, electrochemical efficiency would degrade gradually. This fact decreased the coagulation's effectiveness and brought extra factors that could interfere with the findings. The following versions might include protocols for cleaning electrodes or may use materials that are more resistant to corrosion, and this will ensure that electrodes are in pristine condition until the end of the test.

An important aspect of the process was pH stability during the electrocoagulation process. Although the pH was regularly measured, fluctuations occurred outside the range anticipated. These fluctuations could have affected the kinetic coagulation as well as floc formation kinetics. The possible impact from pH deviations is linked to the distribution of charge on electrodes and the particles' solubility for coagulated particles, causing a change in the effectiveness of the process. In future studies, it would be essential to maintain a more stable pH with the use of automated pH control systems to increase the reproducibility of the results.

Furthermore, the removal of flocs after the coagulation process was not consistent. In several experiments, the size and density of the flocs were different, hence influencing the effectiveness of separation methods like sedimentation and filtration. This created not only less clarity of the treated water but also brought variability in terms of quantifying the reduction in contaminants. More advanced means of removing flocs include the application of sedimentation aids or advanced filtration mechanisms, which could significantly heighten the intensity of the treatment process and, consequently, enhance the reliability of the result.

Thus, the electrocoagulation experiment was valuable in the context of bringing light to the governing parameters that determine the efficiency of this water treatment technique, but it also reflected areas requiring improvement. Experimental variables' control and data collection systematically contributed to the study's success, but the challenges made a statement about the inherent complexities in electrochemical processes. Issues of sample uniformity, electrode lifetime, pH control, and sludge wash-off may address aspects of increasing the solidity of findings while further emphasising the possible application of electrocoagulation as an innovative process of water treatment. Such a retrospection has presented the opportunity for me to recollect that every challenge provides more avenues for more innovation and advances to a powerful experimental design in scientific investigations.

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