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Title Perniciousness of microplastics in the ocean and electrocoagulation in microplastic removal in effluent treatment process

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Abstract:

In recent years, the awareness of microplastic pollution has been rising gradually. Unpredicted phenomenon, facts and reports on perniciousness prompt more researches of removal microplastics from water circulation. Since the doubtful feasibility of direct removal in ocean and finding a perfect alternative for plastic, and obvious human impact on microplastic distribution, wastewater treatment represents a more practical solution. This report will mainly focus on electrocoagulation, which is one of the technologies used to remove microplastics in effluent treatment. There are three main stages of the mechanism: dissolution, coagulation and flocculation, and during this process many factors including electric current, temperature, initial pH and electrode material would influence the removal efficiency. Electrocoagulation exceeds other technologies in environmental compatibility, operational cost and good application etc., while drawbacks such as high electric consumption, unstable yield and sacrificial electrode affects the applied range, where future researches can make efforts on by optimizing on the existing foundation and fostering new technical combination.

Keywords: microplastics; electrocoagulation; ocean; water; wastewater treatment.

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1. Introduction

After 1907 when Leo Baekeland first fully synthetic plastic, this novel material was subsequently improved during World War II and widely used since 1950 [1]. In contemporary society, plastic has become an integral component in both industrial production and everyday life. However, it affords both benefits and challenges. Because of the strong stability which brings hundreds of thousands of years of decomposition, it is considered that pollution caused by plastic accumulation is poorly reversable on the premise of slow biomineralization and no human remediation, even though it seems that the environment contributes positively to the degradation. This problem in marine environments has gradually entered the public eye [2]. Reports in the 1970s covered small plastic grains in the ocean [3]. In the year 2014, marine ecologist Richard Thompson directed an innovative investigation that revealed the dispersal of microplastics throughout the oceanic ecosystem [4].

Microplastics (MPs), just as its name implies, are defined as plastic fragments less than five millimeters, is the product of environmental impact on plastics. Materials such as polypropylene, polystyrene, polyvinylchloride and polyethylene terephthalate are some major oceanic Mps found by different researchers [5]. These tiny particles are categorized into primary microplastics, which are produced at the microscale from various products such as glitter, and secondary microplastics, which are derived from the breakdown of larger plastic items by chemical, mechanical or biological interactions [6].

Distribution of oceanic microplastic is highly correlated with human activities, which is the essential source of microplastic emission, including daily necessities such as plastic packing material, cosmetics and synthetic textiles, recreation, transportation, fishing and industrial manufacture.

WHO in 2019 reported that microplastics are widely found in different places, including air, fresh, seawater, bottled water, water, wastewater, tap water and food, which illustrates a concerning fact that microplastics is now become all-pervasive [7].

Reports in 2009 points that in oceans worldwide, small plastic debris (microplastics) can be sought out [8], even in polar areas such as Antarctica, which increases the proportion of microplastics being ingesting by marine organisms. Meanwhile, the durability of microplastic allows accumulation and migration in and between vectors such as fish and plants. This gives access to microplastics passing into and enriching in the marine food web and the whole food chain. Furthermore, microplastics can function as a carrier for diverse array toxic pollutants, encompassing heavy metals, dichlorodiphenyltrichloroethane (DDT) and those organic and inorganic pigments, which hence poses great threat to wide range of creatures and cause severe ecological risks.

Microplastics present in the environment have adverse effects on the health of both animals and humans. There are three main routes that microplastics enters human body such as inhalation, ingestion and skin contact [9], thus subsequently cause pulmonary exposure , gastric exposure and dermal exposure [10]. Microplastics, acting as vectors for toxicity and pathogens, may be absorbed via inhalation, potentially initiating a variety of diseases. For instance, studies examining animals' absorption rates have revealed a positive correlation between occupational exposure and increased incidences of cancer and pulmonary inflammation [11]. For soil containing microplastics, it is found that some organism fed on soil such as earthworms ingest microplastic and hence undergo associated problems [12]. Some parameters related to soil quality itself varies under the presence of MPs, such as water holding capacity and soil bulk density. Climate can be influenced due to the greenhouse gas emission and plastic pollution generated by MPs.

These hazards make the problem urgent. Given the questionable viability of direct removal from the ocean and the quest for a suitable substitute for plastic, removing microplastics from waste water can be a feasible, immediate solution. Despite existing water treatment which can remove most of the microplastics, some MPs can still bypass the water treatment plants and enter the ocean eventually. Currently, a multitude of technologies have been advanced in the domains of physics, chemistry, and biology for the elimination of MPs. These include methods such as membrane filtration, coagulation, adsorption, photodegradation and magnetic separation. Among these techniques, EC stands out as one possessing both advantages and drawbacks.

Electrochemical technology, electrocoagulation, constitutes a cost-effective three-stage effluent treatment modality that obviates the necessity for chemicals or microorganisms typically employed in conventional chemical coagulation and the traditional activated sludge process. Electrocoagulation is a process of solidifying, or semi-solidifying suspended solids in liquid by passing an electrical current through it. This technology used to be utilized in the medical industry, but now it has been applied to the separation of microplastics from wastewater as well. The aim of this paper is to analyze the technical features and development trends of electrocoagulation for microplastic treatment.

2. Mechanism of electrocoagulation

Electrocoagulation is a process that both physically and chemically. The basic procedure of EC can be summarised into three critical stages (ranging from the generation of ions to the formation of flocs): (1) Dissolution: separation of metal ions from anode under the electric field; (2) Coagulation: combination with suspended particles (microplastics) to produce flocs; (3) Flocculation: coagulant forms a sludge layer for retaining particles [13].

2.1 Dissolution

Electrocoagulation is a process that introduce metal ions in situ by sacrificing anodes. Upon the supply of an electric current from an external source, electrolysis, which uses electricity to trigger a non-spontaneous chemical reaction to occur, happens in the device. A series of reactions occurs spontaneously which can be generalized into two main redox reaction: metal (M) in anode is oxidised into its cation (Mn^+); reduction happens which turns water into hydrogen ions (H^+) and hydroxyl ions (OH^-) due to the cathode hydrolysis, then hydrogen ions pair together, forming hydrogen gas [14].

$$M \rightarrow M^{n+} + ne^- \quad (1)$$

$$2H_2O + 2e^- \rightarrow 2OH^- + H_2 \quad (2)$$

Anode dissociation follows Faraday's law, which indicates the relationship between number of metallic ions generated and some other factors.

$$m = ITM_w / ZF \quad (3)$$

Where, F is Faraday's constant (96,485C/mol), m is mass of anode dissolved, I is current, T is time of operation, Mw is molecular weight of material, and Z is number of electrons involved in the reaction.

Several reports suggested that at anode other electrolysis reaction may take place as well when in alkali condition and high anodic potential [15].

$$2H_2O \rightarrow O_2 + 4H^+ + 4e^- \quad (4)$$

2.2 Coagulation

After electrolysis occurs, metal cations and hydroxyl anions are produced and combined, forming hydroxide complexes, either monomeric or polymeric species. The dominant species is determined by the pH.

$$M^{n+} + xOH^- \rightarrow \left(M\left(OH\right)_x\right)^{n-x} \quad (5)$$

Metal polyhydroxide complexes, which are mainly positively-charged cations, have important property of the presence of metal in its structure, favouring the adsorption of contaminants including colloidal particles. Destablization and neutralization of the surface charge of suspended particles is achieved due to its reaction with metal hydroxyls, which allows the approch and hence combination under the effect of van der Waals forces. Besides, those 3-dimensional holes between the layers of metal hydroxides provide convinience to higher absorption rates. These complexes thus act as coagulants which form aggregates with pollutants.

2.3 Flocculation

Aggregates concentrates into flocs due to factors including Induced Dipole - Induced Dipole force. Once the floc is generated, the floc may gather at the bottom or form a floc-foam layer at the surface together with the electrolytic gas, hydrogen gas and sometimes oxygen gas, by electro-flotation. Flotation is the outcome of three consecutive stages: (1) the collision between flocs and hydrogen gas bubbles; (2) the adherence or the formation of an aggregate of H2 bubble-floc; and (3) the transportation of this aggregate to the liquid's surface, where the particles are subsequently collected.

3. Factors influencing electrocoagulation

Due to the traits, such as the usage of electrochemical principles and so on, of the technology, several variables can lead to different effect and efficiency. Anode materials, current density, types, shapes and concentration of microplastics in wastewater, the pH, the bubble size and position and agglomerate size all affect the removal of microplastics.

3.1 Electric current

Electric current is one of the most crucial factors in electrocoagulation process. According to Faraday's law, the amount of metal cations produced is directly proportional to the current density. Therefore, methods to enhance the current density such as voltage and reducing the interelectrode distance and increasing the electrode area, can also apply to increase the rate of formation of coagulate, and hence improve the effectiveness of removal. High voltage allows faster growth and larger size of flocs, contributing to better coagulation, and hence increased electrical potential leads to a rise in the quantity of oxidize metal which subsequently increases the number of flocs with high adsorption rates, improving removal efficiency [16].

3.2 Operating temperature

Temperature is considered as a fundamental parameter that affects efficiency [17]. High temperature results in elevated conductivity, thereby leading to reduced energy expenditure. Meanwhile, it raises the mechanism energy of partials, leading to increase in frequency of collision and hence speed up the rate of reaction. Increase in temperature also decrease the solubility of electrolytic gases, making flotation easier and more efficient to occur. Despite those above, It has been observed that higher temperatures can induce contraction in the larger pores within the metal hydroxide complex, leading to the formation of dense flocs which are more prone to depositing on the electrode surface, therefore, decreasing the absorption rate.

3.3 Initial pH

It has been established that pH is a critical parameter affecting the efficacy of the electrocoagulation process, as it predominantly depends on the initial pH level of the electrolyte, which is particularly true during the initiation phase of coagulant formation. Variations in pH values can lead to alterations in the types of metal hydroxide complexes generated. In the course of a previous research, it was observed that the removal efficiency under acidic electrolyte conditions was notably low, achieving efficiencies of 93.82%, 91.58%, and 93.99% for COD, BOD, and SS, respectively, at a pH of 3. Similarly, under alkaline conditions, the removal efficiency remained disappointingly low, with respective efficiencies of 92.06%, 92.66%, and 89.9% for COD, BOD, and SS at pH 11. However, in a neutral electrolyte solution, the removal efficiencies for COD, BOD and SS reached 98.07%, 98.07%, and 97.64% which is the highest among the data. Consequently, it can be inferred that the optimal pH values are situated within the range of 7 to 9, offering an economically viable and efficient treatment solution for wastewater in practical applications [18].

4. Further trends and suggestions

4.1 Advantages

4.1.1 Environmental compatibility

Electrocoagulation effluent treatment doesn't rely on extra conventional chemical additives. Far less secondary pollution is produced in EC than in chemical coagulation (CC)/chemical filtration (CF) and hence less sludge production. There is no danger of residual chemicals containing toxins and odors making their way into the effluent, where EC excels other approaches such as oxidation treatment and magnetic separation.

4.1.2 Low operating costs

In electrocoagulation process there is no thickener required as there would be in chemical coagulation, which reduces the cost of the operation upfront. Electrocoagulation features a small number of moving components, thereby constituting a relatively straightforward process that necessitates minimal maintenance and supervision. This capability can facilitate significant energy efficiency improvements, an aspect in which approaches such as adsorption, oxidation treatment, and magnetic separation typically demonstrate limited proficiency.

4.1.3 Good application

EC performs remarkably in MPs removal. Microplastics removal efficiency consistently maintains its removal efficiency above 90% and even could reach 99.9% in some treatment facilities [19]. EC also has broad flexibility to many kinds of pollutants in effluent, not just microplastic. Reports before indicates that common water pollutants, such as COD and BOD also can be effectively removed by electrocoagulation. In addition, due to many advanced aspects, for example, aggregates containing microplastics floating on the liquid surface can be easily removed by adsorption bridging and sweep flocculation and the operation of process depends on electricity, EC is easy to automate as well which conforms the present developing trend of full-automatic industry.

4.2 Limitations in practical use

4.2.1 Electrodes are impermanent

Electrocoagulation requires metal ions from sacrificial electrodes to feed the current in solution. Meanwhile, the process of coagulation is an intensive one that places a lot of strain on the electrodes. Thus, necessary regular replacement can lead to extra workforce and resource expenses.

4.2.2 Unstable yield

Yield is hardly guaranteed because of many factors affecting accuracy. Variables including material and arrangement of the electrode, pH, anion concentration, type of power sources, floc stability and current density etc. and external environment surrounding cause deviation between the practical result and the predicted value.

4.2.3 High electricity consumption

Electrical energy consumption serves as a significant economic indicator within the electrocoagulation process. Indeed, the highest voltage produced the quickest treatment with an effective reduction of the pollutants, hence to achieve better effect, cost of electricity cannot be ignored. Meanwhile, in addition to electricity cost, practical electricity conditions may lead to a non-negligible decrease in removal efficiency compared with experiments.

4.3 Possible future directions

Limitations above are possible inducements that cause EC hard to use on the municipal scale, which hence corresponds to future orientations. New research and experiments can focus on how to achieve a permanent supply of metal ions. Approaches such as specific catalysts to maintain high removal efficiency at low voltage is well worth studying. Furthermore, new attempts can focus on combinations of technologies in other fields with EC in order to achieve multiple-pollutant removal, higher removal rate and efficiency and lower cost.

5. Conclusion

This article presents an overview of perniciousness of

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microplastic in the ocean and electrocoagulation in wastewater treatment as one of the possible approaches. Microplastics are plastic debris less than five millimeters which are small enough to bypass existing wastewater treatment plants and ultimately enter water circulation. The lack of restraint and management can lead to serious consequence due to the possible detriment on animals, soil quality, climate and humanity etc. and therefore new technologies are developed to remove microplastics in effluent which would finally flows into the ocean. Electrocoagulation, as one of them, demonstrated considerable potential in removing microplastics in wastewater for long-term sustainable developing goal based on the findings. Mechanism of EC is mainly summarized into dissolution, coagulation and flocculation, utilizing electrochemical theory. This technology can significantly reduce the amount of MP and other pollutants, as well as being environmental-friendly and low operating cost, while drawbacks such as regular electrode replacement and high electrical consumption still limits its appliance, which also points out future improvements corresponding prolonging components' lifespan, enhancing energy efficiency and new cooperation with other fields.

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