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ELECTRO-COAGULATION TECHNIQUE USING IRON [FE] AND ALUMINUM [AI] FOR MICROPLASTICS REMOVAL FROM FASHION INDUSTRY WASTEWATER, THAILAND

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ABSTRACT: The textile sector is considered as the 3rd largest source of water pollution and land degradation during 2020. 20% of the world's water pollution is linked with textile production and utilisation. Textile washing releases 14 million tons of microplastics, according to European Environmental Agency estimates. Wastewater Treatment Plant [WWTP] has declared everyday normal releases of more than 4 million MP particles because of its tiny size (<5 mm) and low thickness (<1.2 g/cm^3). Electrochemistry for the removal of tinny pollutants is recognised as an efficient treatment mechanism. The main aim of this research paper is to identify the efficiency of electro-coagulation technology using Fe and Al as anode and cathode in microplastic removal from Thailand's textile industries. Results show the maximum 100% microplastic removal efficiency with pH 10 at a current density of 30 A/m^2 within 60 minutes of the current supply. This paper helps to understand the role of electro-coagulation in Thailand textile wastewater plants and adopt the best available technique for microplastic removal.

KEYWORDS: best-available technology, electro-coagulation, microplastics, wastewater treatment plant, removal efficiency

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Introduction

In Thailand, industries are using conventional wastewater treatment plant systems. Conventional wastewater treatment plants [WWTP] are not capable of capturing all the contamination and microplastic [MP] released from textile industrial wastewater before discharge into the waterbodies (Conley et al., 2019). Microplastics (MPs) are believed to be the primary source of contamination from wastewater treatment facilities (WWTPs) (De Falco et al., 2018). Over 4 million MP particles are discharged daily on average by WWTPs, according to reports (Liu et al., 2021; Tiffin et al., 2022), because of their low density (<1.2 g/cm^3) and small size (<5 mm). Conventional wastewater treatment methods cannot remove MPs, and the combined finished effluent is released into natural water bodies. The harmful effects of microplastics on the environment biota and trophic chains, as well as on people, are directly responsible for their presence in water (Gangula et al., 2023).

The yearly worldwide plastics formation reached north of 359 million tons in 2018 (Astawa, 2022), and a moderate amount of 13 million tons of plastics was released into massive water resources annually (Liu et al., 2021). According to Bayo et al. (2020), 60-80% of the plastic discharges consist of microplastics, which are particles ranging in size from 0.1 μm to 5 mm. Microplastics (MPs) can be named essential or auxiliary, depending on their source (Rosariawari et al., 2021). These particles can also take various forms and textures. Research has shown that MP contamination has become a rising danger, particularly in the oceanic climate and in landfills. More than 600 different kinds of organic entities have been shown to contain MPs in the human diet, including table salt, beer (Kosuth et al., 2018), drinkable water, and the lungs (Song et al., 2022). MPs are present in Asia, Europe (Sadri & Thompson, 2014), Antarctica (Bessa et al., 2019), and the Americas (Taylor et al., 2019). The unfavourable impacts of MPs are legitimate on different marine life forms (Gangula et al., 2023).

Effect of Textile Industry Microplastics on Waterbodies

Both direct outflows to surface water (Folbert et al., 2022) and the movement of particles by wind, run-off, wastewater, and garbage clearance (Ngo et al., 2019) result in microplastic contamination of freshwater and marine environments. Microfibers appear to have more potential than other filaments to enter the pecking order; they are primarily derived from the synthetic textile industry (Jemec et al., 2016). On the ground microplastics mass and form permit them to be promptly expended through oceanic life forms (Akyildiz et al., 2023) and are more inclined to become caught in huge clusters inside the aquatic life stomach, causing blockages (Kosuth et al., 2018).

Release of Microplastics throughout the lifecycle of Textiles

Figure 1 shows the path of release and fate of microplastics from the textile industry in freshwater, marine water, air, and soil. Microplastics can be delivered anytime in the synthetic textile value chain, from production to use. Microfibers can enter the food chain and water bodies, become a part of the human body, and absorb into human tissues and organs, as shown in the literature review.

Microplastic leakage during the Operational Stages

A large amount of microplastic is released from the textile industry during the clothing manufacturing process. The textile industry in Asian nations, such as Thailand, typically uses complicated, three-stage procedures.

Step 1: Raw material synthesis of the fibre (leakage of microfibre)

After a laborious polymerisation process, polyester, oil, natural gas, and coal are mostly used to manufacture fibres. This is the initial phase of the synthetic textile production process. This procedure transforms the raw material into a rope with a particular texture.

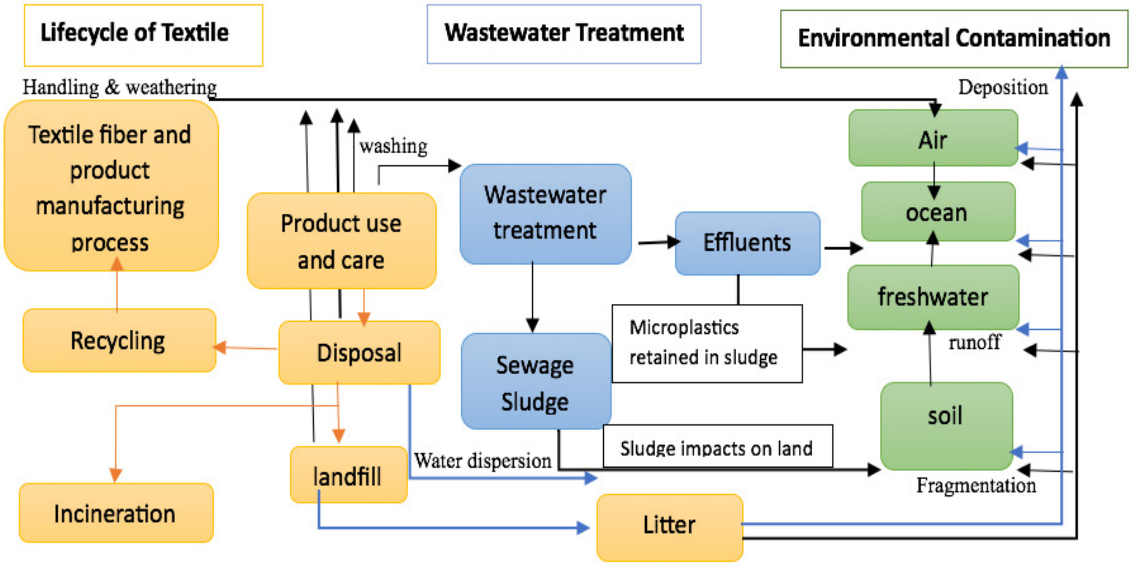

Figure 1. Release and fate of microplastic fibers from textiles

Step 2: Production of yarn and fabric (leakage of microfibre)

Through this technique, the yarn is transformed into various woven characteristics. To obtain fibres of varying quality, yarn is tufted and knitted (Silva & Nanny, 2020). Water-based techniques used in this process produce wastewater that contains chemicals, dyes, and microfibers (Enfrin et al., 2022).

Stage 3: Distribution of the finished product

This phase entails the clothing's final packaging and delivery to the market (Xu et al., 2021). Microplastics are generated not only during the textile production process but also when washing clothes (Sun et al., 2019). Dyed polyester fabric is a typical raw material used by businesses. The most prevalent type of plastic used in the textile industry is polyester. Numerous microplastics are released into the environment because of the use of various dyes and printing chemicals in the industry. This industry uses a weaving approach that transforms polyester into fibres (Chan et al., 2021). The textile industry commonly uses the Air Jet Loom, Rapier Loom, Water Jet Loom, and Jacquard Loom. Yang et al. (2023) described the weaving process, which also includes the sizing, drawing, denting, looming, and weaving processes with primary (shading, picking, and beating up) and secondary (letting off, taking up) loom motions (Čurlin et al., 2022).

Electro-coagulation (EC) is a prevalent technique for expelling microplastics from wastewater from the material industry. This method includes the utilisation of electrical flows to break up metal cathodes, normally iron (Fe) and aluminium (Al), in the wastewater. The broken down metal particles respond to shape hydroxides, which go about as coagulants. These coagulants undermine the suspended microplastic particles, making them total into bigger flocs that can be handily isolated from the water through sedimentation or buoyancy. Contrasted with conventional methods, EC offers a few benefits: it is chemical-free, produces negligible muck, and works effectively across a scope of pH levels and toxins. Given the critical microplastic contamination in Thailand's textile industry wastewater, EC presents a promising solution for moderating the natural effect and advancing cleaner production practices.

This study investigates the potential of electro-coagulation (EC) with iron (Fe) and aluminium (Al) electrodes to remove microplastics from textile wastewater. This research seeks to showcase the effectiveness of EC as a viable solution to reduce microplastic pollution, promote cleaner production practices, and improve the sustainability of wastewater treatment in Thailand's fashion industry, ultimately contributing to the global effort to combat microplastic contamination.

Methodology

Study Area

Thailand contains approximately 1400 industries dealing directly or indirectly with fabric products. The study area in this research includes the largest textile industry in Thailand. Industry [A] was using conventional wastewater treatment plants. The samples were collected directly from the industry. The name and details of the industry are confidential; therefore, we refer to the industry as Industry [A]. After sample collection, the electrocoagulation experiment was performed in the wastewater treatment laboratory.

Materials and Methods

Electrocoagulation for Microplastic Removal from Wastewater

Advanced electrocoagulation setups with iron and aluminium applications were used in this study. The iron and aluminium terminals (anodes), a DC power supply, and an EC cell (cathode) comprise the EC unit (Rosariawari et al., 2021). According to Singh et al. (2017), cathode arrangement has been shown to have an impact on coagulant disintegration and bubble type, which in turn affects mass exchange, mixing, and buoyancy. The breakdown of the cathode and anode results in the production of hydroxides, oxyhydroxides, and polymeric hydroxides (Badawi & Zaher, 2021, Ghanbari et al., 2014). According to (Wei et al., 2010)in an ECF cycle, coagulants formed by electrolytic oxidation of the conciliatory cathode weaken the pollutants and then group the weaker stages to form flocs. Electrogenerated hydrogen or oxygen typically drifts toward the outer layer of the ECF cell (Mirjalili & Zohoori, 2016). Different electrochemical reactions occur in the ECF, which can be summarised as follows (Rosariawari et al., 2021).

In Anode

$$M\ (x)\ M\_\big((aq)\big)^{\wedge}\ (n+) + ne - \tag{1}$$

$$2H2O(1) \rightarrow 4H\_(aq))^{\wedge} + [O2]\_(g) + 4e - \tag{2}$$

In the cathode

$$M\_\big((aq)\big)^{\wedge}(n+) + n^{\wedge}(e-) \rightarrow M_{(-)}\quad ((s)) \tag{3}$$

$$[2H2O]\_\big((1)\big) + 2\_(e-)[H2]\_\big((g)\big) + 2OH \tag{4}$$

Responses (1-4) show that the electro-created metal particles (Mn+) proceed through further unconstrained responses with relative hydroxides and polyhydroxides that have a solid proclivity for scattered particles and counter particles that achieve coagulation quickly (Emamjomeh & Sivakumar, 2009).Moreover, the gasses generated at the terminal's various particle and coagulant totals raised them via an interaction akin to buoyancy, hastening the effects between particles and coagulant by inducing genuine blending (Hooshmandfar et al., 2015). Advanced wastewater treatment systems contain many stages in the treatment process (Mahmoud et al., 2021), but electrocoagulation systems contain fewer stages and are unsure of the 100% MP removal efficiency within the system.

Parameters for the Electrocoagulation Set-up

Dependent variables, independent variables, and fixed variables with parameters and values used in the study are listed in Table 1.

In electrocoagulation cycles, a mixture of physico-substance boundaries inside an electrocoagulation reactor (Akyol et al., 2015) moves the prevailing division component. In addition, the physicochemical properties of the toxin impact its communications inside the framework and possible expulsion mechanism. Along these lines, different outcomes have been accounted for throughout literary works (Fragão et al., 2021), particularly regarding the use of various anode textiles. In the extent of material and natural wastewater management using electrocoagulation (Ghernaout et al., 2011), expressed that Fe was better than Al. Few researchers observed that iron was more compelling to decrease COD, while Al with extra viability and lightness powers are the two primary variables deciding the toxins partition system and in eliminating tone. Electrocoagulation/buoyancy (ECF) comprises the ageing of the coagulant in-situ with the breakdown of metal particles from the consumable anode and the concomitant formation of hydroxide particles at the cathode. In ECF, tiny air pockets of hydrogen gas produced by the cathode intrude on toxins at the outer layer of the ECF cell. Thus, electrons are the primary professionals used in ECF that deal with wastewater treatment, as opposed to using artificial materials and microbes (Wei et al., 2010).

Table 1. Fix & Independent Variables for the 100% microplastic removal efficiency in Electro-coagulation Techniques

Parameters	Values
Fix Variables	
Treatment Process	Electro-coagulation Process
Magnetic Stirrer Speed	200 rpm
Sample Volume	1 l
Distance B/w Anode &Cathode	5 mm
Temperature	26 +- 30°C
Independent Variable	
Current density (A/m^2)	10 A/m^2, 20 A/m^2 ,30 A/m^2
pH	5, 7, 10
Retention time (Min)	10,20,30,40,50,60,70,80,90,100,120,140
Anode-Cathode	Al-Fe
Dependent Variable	
Removal Efficiency	MP Concentration

Electrocoagulation Set-up

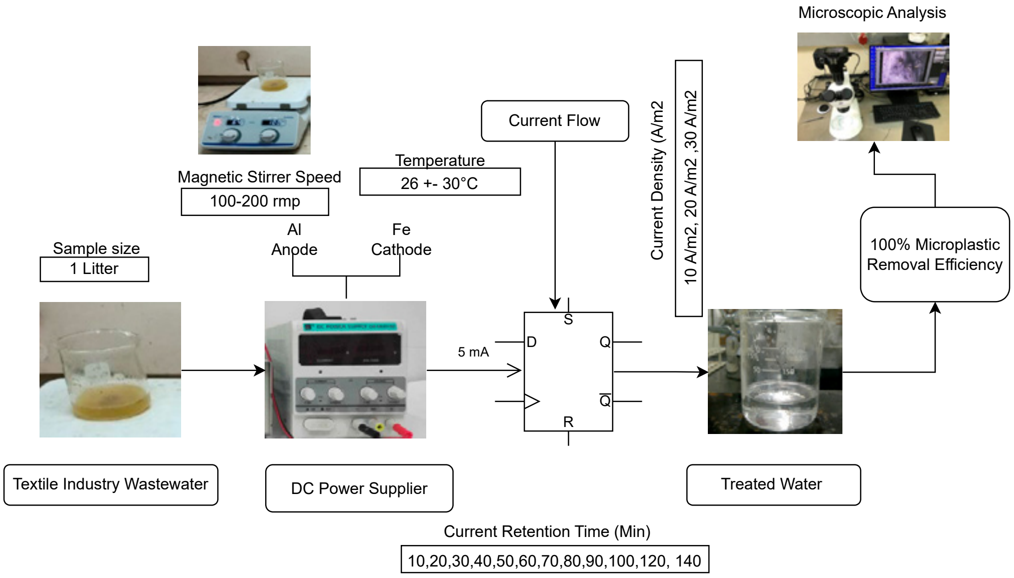

Figure 2. Electro-coagulation Setup for Research Study

The formula for the removal efficiency calculation

The microplastic evacuation proficiency can be computed using the following conditions:

$$RE\ \% = Ci - Cf\ Ci\ \times 100 \tag{5}$$

In the above equation, the initial and final microplastic concentrations are represented by Ci and Cf, respectively.

Results

Removal efficiency at different current densities

The microplastic removal efficiency varied with different current densities over time. All parameters, such as coagulant dosage, current density, and current supply period, are also important factors to keep under control during calculation because they directly affect coagulant generation. The maximum removal efficiency was recorded with a current density of 10 A/m^2 within 90 mixture time intervals. 100% removal efficiency was noted at different times with different current densities, as shown in Figure 3. Microplastics 100% removal efficiency was recorded at 10 A/m^2, 20 A/m^2, and 30 A/m^2.

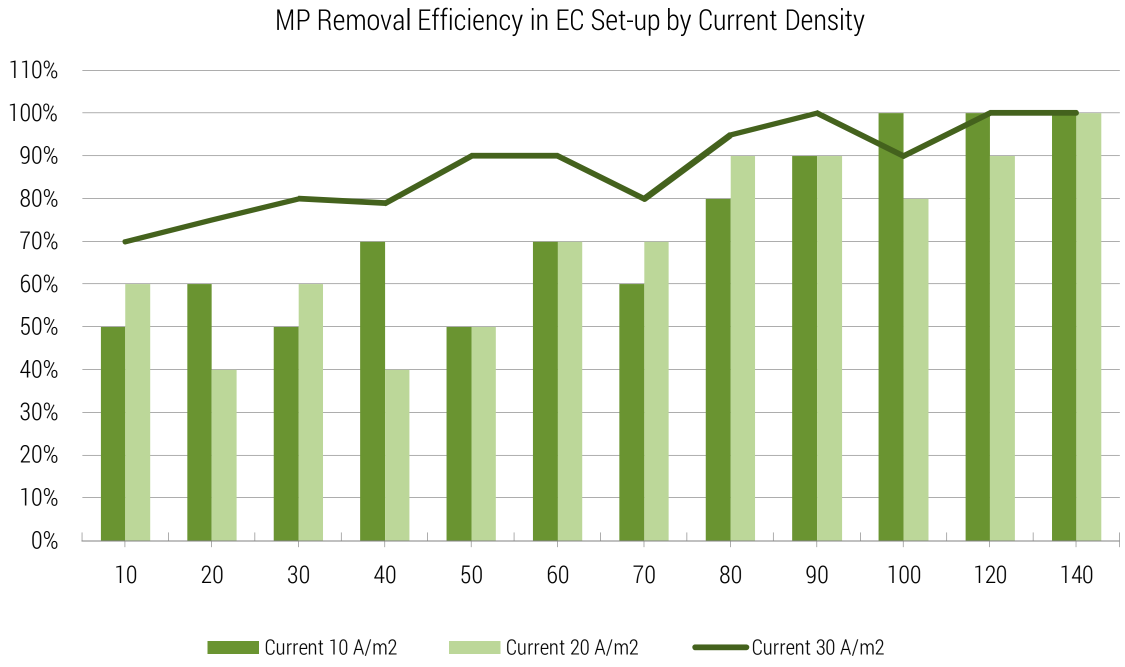

Figure 3. Microplastics Removal Efficiency in EC Set-up by Current Density

At neutral pH with high current density, bubble generation and coagulant formation are higher than normal. The obtained results show maximum removal with low current density at high current supply periods and at high current density.

Removal efficiency at different pH values

Domestic wastewater typically has a pH range between 7.0 and 7.5. The pH of textile industrial wastewater was found to be a minimum of around 7.0 pH and a maximum of around 9.0 pH in a case study published in the Journal of Industrial Pollution Control. The results show 100% microplastic removal efficiency with different pH values, as shown in Figure 4. According to the Faraday law, bubble formation and coagulant generation increase at neutral pH with high current density.

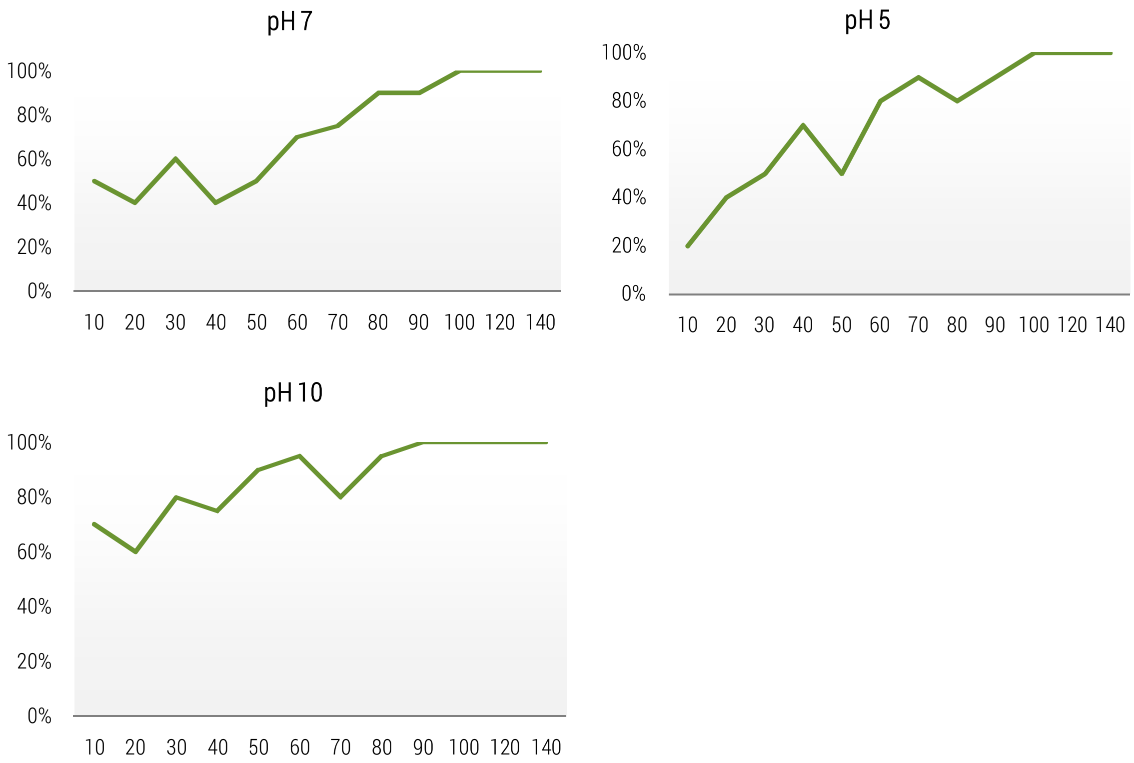

Figure 4. MP Removal Efficiency in EC Set-up by the different pH level

At pH 10, the maximum removal efficiency of MP was observed for 60 min. Research has investigated the effect of Al(OH) reactions and aluminium compound formation at different pH values and found strong bonds between Al(OH)s at high pH (Hu et al., 2016). This could be the reason for the maximum removal of microplastics at high pH.

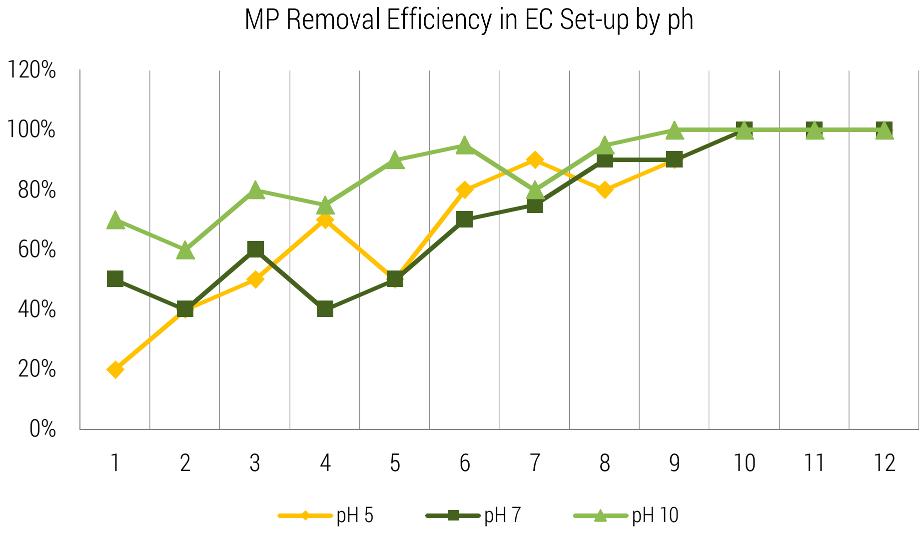

Figure 5. Cumulative Microplastics Removal Efficiency with different pH range

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Discussion

The effectiveness of various wastewater treatment methods in getting rid of these particles varies. It was recently observed that electrocoagulation, or EC, and electrocoagulation-electroflotation (EC/EF) are very effective procedures that yield clearance rates of more than 99% and 100%, respectively. In addition, membrane bioreactors (MBR), which combine biological digestion with membrane filtration, also exhibit excellent performance, exceeding 99%, but this is very expensive (Hidayaturrahman & Lee, 2019). Conventional activated sludge (also known as methods can reach removal rates of 97.1 % and 95%, respectively, while fast sand filtering and dissolved air flotation (DAF) can reach up to 97% efficiency. Laboratory-scale membrane filtration achieves 100% efficiency, while iron-based coagulation/flocculation shows a 93.11% efficiency. These results suggest that while the most effective approaches are EC/EF, MBR, and membrane filtration, traditional procedures like CAS, sand filtration, and DAF are still important (Miranda et al., 2020).

Table 2. Microplastics Removal Efficiency of Different Treatment Methods

Treatment method	Removal efficiency	Key findings	Source
Electrocoagulation (EC)	>99%	EC is highly effective in removing microplastics, with efficiencies exceeding 99% in synthetic solutions.	Emamjomeh & Sivakumar (2009)
Electrocoagulation-Electroflotation (EC/EF)	100%	EC/EF achieved 100% removal efficiency for different polymer types at optimal conditions.	Akarsu et al. (2021)
Membrane Bioreactor (MBR)	>99%	MBR systems show high removal efficiencies, typically over 99%.	Akarsu et al. (2021)
Conventional Activated Sludge (CAS)	97%	CAS processes achieve up to 97% removal efficiency, with most microplastics removed in secondary treatment.	Corpuz et al. (2023)
Rapid Sand Filtration	97.1%	Sand filtration effectively removes microplastics with an efficiency of 97.1%.	Wang et al. (2021)
Dissolved Air Flotation (DAF)	95%	DAF achieves up to 95% removal efficiency for microplastics.	Piaggio et al. (2022)
Coagulation/Flocculation	93.11%	Iron-based coagulation showed a 93.11% removal efficiency in industrial wastewater.	Chadha et al. (2022)
Membrane Filtration	100%	Laboratory-scale membrane filtration methods achieved 100% removal efficiency.	Hube et al. (2020)

Conclusions

Developing countries still rely on conventional wastewater treatment systems, but it is not enough to remove 100% microplastics and other contaminants from wastewater. After a thorough study of the mechanism of the textile industry, indications of the formation of microplastic contamination and a review of the advanced working mechanism of the electrocoagulation and Nanofiltration membrane technology.

However, EC is not without disadvantages, even with the considerable increase in wastewater treatment that it provides. The requirement for regular electrode replacement and maintenance, which can raise operating expenses and complexity, is one of the major

challenges. Adjustments specific to the different industrial effluents may also be required due to the fact that the particular composition of the wastewater may have an impact on the efficiency of EC. A possible drawback is the potential for the insufficient elimination of the tiniest microplastic particles, which could survive the treatment procedure. In order to achieve greater removal efficiencies, EC must be integrated with other treatment methods, such as nanofiltration membranes. Further-more, EC technology adoption by isolation has no ability to fully solve the problem of microplastics contamination.

To reduce the production of microplastics at the source, innovative and modified textile production procedures must be implemented immediately. Reducing the clothing industry's overall environmental impact requires implementing cleaner production techniques, converting textile materials, and implementing more sustainable manufacturing practices. In conclusion, even though electrocoagulation is an outstanding method for removing microplastics from textile wastewater, more study and development are needed to optimise the method's efficiency and overcome its limitations. To effectively address microplastic contamination in developing nations, EC must be used in conjunction with other innovative treatment techniques and sustainable textile production methods. We can come to the conclusion that one of the most effective techniques presently in use for removing microplastics from clothing is electrocoagulation.

Statement of conflicting interests

The authors declare that none of the work reported in this study could have been influenced by any known competing financial interests or personal connections.

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ELECTRO-COAGULATION TECHNIQUE USING IRON [FE] AND ALUMINUM [AI] FOR MICROPLASTICS REMOVAL FROM FASHION INDUSTRY WASTEWATER, THAILAND

ABSTRACT: The textile sector is considered as the 3rd largest source of water pollution and land degradation during 2020. 20% of the world's water pollution is linked with textile production and utilisation. Textile washing releases 14 million tons of microplastics, according to European Environmental Agency estimates. Wastewater Treatment Plant [WWTP] has declared everyday normal releases of more than 4 million MP particles because of its tiny size (<5 mm) and low thickness (<1.2 g/cm^3). Electrochemistry for the removal of tinny pollutants is recognised as an efficient treatment mechanism. The main aim of this research paper is to identify the efficiency of electro-coagulation technology using Fe and Al as anode and cathode in microplastic removal from Thailand's textile industries. Results show the maximum 100% microplastic removal efficiency with pH 10 at a current density of 30 A/m^2 within 60 minutes of the current supply. This paper helps to understand the role of electro-coagulation in Thailand textile wastewater plants and adopt the best available technique for microplastic removal.

KEYWORDS: best-available technology, electro-coagulation, microplastics, wastewater treatment plant, removal efficiency

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