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Electro-coagulation as an Efficient Method for Wastewater Treatment

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Abstract

Electro-coagulation (EC) is an advanced electrochemical treatment technique increasingly applied for the removal of pollutants from industrial and municipal wastewater. In this process, coagulant metal ions are generated in situ through the anodic dissolution of sacrificial electrodes, commonly iron or aluminum, under the application of direct current. These metal ions undergo hydrolysis to form metal hydroxides, which effectively destabilize and aggregate a wide range of contaminants, including suspended solids, heavy metals, emulsified oils, dyes, phosphates, pathogens, and organic compounds.

Electro coagulation integrates the mechanisms of coagulation, flocculation, flotation, and electrochemical oxidation within a single treatment unit, thereby eliminating the need for external chemical coagulants. Compared to conventional chemical coagulation, EC offers several advantages such as higher pollutant removal efficiency, effective treatment of highly colored and turbid wastewater, improved removal of colloidal particles, and reduced sludge production.

The performance of the EC process is strongly influenced by operational parameters including electrode material, current density, pH, solution conductivity, and treatment duration. Electrocoagulation has been successfully employed in the treatment of textile effluents, metal plating wastewater, oil- and grease-laden wastewater, pharmaceutical effluents, municipal sewage, and landfill leachate. Recent studies have also demonstrated enhanced treatment efficiency through the integration of EC with membrane filtration and other advanced processes.

Keywords: Electrocoagulation, wastewater treatment, pollutant removal, electrochemical process.

Introduction

Electrocoagulation (EC) is a rapidly growing electrochemical process for wastewater treatment that has gained considerable attention in both research and industrial settings. In this method, sacrificial metal electrodes (typically iron or aluminum) are dissolved under direct current to release metal ions, which hydrolyze to form metal hydroxides that act as in situ coagulants. These hydroxides destabilize and aggregate pollutants such as suspended solids, heavy metals, dyes, oils, and organic compounds, thereby facilitating their removal [7-8].

Compared to conventional chemical coagulation, EC eliminates the need for external chemical coagulants, reducing chemical consumption and secondary pollution [7]. The process also integrates coagulation, flocculation, flotation, and electro-oxidation within a single reactor, enhancing overall efficiency [9]. Another important advantage is the ability to remove very fine colloidal particles: the electric field mobilizes charged colloids, increasing their collision and aggregation probability, which is often difficult in traditional coagulation processes [7].

Operational parameters such as current density, pH, conductivity, electrode material and configuration, and treatment time strongly influence EC performance. For example, optimization studies using Al-based EC for greywater treatment found that current density and pH significantly affect removal efficiency, with optimized conditions achieving COD removal of over 86% [10]. Also, continuous-flow EC systems have been developed to treat industrial organic pollutants, showcasing high removal efficiencies and improved scalability [11].

EC has been successfully applied to a wide variety of wastewater types, including on-site wastewater (for phosphorus removal), textile effluents, mineral processing wastewater, and municipal sewage [6-9]. Its adaptability and relatively simple configuration make it suitable for decentralized and modular systems, as well as for integration with other processes (e.g., adsorption or advanced oxidation) to meet stringent discharge standards.

Despite its strengths, EC still faces challenges, including electrode passivation, higher energy consumption for low-conductivity waters, and management of the generated sludge [8,11-15]. Ongoing research is focused on improving reactor design, developing hybrid systems, and optimizing process parameters to enhance efficiency, reduce costs, and extend the technology's application.

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1. Materials and Methods

Effluent Treatment Plant (ETP) Method

The conventional **ETP process** was studied to evaluate its treatment efficiency. The ETP system generally consists of the following units:

i). **Equalization Tank:** The wastewater was collected in an equalization tank where continuous mixing was provided to maintain uniform composition and flow rate.

ii). **Coagulation and Flocculation:** Chemical coagulants such as alum ($Al_2(SO_4)_3$) or ferric chloride ($FeCl_3$) were added to destabilize colloidal particles.
The water was then slowly mixed to promote the formation of flocs.

iii). **Sedimentation:** The formed flocs settled at the bottom of the sedimentation tank by gravity, separating the suspended solids from the treated water.

iv). **Biological Treatment:** In the aeration tank, microorganisms decomposed organic matter in the presence of oxygen. This process reduced BOD levels.

v). **Secondary Clarification:** Biomass and remaining suspended particles were settled in a secondary clarifier.

vi). **Filtration and Discharge:** The treated water was filtered through sand filters and discharged according to environmental standards.

Electrocoagulation (EC) Method: Electrocoagulation is an electrochemical technique used to remove contaminants from wastewater using sacrificial metal electrodes.

2. Characterization of Wastewater

Characterization of the wastewater was carried out before and after treatment to evaluate the efficiency of both ETP and electrocoagulation processes.

i). **pH Measurement:** The pH of the wastewater samples was measured using a calibrated digital pH meter**.** pH plays an important role in the efficiency of the electrocoagulation process.

ii). **Turbidity:** Turbidity was measured using a turbidity meter and expressed in NTU (Nephelometric Turbidity Units)**.** High turbidity indicates the presence of suspended particles in wastewater.

iii). **Biological Oxygen Demand (BOD):** BOD was measured using the 5-day BOD test method. This test determines the amount of dissolved oxygen required by microorganisms to decompose organic matter.

iv). **Total Dissolved Solids (TDS):** TDS was measured using a conductivity meter or TDS meter. It represents the total amount of dissolved substances in water.

Experimental Details

All the experiments were conducted in continuous process. In each experimental run, a wastewater sample of 1.2 liters was collected and placed in an electrolytic cell. The sample was rigorously stirred by a stirrer. Iron electrodes were dipped into the solution upto an active surface area of 72cm2 and the following currents of 0.12, 0.25 and 0.30 amp (0.36 amp-15V, 0.25) were passed for a contact time of 5, 10, 15 and 20 minutes. After passing each current for each time period, the sample was transferred into another beaker, and measured for pH. The measured sample was then taken to the jar test equipment, where it was rapidly mixed for 1 minute at 100 rpm. After a rapid mix for 1minute, the sample was kept for flocculation by setting the speed of the paddles at 30 rpm for 20 minutes. Subsequently, the flocculated sample was kept undisturbed for 20 minutes, in order to allow the flocs that formed during the flocculation to settle down. After a settling time of 20 minutes, 250 ml supernatant sample was collected to perform the physical and chemical analysis according to APHA standards. Similar analysis was done with the influent raw municipal wastewater samples before starting the experiment. After each continuous experiment, samples were again filtered with 0.45µm filter paper, to remove the electricity produced sludge, chlorides, alkalinity and a 20ml sample was collected to perform the Total suspended solids analysis with APHA standard experiments.

Observations and Observation Table:

The analysis result of untreated sample is presented

Table 1: Analysis of untreated sample

Sr. No.	Parameter	Unit	Result
1	pH	-	5.7
2	B.O.D	mg/L	140
3	Turbidity	NTU	329
4	TDS	mg/L	2018
5	Hardness	mg/L	270

Table 2: Treated sample from effluent plant

Sr. No.	Parameter	Unit	Result
1	pH	-	6.78
2	B.O.D	mg/L	56.3
3	Turbidity	NTU	95
4	TDS	mg/L	83
5	Hardness	mg/L	75

Table 3: Analysis of treated sample from electrocoagulation reactor model

Sr. No.	Parameter	Unit	Result
1	pH	-	7.8
2	B.O.D	mg/L	48.7
3	Turbidity	NTU	14
4	TDS	mg/L	56
5	Hardness	mg/L	14

Result and Discussion:

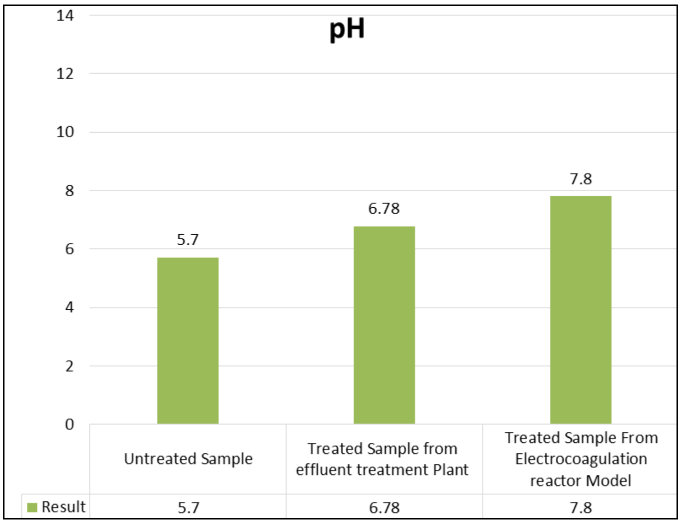

Fig 1: pH Graph

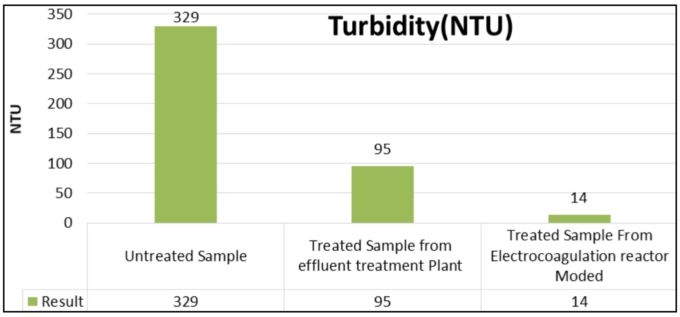

Fig 2: Turbidity Graph

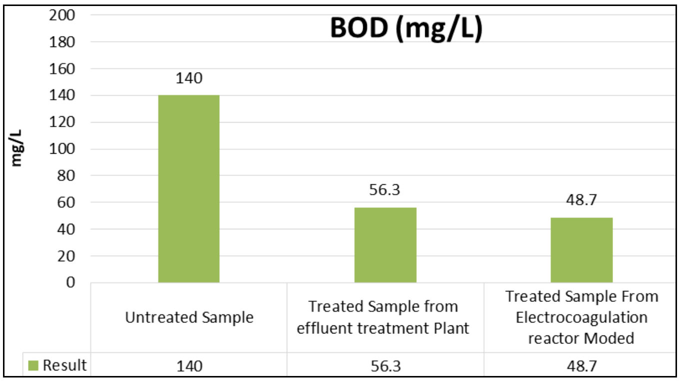

Fig 3: BOD Graph

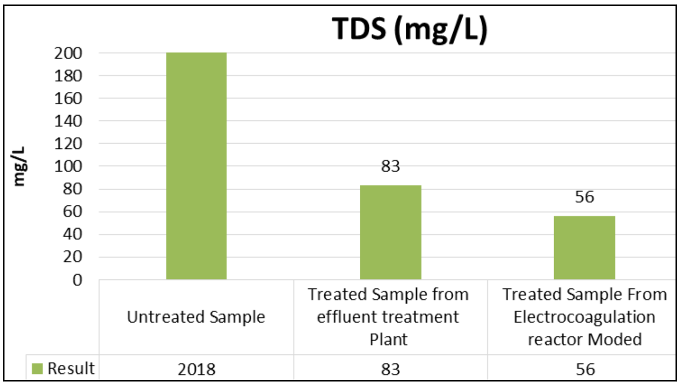

Fig 4: TDS Graph

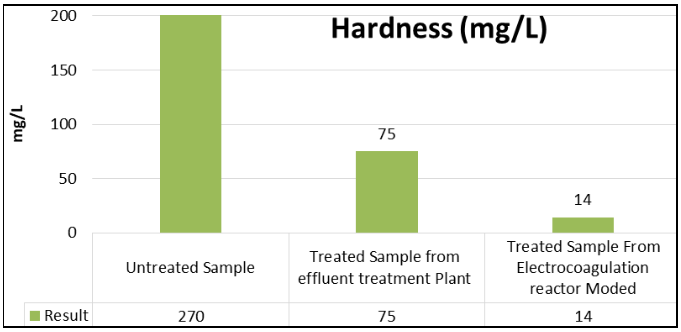

Fig 5: Hardness Graph

The experimental results clearly demonstrate that electrocoagulation (EC) is a highly effective technique for wastewater treatment. In comparison with the conventional Effluent Treatment Plant (ETP) process, EC exhibited significantly higher removal efficiencies for key parameters such as turbidity, biochemical oxygen demand (BOD), and suspended solids. This enhanced performance can be attributed to the in situ generation of coagulant species during the electrocoagulation process.

Unlike traditional chemical coagulation, where external chemicals are added, EC produces metal hydroxides directly from sacrificial electrodes. These hydroxides possess a high adsorption capacity and effectively destabilize colloidal particles, leading to improved aggregation and subsequent removal. Additionally, the simultaneous occurrence of electrochemical reactions, flotation, and coagulation within a single system further enhances pollutant removal efficiency.

Another important observation is the reduction in sludge generation in the EC process. The sludge produced is comparatively denser and more stable, making it easier to handle and dispose of than the bulky sludge generated in conventional treatment methods. Moreover, the treatment time required for EC was significantly shorter, indicating faster reaction kinetics and improved process efficiency.

The superior performance of EC also suggests its suitability for treating wastewater with high turbidity and organic load. However, operational parameters such as current density, pH, and electrode material must be carefully optimized to achieve maximum efficiency while minimizing energy consumption.

Overall, the findings confirm that electrocoagulation is a reliable, cost-effective, and environmentally sustainable alternative to conventional wastewater treatment methods. Its ability to achieve higher removal efficiencies with lower chemical usage and reduced sludge production makes it a promising technology for future large-scale and decentralized wastewater treatment applications.

Conclusion

The results showed that both ETP and EC processes were effective in reducing pollutants present in wastewater. However, the electrocoagulation method demonstrated higher removal efficiency for several parameters such as turbidity, biological oxygen demand (BOD), and total suspended solids (TSS).

During the electrocoagulation process, metal ions released from the electrodes formed hydroxide flocs that effectively adsorbed and removed contaminants from wastewater. The hydrogen gas bubbles generated during the reaction also helped in the flotation of suspended particles, improving the separation process.

Compared to the conventional ETP treatment, the electrocoagulation process offers several advantages, including: Higher pollutant removal efficiency, Lower chemical consumption, reduced sludge production, shorter treatment time, simpler operation and maintenance.

Based on the experimental results, it can be concluded that electrocoagulation is a promising and efficient technique for wastewater treatment.

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