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Wastewater Treatment using Electrocoagulation Oxidation Processes

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Abstract: *The control of environmental pollution and also the treatment of polluted water are of great concern. Within the past decade, electrochemical coagulation process has emerged as most effective wastewater treatment process as compared to conventional techniques of treating wastewater. Electrocoagulation is robust, cost effective, reliable, low sludge generating process, it has automation amenability and it has high pollutant removal efficiency. It has been proved effective in treating various types of wastewater but is seldom accepted. The aim of the review is to explain the basics and up to date advancement of electrocoagulation method for the improvements in the pollutant removal efficiency. In this review paper, an overview of electrocoagulation method with effect of key operational parameters on it is provided. Limitations of the method are also represented for the better understanding of the mechanism of pollutant removal and its optimization. The recent advancements and future scope of the electrocoagulation process are also reviewed.*

Keywords: Electrocoagulation; wastewater; poly hydroxides; sacrificial electrode

I. INTRODUCTION

In a world where the demand for freshwater is constantly increasing, and where limited water resources are under constant pressure and constraints, it has become unthinkable to neglect the opportunities offered by wastewater reuse. As such, wastewater will not be managed as "waste". It needs to be seen as a resource, rather than a burden to be disposed of. They are potentially a sustainable and affordable source of water, energy, nutrients, organic materials and other valuable by-products throughout the year. According to The United Nations WWRD (2017), for successful wastewater reuse, it is important to move from the "treatment and disposal" wastewater management paradigm to one based on "reuse, recycling and resource recovery". The objective of this chapter is to clarify the concept of wastewater, its origins and its potential risks. It also aims to address the various opportunities made possible through the reuse of wastewater.

Introduction of Wastewater

One of the most important challenges of the 21st century is the problem of water scarcity. Around 2 billion people in the world lacks convenient access to safe drinking water and an average of 7.8 million people die every year due to poor water hygiene and sanitation. Moreover, drought affects around 55 million people annually, which in turn causes more than US$5 billion of economic loss. Since 1980, the annual usage of water has increased by 1%, and this trend is expected to continue until 2050. The demand for reusable waster is echoed from various sectors including industrial, agricultural and residential sectors. As such, treatment of wastewater might be a solution to the problem of water shortage. Primary treatment, secondary treatment, and tertiary treatment are the three main phases of conventional wastewater treatment process. Primary treatment consists of bar screen and sedimentation basin to eliminate the suspended solids present in wastewater. Secondary treatment includes biological processes viz. biological filter process and activated sludge process to degrade the complex organic molecules into non-toxic compounds. Tertiary treatment consists of chlorination, ultraviolet disinfection and membrane bioreactors for extensive water purification The schematic outline of a typical wastewater treatment plant

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In general, the water treatment process can be categorised into either degradation technique or separation technique. Separation technique transfers the contaminants in water from one phase to another, most commonly into the solid phase. The finest illustration of this phenomenon is the adsorption process. However, separation technique like membrane

Wastewater treatments

The increasing volume of wastewater generated by domestic, industrial, and commercial activities necessitates effective treatment methods. Wastewater treatment plants (WWTPs) are designed to remove physical, chemical, and biological contaminants before the water is released into natural water bodies or reused.

1. Preliminary Treatment Preliminary treatment involves the removal of large debris and grit to prevent damage and clogging of downstream equipment:

E.g :- Screening ,Grit Removal

2. Primary Treatment This stage focuses on removing settleable solids and organic matter through sedimentation:

E.g :- Sedimentation Tanks (Primary Clarifiers)

3. Secondary Treatment Secondary treatment biologically degrades dissolved and colloidal organic matter:

E.g :- Activated Sludge Process, Trickling Filters, Oxidation Ponds.

4. Tertiary Treatment Advanced treatment that further purifies the effluent:

E.g :- Filtration, Disinfection.

5. Sludge Treatment Sludge, the by-product of wastewater treatment, must be managed effectively:

E.g :- Thickening, Digestion

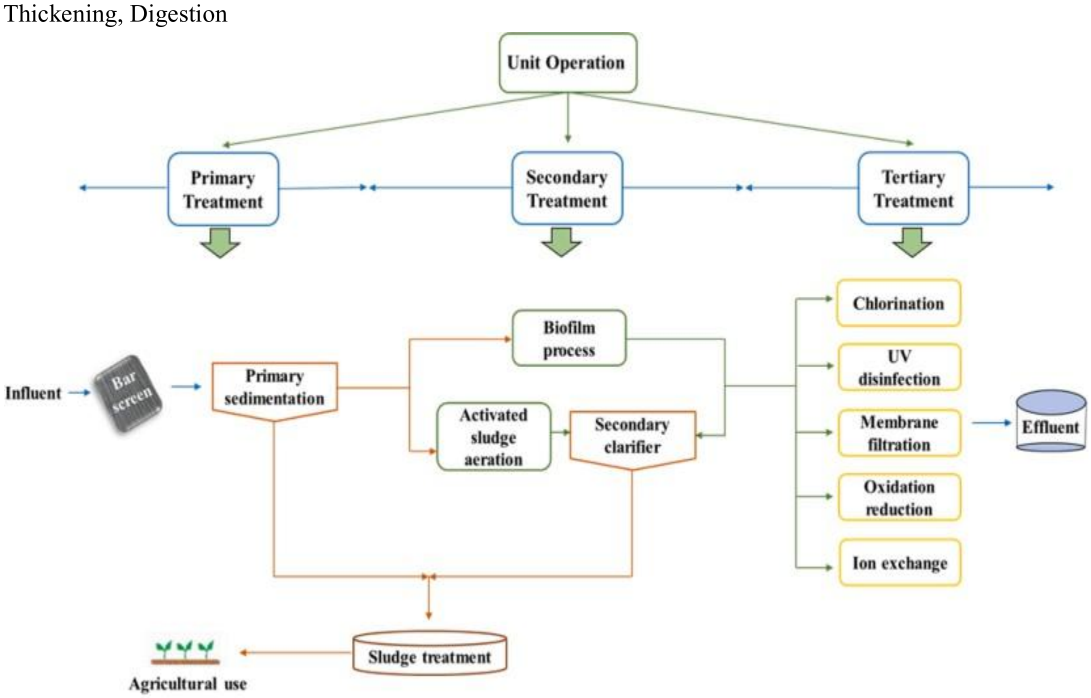

Fig. 1. Flowchart of the conventional wastewater treatment plant.

Overview of Electrocoagulation (EC) Process

Electrocoagulation is a water treatment technique that has received significant attention in the field of pollutant degradation from different wastewaters (industrial and domestic). It is a comparatively low-cost technique that breaks the stable emulsion and suspension in a solution using salt polymers or polyelectrolytes. The reduction of cathodic impurities in water with subsequent electro-flotation, is one of the crucial reaction that occurs during

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electrocoagulation. The hydrogen or oxygen bubbles generated by the electrodes assist in lifting the coagulated particles via electro-flotation Fig. 2 represents the schematic layout of an electrocoagulation reactor. The main operational parameters which influences the electrocoagulation process are inter-electrode distance, solution pH, type of electrodes, applied current density and electrode configuration. As a result, in every electrocoagulation study, these operational parameters must be optimised . The electrolysis effect is responsible for chemical and physiochemical phenomenon in electrocoagulation. This indicates that electricity is required for the production of coagulants via anodic dissolution, destabilization of particulate and pollutant suspension as well as floc formation by aggregation of the destabilised phase . Electrocoagulation process is based on the phenomenon of electrochemistry, in which oxidation or loss of electron takes place at the cathode whereas reduction or gain of electron occurs at the anodic surface . As in-situ coagulants are produced during the treatment, electrocoagulation process does not necessitate the use of added chemicals

Though the EC process has been extensively used for water and wastewater treatment, however, there are few limitations associated with the process such as rapid consumption of sacrificial anodes, leading to its periodic replacement and reduction in process efficiency due to the occurrence of electrode passivation. Also, the generated floc in the treated sample contains high concentration of metal ions which cannot be directly discharge into the environment, thereby requiring an additional post-treatment method in order to satisfy the environmental legislations. It is suggested that the combination of EC process with other water treatment techniques can overcome such limitations. Therefore, the use of electrocoagulation as a pre-treatment process could promote environmental and economic sustainability for the effective removal of various wastewater contaminants

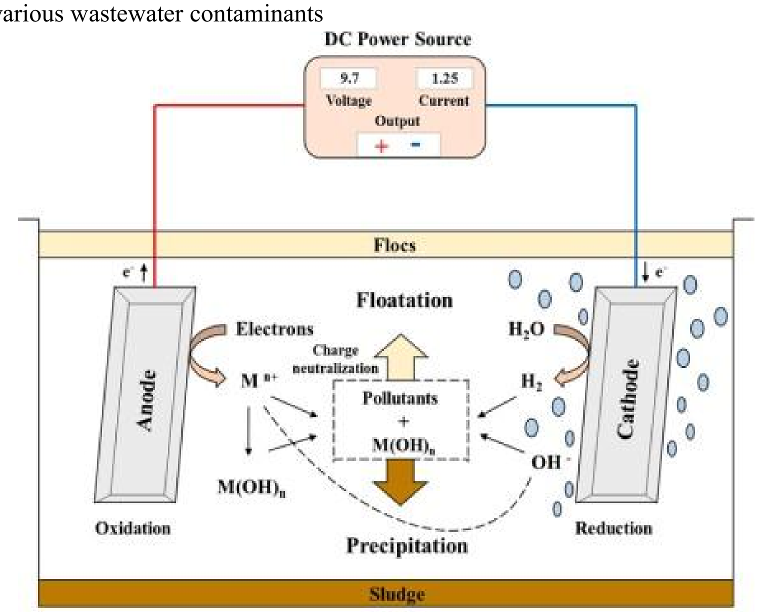

Fig. 2. Schematic diagram of the electrocoagulation process.

Mechanism and removal kinetics of electrocoagulation

The electrocoagulation process is widely used to destabilize the pollutants present in the form of dissolved or suspended particles in the electrolytic solution through the application of electric current. The electrocoagulation set up comprises of an electrolytic cell and a series of sacrificial metal electrodes (usually SS or Al) coupled to a controlled DC power source. The cathodes and anodes used during the process can be made either from the same or different materials . There are seven important steps in electrocoagulation mechanism viz. (i) formation of metal cations due to the supply of electric current to the anodes; (ii) production of hydroxyl ions due to cathode hydrolysis; (iii) interaction of metal cations with hydroxyl ions to form metal hydroxides; (iv) oxidation of toxic contaminants into harmless intermediate products; (v) charge neutralization of contaminants due to its reaction with the metal hydroxides; (vi) adsorption of charge neutralized contaminants on metal hydroxides, followed by its removal via sweep coagulation and (vii) gas

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formation (H2 gas) at the cathode lifts the generated flocs to the solution surface via sweep flotation Thus, the degradation of contaminants in EC process is primarily attributed to three phenomena viz. adsorption, coagulation, and floatation.

Overview of Oxidants: -

Properties of Sodium Persulphate

1. Strong Oxidizing Agent: Sodium persulphate is a strong oxidizing agent that can enhance the EC process by increasing the oxidation potential.
2. High Solubility: Sodium persulphate has high solubility in water, making it easy to add to the EC process.
3. Stability: Sodium persulphate is stable in water and can persist for a long time, allowing for effective treatment.

Mechanism of Action in Effluent

1. Oxidation: The EC process with sodium persulphate can oxidize pollutants and contaminants in the effluent, making them easier to remove.
2. Coagulation: The EC process can also cause the coagulation of pollutants and contaminants, making them easier to remove.
3. Adsorption: The EC process can also involve the adsorption of pollutants and contaminants onto the surface of the electrodes or other materials.

Effect on A+ and OH- Ions

1. A+ Ions: The addition of sodium persulphate can increase the concentration of A+ ions (such as aluminum or iron) in the EC process. These ions can react with pollutants and contaminants, making them easier to remove.
2. OH- Ions: The EC process can also produce OH- ions, which can react with pollutants and contaminants, making them easier to remove. The addition of sodium persulphate can enhance this process by increasing the oxidation potential.

How it Works in Effluent

1. Electrode Reactions: The EC process involves electrode reactions that can break down pollutants and contaminants in the effluent.
2. Oxidation-Reduction Reactions: The EC process can also involve oxidation-reduction reactions that can convert pollutants and contaminants into less harmful substances.
3. Coagulation-Flocculation: The EC process can also involve coagulation-flocculation reactions that can remove pollutants and contaminants from the effluent.

Properties of Thiosulfate

Thiosulfate (S2O32-) is a reducing agent with the following properties:

1. Reducing agent: Thiosulfate can reduce certain pollutants, such as heavy metals, by donating electrons.
2. Complexing agent: Thiosulfate can form complexes with certain metal ions, enhancing their removal.
3. Stability: Thiosulfate is relatively stable in water, allowing for effective use in wastewater treatment.

Mechanisms of Electrocoagulation with Thiosulfate

The mechanisms of EC with thiosulfate involve:

1. Electrocoagulation: The electric current generates coagulants, such as aluminium ions (Al3+), which react with pollutants to form precipitates.
2. Reduction: Thiosulfate reduces certain pollutants, such as heavy metals, making them more easily removable.
3. Complexation: Thiosulfate forms complexes with certain metal ions, enhancing their removal.
4. Co-precipitation: The coagulants generated during EC can co-precipitate with the reduced and complexed pollutants.

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Chemical Reactions

When thiosulfate is used with aluminium electrodes, the following reactions occur:

1. Anode reaction: $Al \rightarrow Al^{3+} + 3e^-$ (aluminum ions are generated)
2. Cathode reaction: $2H_2O + 2e^- \rightarrow H_2 + 2OH^-$ (hydroxide ions are generated)
3. Thiosulfate reaction: $S_2O_3^{2-}$ + pollutant → reduced pollutant + $S_2O_6^{2-}$ (tetrathionate)
4. Complexation reaction: $S_2O_3^{2-}$ + metal ion → metal-thiosulfate complex

When using stainless steel (SS) electrodes, the reactions may differ:

1. Anode reaction: $Fe \rightarrow Fe^{2+} + 2e^-$ (iron ions are generated if the SS anode is sacrificial)
2. Cathode reaction: $2H_2O + 2e^- \rightarrow H_2 + 2OH^-$ (hydroxide ions are generated)

Properties of Oxone

Oxone (potassium peroxymonosulfate) is a strong oxidizing agent with the following properties:

1. Strong oxidant: Oxone has a high oxidation potential, making it effective for breaking down organic pollutants.
2. High reactivity: Oxone reacts quickly with pollutants, allowing for efficient treatment.
3. Stability: Oxone is relatively stable in water, allowing for effective use in wastewater treatment.

Mechanisms of Electrocoagulation with Oxone

The mechanisms of EC with Oxone involve:

1. Electrocoagulation: The electric current generates coagulants, such as aluminium ions (Al^{3+}), which react with pollutants to form precipitates.
2. Oxidation: Oxone oxidizes pollutants, breaking them down into smaller, more easily removable compounds.
3. Coagulation: The coagulants generated during EC react with the oxidized pollutants, forming larger particles that can be easily removed.

Chemical Reactions

When Oxone is used with aluminium electrodes, the following reactions occur:

1. Anode reaction: $Al \rightarrow Al^{3+} + 3e^-$ (aluminium ions are generated)
2. Cathode reaction: $2H_2O + 2e^- \rightarrow H_2 + 2OH^-$ (hydroxide ions are generated)
3. Oxone reaction: $KHSO_5$ (Oxone) → $K^+ + HSO_5^-$ (peroxymonosulfate ion)
4. Pollutant oxidation: HSO_5^- + pollutant → oxidized pollutant + SO_4^{2-}

When using stainless steel (SS) electrodes, the reactions may differ:

1. Anode reaction: $Fe \rightarrow Fe^{2+} + 2e^-$ (iron ions are generated if the SS anode is sacrificial)
2. Cathode reaction: $2H_2O + 2e^- \rightarrow H_2 + 2OH^-$ (hydroxide ions are generated)

Properties of Air

Air is used in electrocoagulation (EC) to enhance the treatment process. The properties of air that make it useful in EC include:

1. Oxygen supply: Air provides oxygen, which can enhance the oxidation of pollutants.
2. Mixing and aeration: Air can be used to mix and aerate the wastewater, improving the contact between pollutants and coagulants.
3. Flotation: Air bubbles can attach to pollutants, causing them to float to the surface where they can be removed.

Mechanisms of Electrocoagulation with Air

The mechanisms of EC with air involve:

1. Electrocoagulation: The electric current generates coagulants, such as aluminium ions (Al^{3+}), which react with pollutants to form precipitates.

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2. Oxidation: The oxygen in the air can enhance the oxidation of pollutants, making them more easily removable.
3. Flotation: The air bubbles can attach to pollutants, causing them to float to the surface where they can be removed.
4. Coagulation: The coagulants generated during EC can react with pollutants, forming larger particles that can be easily removed.

Chemical Reactions

When air is used with aluminium electrodes, the following reactions occur:

1. Anode reaction: Al → Al3+ + 3e- (aluminum ions are generated)
2. Cathode reaction: 2H2O + 2e- → H2 + 2OH- (hydroxide ions are generated)
3. Oxidation reaction: Pollutants + O2 → oxidized pollutants
4. Flotation reaction: Pollutants + air bubbles → floated pollutants When using stainless steel (SS) electrodes, the reactions may differ:

1. Anode reaction: Fe → Fe2+ + 2e- (iron ions are generated if the SS anode is sacrificial)
2. Cathode reaction: 2H2O + 2e- → H2 + 2OH- (hydroxide ions are generated)

COMPARISON OF OXIDANTS PERFORMANCE

Oxidant	Maximum effectiveness	Minimum effectiveness	Optimum effectiveness
Sodium Persulfate	Strong oxidant, especially with activation	Low activation at neutral pH, poor activation	Best at pH 2-4,moderate conc. activation
Sodium Thiosulfate	Limited use in oxidation, more effective as reducer	Alone,very weak as oxidant	Effective as a reducer in combination with other oxidant
Oxone	Strong oxidant for organic pollutant	Less effective at high pH or low concentration	Best for pH 3-7, with heat or uv for enhanced reactivity
Air (O_2)	Depends on oxygen solubility and system effeciency	Limited without additional reagent or activation	When combined with other oxidant or energy

BENEFITS OF ELECTROCOAGULATION OVER OTHER TREATMENT PROCESS & ITS PHOTOS OF EXPERIMENT

1. Electrocoagulation has low maintenance, investment, treatment and energy costs. It is a relatively easy system to operate. There are no mechanically moving parts, so the system is not subjected to damage.
2. It can process multiple contaminants in one pass. Heavy metals, colloidal solids, organic compounds are removed using a single system as compared to use of multiple systems to remove these many contaminants.
3. It avoids the use of chemical reagents/coagulants, meaning there are no residual chemicals making their way into the treated effluent.
4. It requires a low level of electricity current.

II. CONCLUSION

The conclusion drawn from numerous studies on the electrocoagulation (EC) process enhanced by oxidation techniques is that this hybrid approach offers a highly effective and sustainable solution for wastewater treatment. By integrating EC with oxidation methods—such as electro- oxidation (EO), ozonation, or advanced oxidation processes (AOPs)—researchers have consistently observed improved removal of contaminants including chemical oxygen demand (COD), turbidity, color, and various persistent organic pollutants. These processes benefit from the synergistic effects of coagulant formation and oxidative degradation, which not only enhance the overall treatment efficiency but also help overcome the limitations of each individual method when used alone.

In practical applications, such as in the treatment of petroleum refinery effluents or dairy wastewater, the EC-oxidation systems have achieved removal efficiencies exceeding 90% for key pollutants. Furthermore, these systems have

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demonstrated economic viability, characterized by low energy consumption and operational costs. This makes them suitable for broader implementation in industrial and municipal wastewater treatment settings.

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