Advances in Chemical Engineering and Science, 2019, 9, 109-126
http://www.scirp.org/journal/aces
ISSN Online: 2160-0406
ISSN Print: 2160-0392

A Review of Promising Electrocoagulation Technology for the Treatment of Wastewater

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How to cite this paper: Sadik, M.A. (2019) A Review of Promising Electrocoagulation Technology for the Treatment of Wastewater. *Advances in Chemical Engineering and Science*, **9**, 109-126.
https://doi.org/10.4236/aces.2019.91009

Received: November 5, 2018
Accepted: January 27, 2019
Published: January 30, 2019

Abstract

A review of the literature published on topics interrelated to electrochemical treatment within wastewater by using sacrificial anodes was presented. Electrocoagulation (EC) is a technique used for water and has a great ability on various wastewater treatments, industrial processed water, and medical treatment. It has potential in removing various pollutants such as chemical oxygen demand turbidity, ammonia, color, and suspended solid. One of the most necessities industries is Textile industries which release large volumes of wastewater that contains different dyes. Azo dyes contain strong N = N bond which is not easily broken by conventional methods. The discharge of this type of wastewater to natural watercourse can pose serious environmental impacts to aquatic life. Electrocoagulation (EC) method depends on several factors as electrode material, current density, operation time and PH. The review describes, discusses and compares the types of that electrode influencing the EC process in various wastewater and leachate. Both operating costs and electrical energy consumption values were found to vary greatly depending on the type of electrodes material and solution being treated.

Keywords

Wastewater Treatment, Electrochemical Treatment, Electrocoagulation, Sacrificial Anodes

1. Introduction

There are two main significances of wastewater treatment, one is defending the environment and the other one is sustaining fresh water resources. With the ever increasing standard of drinking water supply and the stringent environmental regulations regarding the wastewater discharge, electrochemical technologies have retrieved their importance worldwide during the past two decades. Electrocoagulation-electro flotation (ECF) technology is a treatment process of applying electrical current to treatment and flocculating contaminants devoid of having to add coagulations. Electrocoagulation has olden times as a water treatment technology having been working to remove a varied of pollutants. The textile industry wastewater varies extensively in terms of composition due to the regular impurity in fibers and the chemicals used in different processes. Various types of dyes are produced worldwide and are used in various industries; the author indicated in **Table 1** some examples in recent applications of Electrocoagulation in treatment of water and wastewater, such as textile, cosmetic,

Table 1. Examples in recent Applications of Electrocoagulation in Treatment of Water and Wastewater.

Reference	Type of wastewater	Anode-cathode	Removal efficiency
Warren, R *et al.* (2018)	Metals	Fe-Fe	Fe (99.17%), Mn (99.97%),
Naraghi *et al.* (2018)	Reactive dyes	Fe-Fe	96% (Color)
P. Mahammedrafi, *et al.* (2018)	Fluoride ions	Fe-Fe	91% fluoride ions
Francisco, P *et al.* (2017)	Whey acids	Al-Fe, graphite and Ti/RuO2	79% - 49% contaminants
LiR *et al.* (2017)	Landfill Leachate	Al-Al	99% - 91%
Bejjany, B *et al.* (2017)	Internal loop airlift	Al-Al	70% - 87% energy consumption
Hariraj, S. *et al.* (2017)	Removal of suspended solids and metals from synthetic water	Al-Al	76.6%, and reduced rates of 99%, 59.2%, and 82.1%, for Cu, Cr, and Zn
Shobhan, M. *et al.* (2017)	Textile mill	(SS-Ti)-(Al-Ti)	90% - 78% (Color)
Seyed Ali *et al.* (2017)	Remazol Black B Dye	Al-Al, Fe-Fe	99% - 91% (Color)
Maghanga, J. *et al.* (2017)	Reactive Black 5	SS-SS	99.4% (Color)
Jorge, V *et al.* (2017)	Palm Oil Mill, Paint Wastewater	Fe-Fe	65% and 76% Total Suspended and Dissolved Solids
Alimohammadi, M *et al.* (2017)	Natural organic matter	Al-Al, Fe-Fe	100% (Color)
Abubaker T *et al.* (2017)	Tannery	aluminum nanoparticles	98.98%, 90.6%, 70.40%, 99.9% and 88.3% of Turbidity, COD, TDS, Chromium and Sulphide
Joseph, T. *et al.* (2017)	Abattoir	Fe-Fe	93% (Color)
Nasser, G .*et al.* (2017)	Herbicide oxyfluorfen, COD	Fe-Fe., S.S-S.S, Fe-Fe	(98.5% - 90%, 99.2% - 85%, 96.1% - 70.5% (Color, COD)
Manoel É *et al.* (2016)	Dye yellow Sirius	Al-Al	95% (Color)
Murat Eyvaz (2016)	Brewing industry	Al-Al, Fe-Fe	
Vidal, J *et al.* (2016)	Acid Black 194	Fe-Fe	100% (Color)
Anmoldeep, S *et al.* (2016)	Brilliant Green, Bromo blue and Brilliant blue	Fe-Fe	100% (Color)

paper, leather, pharmaceutical and food industry [1] [2] and [3]. Lately, electrocoagulation (EC) has been playing noticeable role in the drinking water treatment because it affords some substantial advantages such as quite compact, easy operation, automation, no chemical additives, and reduced amount of slug. Wastewater was considered for COD, Biochemical Oxygen Demand (BOD), pH, conductivity, chlorides, turbidity and color [4], and also in medical waste water [5] [6]. The effect of operating parameters such as current density, electrolysis time, and initial COD concentration was studied. Besides, energy and electrode consumption were examined. Electrocoagulation involves electrodes that are arranged in pairs—anodes and cathodes, whereby anodes (aluminum or iron electrodes) corrode to release active coagulants into solution. These hydroxides/polyhydroxides/polyhydroxy-metallic compounds have a strong affinity treatment of wastewater. Electrocoagulation technology is an alternative method to classic chemical coagulation that involves the use of alum (aluminum sulfate), ferric chloride ($FeCl_3$), or ferrous chloride. EC is talented of reducing chemicals by reason of the fact that the electrodes afford the coagulant *in situ*. However, sulfate (Fe_2SO_4) can be very costly depending on the volume of water treated. The coagulant performed a similar function as the electrodes, neutralizing the charge of the particulates, thus allowed them to collect and settle at the bottom of the tank. In addition, electrocoagulation-flotation is talented of reducing waste production, time and electrical energy consumption for wastewater [7] [8] [9] while [10] and [11] enhanced electrocoagulation device for treating various types of industrial wastewater and observed how electrocoagulation-flotation(ECF) reactor can be effective, according to wastewater type, pH, current density and type of metal electrodes (aluminum, steel). Among all the various technologies available, electrolysis is one of the best. The EC offers a substitute to use metal salt or polymer or polyelectrolyte addition so as to destabilize emulsion and suspension. The EC technology has been employed to remove metal, colloidal solid, particle, and soluble inorganic pollutant from the water/wastewater by applying highly charged polymeric metal hydroxide species. These species neutralize the electrostatic charge on suspended solids to facilitate accumulation or coagulation and the resultant separation from aqueous medium.

2. Electrocoagulation Process

The (EC) technology includes coagulation and precipitation of contaminants by a direct current electrolytic process followed by the separation of flocculent (settling or flotation) with or without the addition of coagulation-inducing chemicals. The water is pumped through a unit which consists of pairs of metal sheets called electrodes that are arranged. A direct current electric field is applied to the electrodes to induce the electrochemical reactions needed to achieve the coagulation. Coagulation technology induces Coagulation and precipitation of contaminants. In an EC process the coagulated ions a produced in "*in situ*" and it involves three successive stages.

1) Information of coagulants by electrolytic oxidation of the sacrificial electrodes.

2) Destabilization of the contaminants, particulates suspension and breaking of emulsions.

3) Aggregation of the destabilized phase to form flocculent.

Electrodes which produce coagulants into water are made from either iron or aluminium. Iron and aluminium cations dissolve from the anodes according to Equation (1) and Equation (2).

$$Fe(s) \rightarrow Fe^{n+}(aq) + ne^{-} \quad (1)$$

$$Al(s) \rightarrow Al^{3+}(aq) + 3e^{-} \quad (2)$$

And at cathode according to Equation (3)

$$2H_2O + 2e \rightarrow H_2 + 2OH^{-} \quad (3)$$

In solution the positively charged ions are attracted with the negatively charged hydroxides to produce ionic hydroxides that have a strong attraction towards dispersed particles as well as counter ions to cause coagulation [12].

3. Overview of Different Types of Water and Wastewater Recently Treated by Electrocoagulation-Electro Flotation (ECF) Technology

The EC process is the electrochemical generation of metal ions (such as Al and Fe) that act as destabilizing agents and leads to neutralization of electric charge for removing pollutants. This process has been proven to be very effective in removing contaminants from waters and is characterized by reduced sludge production, no requirement of chemicals, and ease of operation and electrical energy consumption. [13] demonstrated removal efficiency 91% of fluoride ions from water by Electrocoagulation process and maximum hardness removal 60% - 70%, while [14] studied effluents from different industrial sectors. Using iron anode, Fe (99.17%), Mn (99.97%), TSS (99.35%) and other metals such as Cu, Zn and Cd were removed in more than 99%, while the removal of Pb was very varied. The effluent from the treatment ponds of the waste disposal plant was processed using iron anodes, reaching a removal of 45.14% COD, with an energy consumption of 3.30 kwh/m^3 at a cost of 0.29$/m^3. [15] studied the textile wastewater contain Reactive Black 5 (RB5) as an Azo dye that causes serious damage to the environment and aquatic life in receiving water resources. The findings of this study demonstrated that the highest simultaneous removal performance (96%). With the increasing of reaction time, the energy consumption, electrodes wear, pH, final temperature of effluent, and removal efficiency would increase. Adsorption process could play a small role in the removal of the dye, while it was very effective in improving the performance of the electrocoagulation process. [16] observed few conventional and biological methods are inadequate and insufficient for the treatment of wastewater from dye industries. Advance treatment processes such as electrocoagulation and Fenton oxidation process or combination of these processes can be a better option for treatment of such wastewater. This paper reviews the application of electrocoagulation and Fenton oxidation processes for the treatment of dye wastewater. Both electrode materials exposed similar pollutant removal performances while Al electrode was found cost effective one. [17] renewed electrocoagulation (EC) water-treatment processes. The outcome indicates that a maximum TSS removal efficiency of 76.6% and reduced rates of 99%, 59.2%, and 82.1%, for Cu, Cr, and Zn, respectively. Moreover, kinetic study has also demonstrated that pollutants removal follows first-and second-order model with current density and EC time being dependent. [18] focused on, the performance of an EC process by incorporating titanium plates (Electro-oxidation) for the treatment of textile mill wastewater using Stainless Steel-Titanium (SS-Ti) and Aluminium-Titanium (Al-Ti). The COD removal efficiency of SS coated with sodium alginate hydrogel in combination with Ti was found to be 90% and 87% respectively. The power consumption of SS and Al was found to be 9.6 kWh/m^3 and 5.25 kWh/m^3. [19] carried out a study with wastewater from industrial pulp and paper recycling using electrocoagulation. Aluminum (Al) and Iron (Fe) electrodes were used as the electrochemical cell set up, COD and color removal efficiency with the Fe electrode were 92% and 100%, respectively. Al electrodes had lower efficacy for COD and color removal than the Fe electrode. [20] achieved a 94% chemical oxygen demand (COD), 87% arsenic, 96% iron, and 86% phosphorus removal from landfill leachate. Besides electrical current, reaction time and pH are played a very important role in arsenic and phosphorus removal by electrocoagulation process. [21] reviewed and summarized that the recent development of arsenic removal in EC process including the effects of primary operating parameters, optimization of the EC performance, as well as the evaluation of EC reactor configurations. Production and characterization of EC products with respect to different electrodes are systematically discussed. Besides, this review will contribute to deepening the understanding of EC process for arsenic removal and offer useful information to researchers in this field. [22] carried out a study with surface water by an electrocoagulation-electroflotation process in internal loop Airlift reactor. The electrocoagulation-electroflotation kinetics is rapid and it increases with the increase of the initial electrical conductivity of the solution $\sigma 0$. To achieve a turbidity abatement of 40%, and a reduction of 70% and 87%. As for energy consumption, time, [23] obtained decolourization efficiency of the azo dye Reactive Black 5 (RB-5) from synthetic wastewater 99.4% with Electrical energy consumption 0.75 kWh/m. by using Electrocoagulation (EC) technique. [24] evaluated efficiency almost 100% of electrocoagulation (EC) for the removal of natural organic matter (NOM) by using iron (Fe) and aluminum (Al) electrodes. Electrical energy consumptions were 14.90 kWh/kg Al (or 0.092 kWh/m^3) and 2.88 kWh/kg Fe (or 0.11 kWh/m^3). Specific electrode consumptions were obtained to be 0.0062 and 0.0382 kg/m^3, and operating costs of the EC system were preliminary estimated at 0.057 and 0.119 $/m^3 for Al and Fe electrodes, respectively. [25] employed electrocoagulation technique for treating various wastewaters. Palm Oil Mill Effluent (POME) and Paint Wastewater (PW) using iron electrodes. Results revealed that this process could reduce the concentration of Total Suspended and Dissolved Solids (TSDP), in both POME and PW. The highest removal efficiencies of 65% and 76% were obtained for POME and PW, respectively. [26] successfully removed 99%, 91% of (Remazol Black B) colored water using electrocoagulation process is equipped with iron and aluminum electrodes, respectively. [27] treated tannery wastewater sample using an electrode of aluminum nanoparticles. The investigation of the tannery waste water showed high signs of pollution to remove 98.98%, 90.6%, 70.40%, 99.9% and 88.3% of Turbidity, COD, TDS, Chromium and Sulphide respectively. was carried out a study to investigate Reactive Red 76 (RR) and C.I. Disperse Blue 79 (DB). The process parameters investigated was found optimum efficient for of both dyes removal due to formation of Fe (III) as a coagulant *in situ*. [28] showed that EC technique is effective in abattoir wastewater treatment using Fe-Feelectrodes. The removal efficiency of 93.69%, and 0.55 kWh/L power consumption. [29] used the electrocoagulation process to remove of the herbicide oxyfluorfen and chemical oxygen demand (COD) in aqueous solution. The results showed that the maximum removal efficiency for oxyfluorfen and COD were (98.5% and 90%), (99.2% and 85%) and (96.1% and 70.5%) by using iron (Fe), stainless steel (S.S) and aluminum (Al) The energy consumption in the electrocoagulation process at optimum conditions (15.9, 16.65 and 14.1 KWh/m^3) using Fe, SS and Al electrodes respectively. [30] conducted the efficient removal of fluoride from the drinking water. Electrocoagulation technology provides some significant advantages such as quite compact, easy operation, automation, no chemical additives, high velocities and reduced amount of sludge. [31] investigated electrocoagulation process on the treatment of brewing industry effluents. The process operated with electrocoagulation reactor including four plate electrodes. Two electrode materials, Fe and Al, were separately employed in parallel connection. [32] used electrocoagulation process (EC) for the elimination of Acid Black 194 textile dye from synthetic and textile wastewater (effluent) contaminated with Acid Black 194 dye, was carried out using aluminum anodes. The final result was absolutely decolourization with pure water have not dye and organic matter. [33] responded high removal efficiency of Brilliant Green, Bromo blue and Brilliant blue from aqueous using electrocoagulation methodology to determine the optimum conditions for the efficiencydye removal from solution [34] investigated, high efficiency more than 95% of decolourization from solutions containing dye yellow Sirius K-CF in aqueous media by applying aluminum electrode in electrocoagulation cell. [35] treated the real textile wastewater taken from dying process of the industry by electrocoagulation (EC) process. The results showed that MP-P mode was the most cost effective for both electrode connection types. The results presented that, according to electrical and sacrificial electrode costs, iron is superior to aluminum but aluminum electrode leads to high turbidity, color and COD removal efficiencies. While [36] made the treatment of sullage wastewater using electrocoagulation technique with stainless steel electrode as sacrificial anode in bipolar connection system and studied the optimum values of voltage, initial pH and electrolysis time were experimented, respectively. The experiments revealed that COD, BOD and SS in aqueous phase were effectively removed. The analysis of the treated water showed that the maximum COD, BOD and SS removal efficiencies were 92.71%, 88.76% and 93.1%, respectively at optimum conditions. [37] successfully removed heavy metal ion of cadmium (Cd), copper (Cu) and nickel (Ni) from a simulated wastewater by electrocoagulation (EC) method. The experimental results indicated that the highest Cd, Ni, Cu removal were 99.78%, 99.98%, 98.90%. [38] successfully removed of 98% of chemical oxygen demand (COD) from distillery effluent by electrocoagulation is becoming increasingly important from environmental and aesthetic point of view. Effluent from distilleries contains certain recalcitrant compounds. [39] reported a research on the removal of Reactive Red 120 in synthesized wastewater through electrocoagulation using solar energy for the purpose of improving economic efficiency of the process. Cost analysis was also performed for the treatment process. Further, the obtained optimum conditions were applied to the treatment of six samples of real textile effluent. Electrocoagulation was satisfactory in only four of the cases. Lastly, efficiency of treating the real samples was evaluated by subjecting the experimental electrodes to the SEM technique removed the phosphate from wastewater by electrocoagulation using aluminum electrodes Additional, the optimum conditions was investigated. The main objectives was determined the maximum removal efficiency of phosphate from synthetic wastewater in batch EC process. [40] investigated experimentally the removal of COD and oil from dairy wastewater using direct current (DC) electrocoagulation (EC). In the EC of dairy wastewater, the effects of initial pH, electrolysis time, initial concentration of COD, and current intensity were examined. The COD in the aqueous phase were effectively removed when aluminum plates were used as sacrificial electrodes. The optimum operating range for each operating variable was experimentally determined. The batch experimental results revealed that COD in aqueous phase was effectively removed. The overall COD removal efficiencies extended 87% and energy consumption was 112.9 kWh/kg. [41] investigated experimentally the removal of dye reactive orange 16 (RO16) by electrocoagulation using iron electrode was conducted in a batch reactor. The effect of operating parameters such as current density, initial concentration of dye, pH and contact time was studied and the electrical energy consumption was calculated. The maximum efficiency of hardness removal was 99.27%. Also COD removal efficiency is increased to 66%. Results show, electrocoagulation process by iron electrode is an effective method for reactive dye removal from colored wastewater. [42] was performed the removal of waste red mud slurry (RMW) from the aluminium industry. The removal efficiencies of V, Si, Al, As, Mo and Ga present in the wastewater at the optimum operating conditions pH, current density and operating time as 97.68%, 82.65%, 98.22%, 99.44%, 99.69% and 99.95% in the EC process, respectively. The sludge produced after the EC process was characterized with scanning electron microscope. The amount of sludge and operating cost at the optimum operating conditions were calculated as 2.138 kg/m^3 and 0.813 €/m. [43] conducted electrocoagulation, electrooxidation and advanced electrochemical oxidation using the electro-Fenton process for removal of indigo carmine dye from aqueous solutions and dye house effluent. The electrocoagulation process was performed by sacrificial iron electrodes, the indirect electrooxidation process by dimensionally stable Ti/Pt and graphite electrodes in NaCl electrolyte solution, and the electro-Fenton process by iron electrodes and added amounts of H_2O_2. All electrochemical experiments are conducted in the same electrochemical cell with the same apparent electrode surface and interelectrode distance, most efficient and economical process operated at very low current densities of 0.33 and 0.66 mA·cm^{-2} and consuming only 4.75 × 10^{-3} and 5.23 × 10^{-3} kWh·m^{-3} of treated solution respectively. The electrocoagulation treatment with iron electrodes and the electrooxidation process with Ti/Pt electrodes conducted at applied current densities of 5 mA·cm^{-2} consumed 0.511 and 0.825 kWh·m^{-3} of treated solution respectively. The proposed procedure is a safe, economical and efficient method for removal of indigo carmine dye from aqueous solutions and dye house effluent. [44] studied the removal efficiency of phenolic compounds by electrocoagulation process, as well as to compare the specific energy consumption (SEC) of these processes under different experimental conditions. Electrocoagulation was carried out on two different samples of water: model water of mimosa tannin and olive mill wastewater (OMW). Low carbon steel electrodes were used in the experiments. It was found that electrocoagulation treatment of effluents containing phenolic compounds involves complex formation between ferrous/ferric and phenolic compounds present in treated effluent, which has significant impact on the efficiency of the process. [45] used iron, aluminum and stainless steel electrodes to treat the textile industry wastewater in batch reactor by electrocoagulation method. The result indicates that electrocoagulation is very efficient and was able to achieve color removal (99.46%) and COD removal (90.12%) in the presence of iron electrode. The COD and Color removal by aluminum and stainless steel electrodes were achieved at high voltages. The energy consumption was low in case of iron electrode when compared to aluminum and stainless steel electrode for the maximum COD removal. The effluent wastewater was clear but involves post treatment to meet direct discharge standards. [46] [47] reviewed that Electrocoagulation for treating industrial effluent due to its flexibility and environmental compatibility. This technique uses direct current source between metal electrodes immersed in the effluent, which causes the dissolution of electrode plates into the effluent. The metal ions, at an appropriate pH, can form wide range of coagulated species and metal hydroxides that destabilize and aggregate particles or precipitate and adsorb the dissolved contaminants. Therefore, the objective of the present manuscript is to review the potential of electrocoagulation for the treatment of industrial effluents, mainly removal of dyes from textile effluent. [48] studied the removal of brilliant green dye from aqueous solutions in a batch stirred electrocoagulation (EC) reactor using iron electrodes. The experimental results showed that 99.59% dye removal was observed for initial dye concentration of 100 mg/L with current density of 41.7 A/m^2, initial pH of 4.0 at the end of 30 min of operation. It was observed that, an increase in current density, time of operation and decrease in inter electrode distance improved the dye removal efficiency. Optimum pH for highest dye removal was 4.0 - 10.0. It was also observed that increase in salt (NaCl) concentration in the solution reduces the specific electrical energy consumption (SEE) [49] reviewed the mechanism, affecting factors, process, and application of the electrocoagulation process. The electrocoagulation (EC) process is an electrochemical revenues of presenting coagulants and removing suspended solids, colloidal material, and metals, as well as other dissolved solids from water and wastewaters. The EC process has been successfully employed in removing pollutants, pesticides, and radionuclides. This process also removes harmful Microorganisms. More often during EC operation, direct currents applied and electrode, plates are sacrificed (dissolved into solution). The dissolution causes an increased metal concentration in the solution that finally precipitates as oxide precipitates. [50] remarkable removal of 100% of phenol from oil refinery waste effluent with lower energy consumption by using electrocoagulation technology using an electrochemical reactor with a fixed bed anode made of randomly oriented Al raschig rings packed in a perforated plastic basket located above the horizontal cathode. Removals of Methylene Blue dye by using an electrocoagulation process have been investigated by [51], the optimum electrolysis time, current density, concentration of the electrolyte (NaOH) were established. The utilization of an electromagnetic field enhanced the dye removal and power consumption due to the induced motion of paramagnetic ions inside the solution. [52] effectively treated hospital wastewater .The percentage removal of Total dissolved solids; Suspended solids are 96.98% and 91.89% respectively. hospital wastewater contain solids, BOD, COD, phenols, radioactive isotopes, pathogens such as bacteria, viruses, blood, body fluid, sweat, contaminated organs, disinfectant, pharmaceuticals as well as hazardous chemicals can be effectively removed by Electrocoagulation method. [53] conducted to investigate the applicability of the electrocoagulation technique for the treatment of domestic wastewater. Iron electrodes are used and the sample is made up to run at different intervals of time, showed that only current (C) and treatment time (t) have correlation with each other. It observed that the batch which is operated at 0.25 A for 20 minutes has maximum removal efficiency of Chemical Oxygen Demand, Total Dissolved Solids, pH, Color, chlorides etc. [54] treated of sewage water by electrocoagulation using stainless steel, iron and aluminum electrodes, the optimum condition for this treatment is detected. The optimum treatment condition reduced COD by 98.07%, BOD by 98.07%. [55] treated paint manufacturing wastewater (PMW) by electrocoagulation (EC) process. Effects of operating parameters for the EC process such as electrode type (Al or Fe), initial pH, current and operating time were examined for optimum operating conditions. The highest removal efficiencies for COD and TOC in PMW were obtained with 93% and 88% for Fe and 94% and 89% for Al electrodes at the optimum conditions Costs for removal were calculated for Fe and Al electrodes as 0.187 €/m^3 and 0.129 €/m^3. By comparing electrode's result Al electrode was better than that of Fe electrode in terms of removal efficiency and operating cost. [56] employed electrocoagulation (EC) for removals of color, chemical oxygen demand (COD) and total organic carbon (TOC) from baker's yeast effluents (BYEs) in a batch EC reactor using aluminum electrodes. The maximum color, COD and TOC were 88%, 48% and 49% and operating costs were 0.418 €/m^3. [57] treated of marble wastewater by electrocoagulation using Aluminium and iron electrodes were investigated. The sample used was from the marble-processing plant. The optimum values of initial pH, current density and electrolysis time was carried out using Aluminium electrode, the removal efficiencies obtained for turbidity, suspended solids, chemical oxygen demand and total solids were 98.5%, 99.2%, 55.2% and 92.4%, respectively and electrode energy consumptions were 0.143 kWh/kg, iron electrode, the optimum removal efficiencies for turbidity, suspended solids, chemical oxygen demand and total solids were determined as 94.3%, 99.1%, 54.2%, and 96.1%, respectively. Energy and electrode consumptions were 0.0571 kWh/kg. [58] treated of tannery effluent to reduce chromium and COD The result indicated that 86% COD removal and 1.2 $kWh{\cdot}m^{-3}$ energy consumption, 0 turbidity, 91% color abatement, 0 ppm chromium. [59] conclusively shown that the feasibility and utility of the difference between using Electrocoagulation (EC) and chemical coagulation (CC) in EC the coagulant is added by electrolytic oxidation of an appropriate anode material, while in CC dissolution of a chemical coagulant is used. These different methods in fact induce different chemical environments, which should impact coagulation/flocculation mechanisms and subsequent floc, formation. Hence, the process implications when choosing which to apply should be significant. This study elucidates differences in coagulation/flocculation mechanisms in EC versus CC and their subsequent effect on floc growth kinetics and structural evolution. A buffered kaolin suspension served as a representative solution that underwent EC and CC by applying aluminum via additive dosing regime in batch mode. In EC an aluminum anode generated the active species while in CC, commercial alum was used. Aluminum equivalent doses were applied, at initial pH values of 5, 6.5 and 8, while samples were taken over pre-determined time intervals, and analyzed for pH, particle size distribution, ζ potential, and structural properties. EC generated fragile flocs, compared to CC, over a wider pH range, at a substantially higher growth rate, that were prone to restructuring and compaction. The results suggest that the flocculation mechanism governing EC in sweep flocculent conditions is of Diffusion Limited Cluster Aggregation (DCLA) nature; versus a Reaction Limited Cluster Aggregation (RLCA) type. [60] used Electrocoagulation technology for purifying firefighting water containing fluorinated surfactants. Electrocoagulation with aluminum electrodes followed by filtration removed turbidity from pilot firefighting water. Fluorinated surfactant removal was 71% - 77% and was not considerably increased by higher charge loading. Flocculent separation in bulk solution was completed by filtration. [61] studied the efficiency of electrocoagulation treatment process using aluminum electrodes to treat synthetic wastewater containing Reactive Red 198. The effects of parameters such as voltage, time of reaction, electrode connection mode, initial dye concentration, electrolyte concentration, and inter electrode distance on dye removal efficiency were investigated. In addition, electrical energy consumption, electrode consumption, and operating cost at optimum condition have been investigated. The results showed that dye and chemical oxygen demand removals were 98.6% and 84%, respectively. Electrode consumption, energy consumption and operating cost were 0.052 kg/m^3, 1.303 kWh/m^3 and 0.256 $US\$/m^3$, respectively. It can be concluded that electrocoagulation process by aluminum electrode is very efficient and clean process for reactive dye removal from colored wastewater. [62] used electrocoagulation (EC) technology to treat wastewater from landfill leachate, characterized by COD, high concentration of nitrogen and dark color. The findings, the experimental result specifies current density, the inter-electrode distance and the stirring speed. The removal efficiencies of COD, total nitrogen, color and turbidity were respectively 70%, 24%, 56%, and 60% with Al electrodes and 68%, 15%, 28%, and 16% with Fe electrodes. Electrical energy consumption and operating cost with Al electrodes were 0.022 (kWh/L), 0.54 ($US\$/m^3$ leachate treated), respectively, and 0.019 (kWh/L), 0.47 ($US\$/m^3$) with Fe electrodes. [63] used electrocoagulation system to remove As (III) and $F(^-)$ ions from water simultaneously. Dimensionally stable anodes (DSA), Fe electrodes, and Al electrodes were combined into an electrochemical system; it is observed that Removal efficiency of As (III) increases with the increase of solution pH. [64] investigated the removal of chemical oxygen demand (COD) and turbidity from cardboard paper mill effluents using aluminum and iron electrodes followed by adsorption of treated wastewater on granular activated carbon (GAC). The maximum removal efficiencies of COD and turbidity under optimal operating conditions for Al and Fe electrode respectively, were 75.37% and 99.93%, and 78.76% and 99.92% for Fe electrode, respectively. [65] inspected the decolorization up to 98%, comparison to CC (limited to 53%) of a synthetic textile wastewater containing Orange II using electrocoagulation (EC). Aluminum and iron electrodes were used. A comparison with chemical coagulation (CC) using the same amount of metal cations as in EC was also carried out. Experimental results showed that EC maximized decolorization (up to 98%) in comparison to CC (limited to 53%). For EC, iron electrodes exhibited the highest decolorization yield and diminished with energy requirements [66] also Performances a study of electrocoagulation process with aluminum electrodes in the treatment of Cu^{2+}, Zn^{2+} and Mn^{2+} containing aqueous solutions from synthetic wastewater showed that type of anion in solutions has a substantial effect on the metal removal. Total removals of copper and zinc reached almost 100% after 5 min, the Mn removals were 85% and 80% in the presence of sulfate and chloride anions, respectively. [67] described an electrocoagulation process for treating laundry waste-water using aluminum plates, electrical current and pH of the influent is a very important effects of the treatment of laundry waste-water In addition, kinetic analysis indicates that the adsorption system obeys a second-order kinetic model. It is concluded that, compared with other treatment processes, electrocoagulation is more effective in treating laundry waste-water under appropriate conditions and [68] was investigated the influence of current density, pH and stirring speed in the treatment of poultry slaughterhouse wastewater (PSW) using electrocoagulation process with aluminum electrodes. The best removal efficiency has been obtained 85%, 98% COD, turbidity respectively Electrical conductivity of investigated wastewater was nearly 2860 μS/cm, which caused energy consumption to be relatively lower.

4. Conclusion

This research has identified a review of efficaciously electrocoagulation application, for the subtraction of precise problematic as toxicity and huge loss quantities of water that unconcerned effectively by Conventional treatment methods. However, this paper has effectively reasoned that the EC technique is alternative method for treatment wastewater. A number of studies using experimental setup in many applications of this promising technology have done better reactors design. From the above literature it can be established that the electrocoagulation is the effective method for the treatment countless wastewater and elimination solids, color, turbidity, BOD and COD. The various rewards for this promising technology are low operation and maintenance cost, high efficiency, time saving, lower sludge production without any addition of chemicals. Maybe this simple reactor in the near future will be in most various factories and water treatment company.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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Abbreviation

AC, alternating current (amp); BOD, biochemical oxygen demand (mg/L); COD, chemical oxygen demand (mg/L); DC, direct current (amp); F, Faraday's constant (96, 500 C/mol); ppm, parts per million; SS, suspended solids (mg/L); TDS, total dissolved solids (mg/L); TFS, total fixed solids (mg/L); TOC, total organic carbon (mg/L); TSS, total suspended solids (mg/L); TVS, total volatile solids (mg/L).

Nomenclature

cost of electricity/kWh
cost of electrode/kg electrode
BP-S bipolar electrodes in serial connections
cost of chemical/kg of chemical
CHC chemical consumption (kg of chemical/m^3 of effluent)
EC electrocoagulation
ELC electrode consumption (kg of electrode/m^3 of effluent)
ENC energy consumption (kWh/m^3 of effluent)
I applied current (A)
M relative molar mass of the electrode (g/mol)
MP-P monopolar electrodes in parallel connections
MP-S monopolar electrodes in serial connections
MS mild steel
nnumber of electrons in oxidation/reduction reaction
SS stainless steel
St steel
telectrolysis time (h)
U applied voltage (V)
V volume of treated effluent (m^3)