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Applications of Electrocoagulation in treatment of Industrial Wastewater : A Review

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Abstract

The aim of this paper is to review the relevant literature that published from 2007 to 2013 on topics related to Electrocoagulation within the wastewater. The Elecrocoagulation applications discussed here were divided into following 4 categories: - textile industry, tannery industry, pulp and paper industry and food industry wastewater.

Keywords: Electrocoagulation, wastewater, current density, electrode

Introduction

Electrocoagulation has a long history, the first plant was built in London in1889 for the treatment of sewage where elecrocoagulation treatment was employed via mixing the domestic wastewater with saline water (Kabdash et al.). The principle of electrocoagulation was first patented in 1906 by A.Edietrich and were used to treat bilge water from ships(Ahmed Samir Naje et al.). In 1909, J.T. Harries received a patent for wastewater treatment by electrolysis using sacrificial aluminium and iron anodes in the United States.

Electrocoagulation is an electrochemical technique for treating wastewater using electricity instead of expensive chemical reagents. An electrocoagulation process has been attracted a great attention on treatment of industrial wastewater because of the versatility and environmental compatibility. This technique has several advantages as compared to conventional methods in terms of use of simple equipment, ease of operation, less treatment time, reduction or absence of chemicals addition. Moreover ,an electrocoagulation process provides rapid sedimentation of electro generated flocs and a less amount of sludge production. Electrocoagulation has the advantage of removing the smallest colloidal particles compared with traditional flocculation-coagulation, such charged particals have a greater probability of being coagulated and destabilized because of the electric field that sets them in motion. In this paper, an attempt has been made to review the literature published on electrocoagulation. The review included direct applications on electrocoagulation in textile, tannery, pulp and paper and food industry.

Background behind electrocoagulation

Electrolysis is a process in which oxidation and reduction reactions take place when electric current is applied to an electrolytic solution. Electrocoagulation is based on dissolution of the electrode material used as an anode. This so called “sacrificial anode” produces metals ions which act as coagulant agents in the aqueous solution in situ. At its simplest, an electrocoagulation system consists of an anode and a cathode made of metal plates, both submerged in the aqueous solution being treated. The electrodes are usually made of aluminium, iron or stainless steel, because these metals are cheap, readily available, proven effective and non-toxic. Thus they have been adopted as the main electrode materials used in electrocoagulation system. The configuration of electrocoagulation systems vary. An electrocoagulation system may contain either one or multiple anode-cathode pairs and may be connected in either a monopolar or a bipolar mode.

Generally, three main processes occur serially during electrocoagulation:
(a) electrolytic reactions at electrode surfaces,
(b) formation of coagulants in aqueous phase,
(c) adsorption of soluble or colloidal pollutants on coagulants, and removal by sedimentation or floatation.

Electrocoagulation is the technique to create conglomerates of the suspended, dissolved or

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emulsified particles in aqueous medium using electrical current causing production of metal ions at the expense of sacrificing electrodes and hydroxyl ions as a result of water splitting. Metal hydroxides are produced as a result of EC and acts as coagulant/flocculant for the suspended solids to convert them into flocs of enough density to be sediment under gravity. The electrical current provides the electromotive force to drive the chemical reactions to produce metal hydroxides.

Following reactions are carried out at different electrodes:

Anode:

$$Al - 3e \rightarrow Al^{3+}$$

Alkaline condition:

$$Al^{3+} + 3OH^{-} \rightarrow Al(OH)_3$$

Acidic condition:

$$Al^{3+} + 3H_2O \rightarrow Al(OH)_3 + 3H^{+}$$

$$2H_2O - 4e \rightarrow O_2 + 4H^{+}$$

Cathode:

$$2H_2O + 2e \rightarrow H_2 + OH^{-}$$

Dissociation of water by EC generate hydroxide ions which are known as one of the most reactive aqueous radical specie and this radical has the ability to oxidize organic compounds because of its high affinity value of 136 kcal . The generated hydroxides or polyhydroxides have strong attractions towards dispersed particles as well as counter ions to cause coagulation. The gases evolved at the electrodes are also helpful to remove the suspended solids in upward direction.

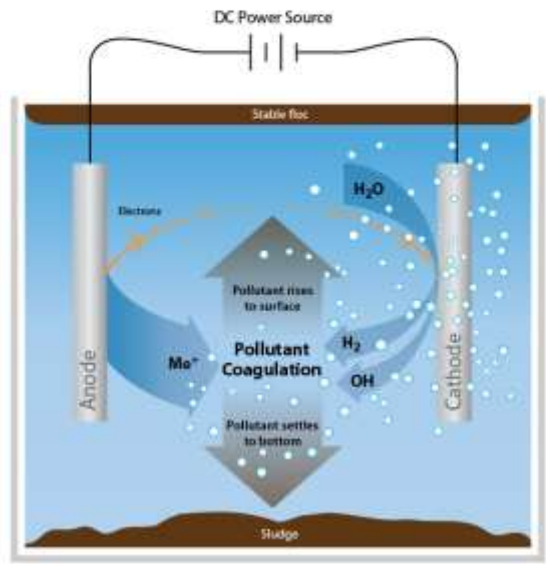

Figure.1 Process of Electrocoagulation

Potential use of electrocoagulation for industrial wastewater

Textile Industry Wastewater

The large quantity of effluent of textile industries has become a significant environmental problem. The textile wastewater is characterized by strong color, a broad range of pH, high COD concentration, suspended particles and toxicity. It is therefore necessary to treat textile effluents prior to their discharge to the receiving water. Many kinds of technologies have been exploited to clean dyeing wastewater .To remove colloidal particles from wastewaters, more effective new technologies have to be used in addition to present treatment technologies. One of these potential technologies is EC technique.

Mehmet et al. studied the treatment of textile wastewater by electrocoagulation using iron and aluminium electrode materials. The effect of relevant wastewater characteristics such as conductivity and pH and important process variable such as current density and operating time on the COD and turbidity removal efficiencies have been explored. The use of iron and aluminum as sacrificial electrode materials in the treatment of textile wastewater by electrocoagulation has been found to be pH dependent. According to the results, in acidic medium, pH<6,COD and turbidity removal efficiencies of aluminum are higher than those of iron, while in neutral and alkaline medium iron is preferable. High conductivity favors high process performances. On the other hand, for the same turbidity and COD removal efficiencies, iron requires a current density of 80-100 A/m2, while aluminum requires 150 A/m2 for a operating time of 10 minutes. The highest removal efficiencies were obtained as 98% for turbidity and between 65-61% for COD using aluminum electrode for pH<6.On the other hand for iron electrodes the turbidity and COD removals reach 98-75% and 77-47% respectively for pH in the range of 3-7.

The work of Norazzizi et al. reports the viability of electrocoagulation process for COD, BOD, color, TOC and surfactant removal from a raw effluent originating from textile industry (COD: 1640-889mg/l, BOD5: 21.4-13.6 mg/l, TOC: 59.3-19.8 mg/l, surfactant: 2.37-1.13 µ mol/l).The effect of operational parameters such as supporting electrolyte concentration, current density ,initial pH and electrolysis time were determined. Various selected metal plate electrodes (10mm x 10mm) and stainless steel were used as anode and cathode respectively. The anode was prepared using eight different electrode materials which in platinum, iridium, palladium, nickel, cobalt, aluminum, silver metal plates and carbon rod. Platinum was found to be the best electrode based on the time taken to decolorize the colored solution. The results obtained show that the percentage of color, COD, BOD, TOC and surfactant removal in the aqueous phase was removed effectively. Under the optimum operating conditions, sodium chloride concentration of 0.1 M, current density of 20 mA/cm2,initial pH of 4 and electrolysis time of 75 minutes, the percentage of color and COD removal efficiency reached 96%,while for BOD,TOC and surfactant the percentage is slightly lower.

The performance of continuous electrocoagulation employed for decolorization and COD removal from a synthetic textile wastewater (COD:600-650 mg/l,300 mg/l basin red dye 5001 B) using iron electrodes was examined by Neha Tyagi et al. The operational parameters including current density and detention time were optimized. The experimental set up used in this study consists of a beaker of 2.0 liter as a reactor to hold a sample of 1500ml.A pair of rectangular iron plates was used as anode and cathode at a spacing of 4cm.The COD and color removal of of dye solution of basic red dye 5001 B was affected by current density and detention time. For a solution with dye concentration of 300 mg/l, COD and color elimination of 76% and 95% respectively were reported, when pH was about 8.5,the detention time 20 minutes and the current density 14-17 mA/cm2.

Merzouk et al. investigate the effects of operating parameters such as pH, initial concentration, duration of treatment, current density, interelectrode distance and conductivity on the treatment of a synthetic textile wastewater in the batch electrocoagulation-electroflotation (EC-EF) process. A batch type EC-EF reactor was operated at various current densities ranging from 11.55 to 91.5 mA/cm2 and various electrode gaps (1,2 and 3 cm). For solution witj 300 mg/l of silica gel, good turbidity removal (89.6%) was obtained without any coagulant when the current density was 11.55 mA/cm2 and with initial ph at 7.5,conductivity at 2.1 mS/cm,the treatment time was hold for 10 minutes and the electrode gap was 1 cm.

Tannery Industry Wastewater

Electrocoagulation for the treatment of leather tanning industry wastewaters has recently attracted great attention. This process, utilizing aluminum, iron and steel electrodes, has proven very effective in removing organic matter as well as some specific inorganic pollutants such as sulphide, trivalent chromium, oil and grease, and ammonia from leather tanning industry effluents.

Banhadji et al. studied simultaneous removal of organic and inorganic pollutants from tannery wastewater. The choice of electrodes material is vital affecting the cell voltage. In this work aluminum was selected as anode material because it requires less oxidation potential. While using iron anode, leads to a black coloration of the liquor which became dark quickly. The results show that aluminum cathode, a current density of 75 A/m^2 in 45 minutes is the optimal condition for removing pollutants from tannery wastewater. At optimum condition, more than 90% of BOD_5, COD, turbidity, Chromium, iron and nitrate were removed. The removal of heavy metals was influence by the formation of oxyhydroxyl species in aqueous solutions which was related to the time and current density. The main mechanism of nitrate removal by electrocoagulation process is aluminum oxidation at the anode that can decompose and reduce nitrate from water.

Inoussa Zongo et al. work shows that electrocoagulation have a limit beyond which the treatment does nothing. Studied effluent considered in this work have a volume of 91262 m^3/year with the respective values of COD and chromium of 1436mg o_2/l and about 185 ppm. Treatment requires the use of an electrochemical reactor of 10.5 m^3/hr flow operating at a current density of 67.5 A/m^2 and 62.5

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V for energy consumed in 1.2 kWh/m^3 effluent and produce 86000 m^3 of clear water of 200 mg o_2/l of COD,O NTU turbidity, 91% abatement of color, 0 ppm of chromium. This treatment effluent will be able to join the local station. Electrocoagulation is a possible solution to tannery wastewater because the effluent after treatment has a COD less than 200 mg o_2/l, which allows it to be sent to the local plant.

Two mechanisms involved in the abatement of organic matters in terms of COD and TOC via electrocoagulation are of importance for the leather tanning industry effluents. The first mechanism is the removal of organic matters by indirect oxidation, apparently through chlorine species formed from chloride ions. The second mechanism with a role in the removal of organic matter, particularly in the colloidal form, is adsorption/ entrapment on freshly produced metal hydroxide flocs. This mechanism is also responsible for the removal of the suspended solids corresponding to turbidity from the leather tanning industry effluents . Therefore, it has been commonly inferred that increasing the amount of metal hydroxide flocs results in an improvement in the removal of organic matter and turbidity. Current density or cell current plays a determining role on the floc formation rate and on the rate and size of the bubble production. At higher cell current or current density, the larger amount of metal dissolution from sacrificial anode accelerates, and brings about a greater amount of metal hydroxide flocs for the removal of pollutants. Furthermore, bubble density increases and bubble size diminishes with elevating cell current or current density, resulting in faster removal of pollutants. Hence, a number of laboratory scale studies have been carried out to reveal the influence of this key process variable on organic matter, colour and turbidity removal performance.

Pulp and Paper mill Wastewater

The pulp and paper industry is water intensive, consuming large volumes of water in the preparation of feed material and in the overall production process. The most significant sources of pollution among various operation stages in pulp and paper industry are wood debarking, pulping, pulp washing, pulp bleaching and papermaking processes. Pulp and paper industry wastewaters are characterized by high levels of organic matter (e.g. COD and TOC), suspended solids and strong color.

The electrocoagulation process was proposed as a pretreatment step for pulp and paper industry wastewaters by Soloman et al. In their study, the best operational conditions giving maximum improvement in biodegradability of the effluent were determined using response surface methodology. Their study demonstrated that the biodegradability index was directly related to both electrolysis time and current density. There was a decrease in the resulting biodegradability index after treatment duration of 6.9 min and current density of 11.29mA/cm^2. At the early stage of treatment, long-chain organic matter such as lignin was converted into lower molecular weight components that did not considerably reduce COD but increased BOD_5, resulting in an increase in biodegradability. The effect of current density on biodegradability index was also explained as a result of the relative contribution of the oxidation and coagulation mechanisms. At a higher current density, the optimal time for maximum biodegradability index was expected to be reached at the early stages of electrocoagulation. In the investigation, the oxidation and coagulation mechanisms started attacking the more easily degradable part at 11.29mA/cm^2 when compared with lower current density values, which may result in a decrease in the biodegradability index.

Vepsäläinen et al. studied the removal of dissolved sulphide and phosphorus in pulp and paper industry wastewater by electrocoagulation. According to their results, current density did not have a noticeable effect on the electric charge or iron concentration required per unit of sulphide precipitated. This is important when considering full-scale applications, where the required electrode surface area of the system depends on the current (A) and current density (mA/cm^2) targets of the treatment. However, high current density increases the voltage and power consumption of the system, and consequently the operating cost of the electrocoagulation process. In their study, current density did not show a significant effect on phosphorous removal rates at 3.6mA/cm^2, 7.1mA/cm^2 and 10.7mA/cm^2. However, current efficiency decreased slightly when current densities were 14mA/cm^2 and 17.9mA/cm^2, and this was attributed to a faster flotation and a shorter contact time between pollutants and the coagulants produced.

Zaied and Bellakhal found that both materials (aluminum and iron) showed similar efficiency in reducing COD and polyphenol index. Nevertheless, with increasing time, rates of COD and polyphenol removal obtained with the aluminum electrode were slightly higher than those achieved with iron electrodes. In addition, aluminum is more effective

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than iron in removing color. Similar observations were also made by Zodi et al. for COD and arsenic removal. In their study, the maximum COD removal at 10 and 15mA/cm^2 were 47% and 68%, respectively, with aluminum electrodes, and 32% and 41%, respectively, with iron electrodes. In their study, more than 91.5% of arsenic was removed with aluminum electrodes at 10mA/cm^2. Arsenic removal efficiency reached 86% and 88% at 10 and 15mA/cm^2, respectively, when iron electrodes were used. Treatment with iron and aluminum electrodes had different kinetics in terms of turbidity removal. In fact, with iron electrodes, turbidity decreased rapidly during the early stages of electrocoagulation; nevertheless, at the end of the treatment, removal remained incomplete. In contrast, with aluminum electrodes there was no turbidity abatement during the early stages of electrocoagulation, but in the later stages aluminum electrodes had higher removal efficiency than that of iron electrodes. On the contrary, Parama Kalyani et al. concluded that the COD and color removals were higher in the case of a mild steel anode than the aluminum anode for the same operating conditions. Katal and Pahlavanzadeh recommended effective electrode combinations for removal efficiencies in treating pulp and paper industry wastewater in the following order: (i) aluminum–aluminum electrode combination for removing color; (ii) iron–iron electrode combination for removing COD and phenol; and (iii) aluminum–iron or iron–aluminum electrode combination for removing colour, COD and phenol at high efficiencies. Ugurlu et al. concluded that formation of the coagulate depends on the structures of the contaminants, thus on the ability of contaminant molecules to be adsorbed on hydrolysis products or flocs. In their study, it was observed that experiments carried out at 12V, treatment time of 2 min and a current intensity of 77.13 mA were sufficient for the removal of lignin, phenol, BOD_5 and COD with aluminum and iron electrodes. The removal capacities of the process using an aluminum electrode were 80% of lignin, 98% of phenol, 70% of BOD_5 and 75% of COD after 7.5 min. By using iron electrodes the removal capacities were found to be 92%, 93%, 80% and 55%, respectively.

Food Industry Wastewater

Wastewater from agro-industries comes from a myriad of sources and their compositions vary greatly. On the whole they are, however, characterized by high COD and BOD due their high level of organic content. Table 1 presents a summary of recent applications of electrocoagulation in the treatment of food industry wastewater.

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Table 1. Applications of electrocoagulation in the treatment of food industry wastewater

Wastewater type	Anode/ Cathode material	Reactor type	Optimum current density	Optimum treatment time	Initial pH	Initial pollutant levels (mg/l)	Optimum removal efficiency (%)	Research group
Baker's Yeast wastewater	Al	Batch	80A/m^2	30 min.	4	COD: 2160 TOC:919 Color:1.9 Abs_{475nm}/cm	COD:48 TOC:49 Color:88	Eahan Genge et al.
Baker's Yeast wastewater	Al/Fe	Batch	70 A/m^2	50 min.	5.5-6.5	COD:2485 TOC:1061 Turbidity:2075 NTU TSS:503	COD:71-69 TOC:53-52 Turbidity: 90-56	Kobya &Delipinar
Dairy wastewater	Fe	Batch	270 A/m^2	50 min.	6-8	COD: 3900 Turbidity:1744 NTU TS: 3090 TN:113	COD:70 Turbidity: 100 TS:48 TN:93	Kushwaha et al.
Almond industry wastewater	Al/Fe	Batch	50-45 A/m^2	15-8.2 min.	4-8	COD: 5300 TOC:1400 BOD_5:1000 Color:18000(Pl-Co) Turbidity:3200 FTU N_{total}:240 P_{total}:3 TSS:3400	COD:81 TOC:74-79 BOD_5:80-67 Color:100-98 Turbidity:99 N_{total}:75-85 P_{total}:100 TSS:100-99	Valero et al.
Tes factory wastewater	steel	Batch	24 V	n.d.	6	COD:293-607 BOD_5:42-193 Color:2004-9210 Pt-Co	COD:91-97 BOD_5:84-42 Color:100	Maghanga et al.
Poultry slauhterhouse wastewater	Al Fe	Batch	n.d.	60 min.	6.1-6.5	COD:2700-3100 Oil & grease:720-950 TS:1440-2380 BOD_5:n.d.	COD:80-84 BOD:84-88 Oil & grease:100 TS:58-70	Asselin et al.
Pasta and cookie processing wastewater	Al	Batch	n.d.	60 min.	3-8	COD:7500 BOD_5:3445 Color:35 Pt-Co Turbidity:1153	COD:80-90 BOD_5:n.d. Color:57	Roa-Morales et al.

Conclusions

This paper has given a review of the successfully electrocoagulation application, for the removal of specific problematic factors (such as color, recalcitrance and toxicity) that cannot be removed effectively via conventional treatment methods. The interest is double: economic and environmental. The technical feasibility study is a good base for future industrial units of the electrocoagulation. However, a number of possible future studies using the same experimental setup are apparent. For optimal performance and future progress in the application of this innovative technology considerably more work will need to be done in better reactor design, understanding and process control has to be provided.

It is apparent that this technology will continue to make inroads into the wastewater treatment arena because of its numerous advantages and changing strategic global water needs.

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