Electro-coagulation A Novel Treatment of Wastewater: A Review

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Abstract- *During last few decades environmental engineering sector has many research and advancement in the various methods for the treatment of domestic and industrial wastewater. This research includes the review on working principle, electrochemistry and its process parameters for electro-coagulation. It also gives review about the advancement in the treatment of industrial wastewater by the method of electro-coagulation in last decade. Electrocoagulation is a complex process involving a multitude of pollutant removal mechanisms operating synergistically. The aim of this paper is to review the relevant literature that published from 2010 to 2015 on topics related to Electrocoagulation within the industrial wastewater.*

Keywords- Electrocoagulation, Wastewater treatment, Dye industry waste,

I. INTRODUCTION

Electrocoagulation is an electrochemical technique for treating wastewater using electricity instead of expensive chemical reagents. Electrocoagulation (EC) is an emerging technology that combines the functions and advantages of conventional coagulation, flotation and electrochemistry in water and wastewater treatment. 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. An electrocoagulation process has been attracted a great attention on treatment of industrial wastewater because of the versatility and environmental compatibility.

1.1. Historical development and reaction mechanism

Electrocoagulation has a long history; the first plant was built in London in1889 for the treatment of sewage where electro-coagulation 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 was 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. [2] Kabda et al. [3] described the 'Electronic Coagulator', which electrochemically dissolved aluminium from the anode into the reaction solution that interacted with the hydroxyl ions produced at the cathode to form aluminium hydroxide. The hydroxides flocculated and coagulated the suspended solids, purifying the polluted water. A similar process was used in Great Britain in 1956, in which iron electrodes were used to treat polluted river water. Thereafter, a wide range of water and wastewater applications followed under a variety of conditions. In early reports, the electrocoagulation process was applied to remove suspended solids; heavy metals; petroleum products; colour from dye-containing solution; aquatic humus; fluorine from water; and urban wastewater. In the last two decades the application has been greatly expanded, and there is currently much interest in using electrocoagulation for treatment of a variety of effluents containing metals, foodstuff, olive oil, textile dyes, fluorine, polymeric wastes, organic matter from landfill leachate, turbidity, chemical and mechanical polishing wastes, aqueous suspensions of ultrafine particles, nitrate, phenolic waste and arsenic as well as municipal wastewater.

1.2. Working Principle

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 metal ions which act as coagulant agents in the aqueous solution *in situ* [2]. 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 aluminum, iron, or stainless steel (SS), because these metals are cheap, readily available, proven effective and non-toxic. Thus they have been adopted as the main electrode

materials used in EC systems [1, 2]. 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.

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:

$Al - 3e \rightarrow Al3^{+}$

Alkaline condition:

$Al3^{+} + 3OH- \rightarrow (OH)3$

Acidic condition:

$Al3^{+} + 3H2O \rightarrow (OH)3 + 3H^{+}$

$2H2O - 4e \rightarrow O2 + 4H^{+}$

Cathode:

$2H2O + 2e \rightarrow H2 + OH^{-}$

1.3 Process Parameters

In electrocoagulation process based on some following parameters shown in fig. 1 are as follows.

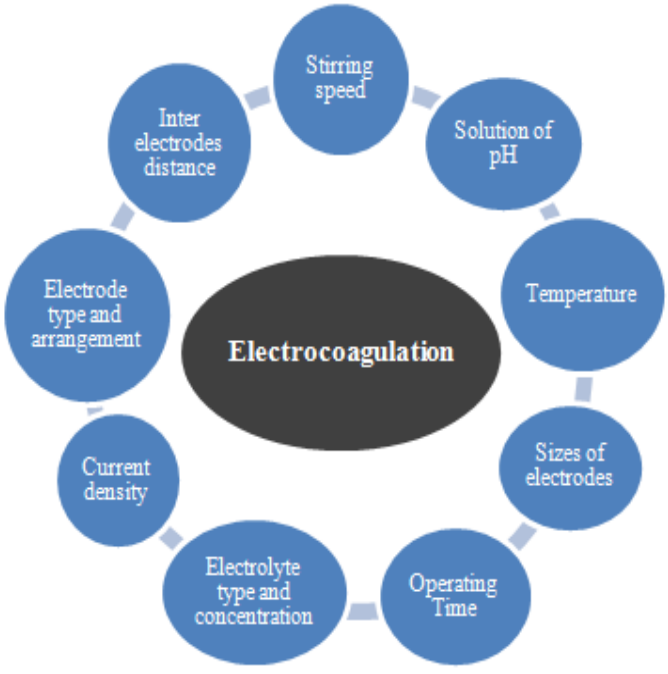

Fig. 1 Process parameters of EC

1.3.1 Current density

Current density is one of the most critical operation parameters in electrocoagulation, having an integral effect on process efficiency. This parameter determines both the rate of electrochemical metal dosing to the water and the density of electrolytic bubble production. A systematic analysis is required to define and refine the relationship between the applied current density and targeted removal (separation) effects. In a typical electrocoagulation experiment, the electrode or electrode assembly is usually connected to an external direct current source. The amount of metal dissolved or deposited is directly proportional to the amount of electricity passed through the electrolytic solution. A simple relationship between current density (mA/cm2*)* and the amount of substances (M) dissolved (g of M/cm2) can be derived from Faraday's law

$W = J \times t \times (M/n) \times F$

Where, *W* is the quantity of electrode material dissolved (g of M per cm2*)*; *J* is the applied current density (mA/cm2*)*; *t* the electrolysis time in s; *M* the relative molar mass of the electrode material under study; *n* the number of electrons in oxidation/reduction reaction; and *F* is Faraday's constant (96,500C/mol).

1.3.2. Solution of pH

The pH of the reaction solution changes during the electro coagulation process, and the final pH of the effluent actually affect the overall treatment performance. It has been reported that when the initial pH value is less than 4 (acidic), the effluent pH increases, while it tends to decrease when the initial pH value is higher than 8 (basic), and the pH of the effluent changes only slightly when the initial pH value is in the neutral range (around 6–8). This situation indicates a pH buffering effect during electro coagulation which is different from traditional chemical coagulation.

1.2.3. Electrolyte type and concentration

Sodium chloride (NaCl) is usually employed to increase the conductivity of the water or wastewater to be treated. Wastewater conductivity affects the Faradic yield, cell voltage and therefore energy consumption in electro coagulation cells. In addition, increasing water conductivity using NaCl has other advantages. NaCl is usually employed as the electrolyte to increase the conductivity of wastewater to be treated by an electrochemical process, and decreases the passivation of the aluminium surface to promote electrocoagulation efficiency. The addition of NaCl can also reduce the electrical energy consumption of

electrocoagulation, as it increases the conductivity of the wastewater.

1.2.4. Electrode type and arrangement

In most studies reported in the scientific literature, aluminium (Al), iron (Fe), mild steel and stainless steel (SS) electrodes have been used as the electrode materials. In a monopolar electrode arrangement of an electrocoagulation cell, each pair of sacrificial electrodes is internally connected with each other, and has no interconnections with the outer electrodes. This arrangement of monopolar electrodes with cells in series is electrically similar to a single cell with many electrodes and interconnections. In series cell arrangement, a higher potential difference is required for a given current to flow because cells connected in series have higher resistance. In this arrangement the same current flows through all the electrodes. On the other hand, in a parallel arrangement the electric current is divided between all electrodes in relation to the resistance of the individual cells. Some authors have used bipolar electrodes with cells connected in parallel, where the sacrificial electrodes are placed between two parallel electrodes without any electrical connection.

1.2.5 Effect of inter electrodes distance

Many researchers have examined the effect of the final electrode distance on the performance of removal of pollutants. Based on these studies, it may be worthwhile to note that the general evolution of the EC performance levels as a common function of inter-electrode distance is based on the pollutants' nature, the electrodes structure, hydrodynamic properties, as well as other factors. [4]

1.2.6 Effect of stirring speed

The stirring mode influences the residual concentrations of the COD, TSS, and color. It has been proven that agitation may improve the kinetics of mass transfer. If coagulant matter does not efficiently disperse within the reactor, the reactor contents are not homogenous and, therefore, display regional differences. If the speed rates are too high, the flocks that are formed within the reactor will be damaged and create smaller flocks that are difficult to extract from the wastewater. [4]

1.2.7 Operating Time

The EC time is another significant parameter that is influential on the electrocoagulation process. Treatment time or electric charge added per volume is proportional to the amount of coagulants produced in the EC system and other reactions taking place in the system. Because the formation and concentrations of metal hydroxides play an important role on pollutant (COD, turbidity and phosphorus) removal, this depends on operation time [6,8].

1.2.8 Temperature

Temperature affects floc formation, reaction rates and conductivity. Depending on the pollutant, increasing temperature can have a negative or a positive effect on removal efficiency.[6]Increasing solution temperature can improve ions transfer from the anode and/or cathode surface to the solution bulk resulting from the decrease in solution viscosity and the consequent increase in the ions diffusivity according to Stocks equation $D\mu/T$=constant, where D, μ and T are ions diffusivity, solution viscosity and solution temperature, respectively[7].

1.2.9 Sizes of electrodes

Many investigators are used to investigate the effect of the electrode size on the percent recovery. They can be seen that the grater size of electrode had a better percent recovery than the smaller sizes. Larger electrode surface area resulted in a greater dispersion of bubbles throughout the reactor, whereas a smaller electrode surface resulted in a concentrated source of bubbles within the reactor, and with increasing the dispersion of bubbles in the reactor probability of collision between the bubbles and coagulant increased leading to increase the percent recovery[5].

II. INDUSTRY WASTEWATER

This and eco-friendliness have led to increasing global interest in electrocoagulation as a research subject. Over the course of the last few decades, literature in the environmental sector has indeed shown a growing interest towards the treatment of different types of wastewater by EC. Particularly during the last few years, the amount of published literature on EC applications seems to have increased substantially.

The aim of this work was to accomplish this, and based on the literature, to present an overview of practical optimum treatment times, current densities, electricity consumption, and operating costs in a wide and versatile range of feasible applications of EC in water and waste- water treatment, studied mainly during the years 2010- 2015.

Table1. Recent applications of EC in the treatment of wastewater

Wastewater type	Anode/ Cathode material	Reactor type	Optimum current density (A/m^2)	Optimum treatment time (min)	Initial pH	Initial pollutant levels (mg/l)	Optimum removal efficiency (%)	Research group
Wastewater containing dyes from textile industry (Direct red 81, azo dye)	AL	Batch	18.75	60	5-9	Dye: 25- 200 (optimum 50)	Dye: 98	Aoudj et al. [11]
Indigo carmine (Acid Blue 74)	Mild Steel/SS	Batch	10.91	180	5-9	Dye: 25 - 100 (optimum 40)	Color: 99/91	Secula et al. 2011 [12]
Paper mill wastewater	Al Al/Fe Fe/Al Fe	Batch	700	30	5-7	COD : 1700, Color: n.d Phenol: 34 BOD: 850 TOC: 910 TSS: 1060	COD: 86, (Fe)Color: 92g (Al) henol: 96g (Fe) BOD: n.d. TOC: n.d. TSS: n.d. TS: n.d.	Katal & Pahlavanzade2011 [25]

III. CONCLUSION

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. EC has great potential in purification of various types of water and wastewater and seems to be a feasible and economical alternative in this field, although more research is needed, especially using larger-scale and/or continuous systems and focusing on the fundamentals of the EC process. 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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