APPLICATION OF ELECTROCOAGULATION IN WASTEWATER TREATMENT: A GENERAL REVIEW

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Abstract - *Worldwide scarcity of water is tending people to reuse the recycled wastewater. This paper reviews the research papers from last 10 year related to Electrocoagulation. The Electrocoagulation applications are discussed for 8 categories of wastewater: Municipal wastewater, Dairy wastewater, Paper and pulp wastewater, Textile wastewater, Leachate, Distillery Wastewater, Livestock wastewater and oily wastewater. Electrocoagulation is a wastewater treatment process by passing the electric current for a predetermined time which will treat and flocculate the contaminants wastewater without adding any coagulant in it. Electrocoagulation used to remove metal, colloidal material, suspended solids, dissolved solids, etc. from wastewater. This paper presents the review of an optimum condition of p^H, electrolysis time, current density, the distance between electrodes, and maximum removal efficiency of the Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD), Turbidity, Total Suspended Solids (TSS), and other different pollutants. The treatment efficiency can be checked by metal electrode consumption, and power consumption for the whole process and pollutant removal per Kg.*

Key Words: Electrocoagulation, Wastewater Treatment, Metal Electrode, Efficiency, COD.

1. INTRODUCTION

Wastewater from different industries considered as the main point source pollutant on the international level. The discharge of untreated effluent from industries in a running stream or in the pond makes it contaminated with different pollutants, which also increases the Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Suspended Solids (SS), etc. By discharging the untreated effluents in stream affects the aquatic life and disturbs the echo system of the water body. Wastewater treatment is mainly associated with two objects, protecting the environment and conserving fresh water resource.

The most common conventional methods of treating sewage includes Aerated Lagoons, Biological Trickling Filter, Anaerobic Digester, Activated Sludge process. This method having advantages and disadvantages also. These treatment methods gives optimum pollutant removal but consumes more space and having long treatment period. To overcome the space and time problem it is necessary to develop compact and quick treatment method for treatment of wastewater.

Electrocoagulation (EC) is one of the simplest methods to treat any kind of wastewater with good effect. Electrocoagulation is a process of passing an electric current through the metal electrode immersed in the wastewater. This metal electrode is commonly known as sacrificial electrodes. The EC process combines four different processes of wastewater treatment which is Coagulation, Adsorption, Precipitation, and Flotation. This process has proven very effective in removing contaminants from water and is characterized by reduced sludge production, no chemical requirement, and easy operation.

There are three main mechanisms on the whole electrocoagulation process: 1. Reduction/Oxidation reactions at a surface of the metal which is being used, 2. Generating the coagulation agent by the electrode in an aqueous phase, 3. Adsorption of soluble or colloidal pollutants on coagulants, and which is removed by sedimentation/flotation.

Electrocoagulation or Electroflotation and Electrooxidation are the two main process in the electrochemistry for treatment of water and wastewater. Different type and shapes of the metal electrode are used in this process. Aluminum and Iron metal electrode is used for the electrocoagulation, where Graphite and Titanium metals are used for the electrooxidation process. [1]

2. Wastewater treatment

2.1 Municipal Wastewater

House, restaurant, shops, etc. are the source of municipal wastewater. Municipal wastewater having a moderate amount of BOD and COD, also it has pH around the neutral range. The application of Electrocoagulation is successfully used in the municipal wastewater treatment using a metal electrode.

Walid (2016) compared the electrocoagulation method and chemical coagulation on municipal wastewater. Aluminum electrode and Alum is used for the experiments. He found that 83.5% of COD and 96.9% of TSS is removed at a current density of $3mA/cm^2$ for the electrolysis time of 60 min. for the chemical coagulation by alum removes the 82% COD, 94% TSS for the 50mg/Lit dose. It is found that the optimum pH for the Electrocoagulation and chemical coagulation coincides with the pH of the raw wastewater [2].

Ahmad (2016) compared the Electrocoagulation, chemical and biological technique for the treatment of wastewater. Chemical coagulation is carried out by using Alum and electrocoagulation is carried out by two aluminum electrodes which are arranged in a monopolar parallel arrangement. Chemical coagulation carried out by alum at the dose of 10 to 80mg/lit. For the different pH, it is found that 82.3% COD and 96.4% TSS is removed for alum dose of 60mg/lit at a pH of 7.5. EC process removes 83.5% COD and 96.9% TSS at the current density of 3mA/cm^2 for the treatment time of 60min. the biological treatment will remove the 83% COD and 90% TSS. It is noted that the optimum pH for the both CC and EC coincides with the pH of the raw wastewater i,e, 7.5. When it comes to the treatment time for wastewater the EC process consumes the less time which is 60min [3].

Sibanda (2017) had compared the four Iron and Aluminum electrodes for COD, Phosphate and Ammonia removal. The author observed that maximum percentage of COD, Phosphate and Ammonia is removed in Aluminum electrode which is 99%, 100%, and 62% for voltage of 15V and electrolysis time of 60min. also, Iron electrode removes the 100% Phosphate for 15V and 60min [4].

Alex (2015) used Aluminum and Stainless steel electrodes as MP-P, where 2cm electrode gap gives better removal in the range of 1-4 cm. Electrolysis time of 25cm and 15V voltage removes 80.70% COD and 61.38% TS [5].

Impa (2015) observed that hydrogen bubbles evolved at cathode takes place at the acidic condition when pH of wastewater increases, also a formation of OH- ions near anode would release H+ leading to decrease of pH. pH ranges divided into three rang acidic (3-5), neutral (7-8), alkaline (12-14) conditions, whereas neutral range removes a maximum percentage of COD 63% for 20V at 30min. Nitrates decrease with increasing electrolysis time in the Neutral range also the rate of nitrate reduction increases with increasing Volts. Hence maximum removal is obtained in a neutral range 62% for 20V and 30min [6].

2.2 Dairy wastewater

The dairy industry is generally considered to be the largest source of food processing wastewater in many countries. In general, wastes from the dairy processing industry contain high concentrations of organic material such as proteins, carbohydrates, and lipids, high concentrations of suspended solids, high biological oxygen demand (BOD) and chemical oxygen demand (COD), high nitrogen concentrations, high suspended oil and/or grease contents, and large variations in pH, which necessitates "specialty" treatment so as to prevent or minimize environmental problems

Edris (2013) author used a preliminary settling unit for the detention time of 12hr. for the 12hr he observed that 22% COD, 16% BOD and 57% TSS is removed only by allowing settling. After settling period it will test for the different voltage and electrolysis time, for voltage of 60V and 60min electrolysis time reduces 98.8% COD, 98% BOD5 and 97.75% TSS. The increase in applied voltage causes the proportional increase in consumption of electrode *i,e* 60V consumes 2.672g while 10V consumes 0.249g. Along with electrode consumption energy consumption also increased for increased in voltage 60V consumes 0.095Kwh/L and 10V consumes 0.095Kwh/L [7].

Chakcho (2017) has compared the electrocoagulation and electrooxidation process for the dairy industry wastewater (pH 6.6) aluminum and titanium electrodes respectively both are arranged in the monopolar parallel arrangements. The author tested wastewater for the different electrolysis time and current densities for the removal of the COD, turbidity, and color from wastewater. The maximum removal of pollutants obtained in the current density of 2.4A/dm^2 for 15min of electrolysis time in EC process which removes 53% COD, 87.52% color and 100% turbidity, the color and turbidity removal is maximum in the 12th minutes. In the electrooxidation process, 91.61% turbidity, 59.46% color, and 42% COD removal is obtained at the current density of 1.8A/dm^2 for the electrolysis time of 60min. It is observed that EC is a fast but incomplete process and EO is a slow process and can improve the efficiency of treatment; coupling the two processes offers a practical hybrid [8].

Marol (2017) treated dairy wastewater using four aluminum electrodes at 1 cm electrodes distance arranged in monopolar parallel series order. Tested for the different pH (6, 7, 8) for the different voltage and electrolysis time for removal of the turbidity and conductivity. The boric acid was added for the electrolysis process. 94% turbidity is removal is observed in the pH 8 for the 25V voltage for 75 min of electrolysis time. Also, 93% of the conductivity is removed for the same parameter of experiments. For the pH 6 and 7, the removal is just below the removal percentage for the pH 8 [9].

Faiqun (2007) treated dairy wastewater using two aluminum electrodes which are arranged at a 5cm distance from each other. A current density of 5.62mA/cm^2 removes 72.38% of COD and 97.98% turbidity for the operation time of 50min at a voltage of 30V. After the treatment, the wastewater is allowed to settle for some time will also affect the treatment efficiency. 96.74% turbidity removed for the settling time of 40min at a current density of 5.62mA/cm^2, similarly, more than 70% of COD is removed for the settling time of 60min for same current density [10].

2.3 Paper and pulp industries

The paper and pulp industry is one of the oldest industries in any country. Every paper and pulp industry is classified into two types based on their quantity of production per day which is 20t/day and 2000t/day. Generally paper and pulp mill waste is characteristised by very strong color, high BOD, High Suspended Solids, high COD/BOD ratio, and having pH slightly alkaline.

Zazouli (2017) has compared the aluminum and iron metal electrodes for the removal of the Color and COD from paper and pulp industry. Factors of initial pH and voltage were tested during the process and optimized. pH 7 gives the best removal of color and COD for Iron and Aluminum electrode than pH 5 and 9. Iron electrode removes 73% COD, 92% color, 63% BOD, and 75% TSS at 20V for 60 min. But For pH 7, Iron electrode removes 90% COD, 100% Color, 63% BOD, 75% TSS at 60V for 60min. Also, Aluminum electrode removes 63% COD, 91% color, 83% BOD, and 99% TSS at 20V for 60 min. But For pH 7, Aluminum electrode removes 87% COD, 99% Color, 99% BOD, 98% TSS at 60V for 60min [11].

Lafi used six iron electrodes at 3cm gap EC process is combined with the addition of CA and Fe salts (2mg/lit) which is tested for the removal of the COD and TSS. Addition of Fe results in the removal of 95% TSS and 96% COD. Also, Addition of Ca resulted in about 90% removal for both TSS and COD after operation time of 30min at a current density $60A/m^2$. Current density $60A/m^2$, operation time 30min and pH 8 are the optimum parameters are removed TSS 82% and COD 84% [12].

2.4 Textile wastewater

The characteristics of textile mill is mainly depends upon the type of fiber which is used in it. They are characteristics by the high color, high COD, high BOD, high total Solids, also it contains some metals such as chromium.

Khandegar (2016) analyzed the effect of electrode shape and current source on EC process. The author uses two aluminum electrodes at 3cm c/c distance arranged in monopolar parallel arrangements. Punched electrodes plates used for the experiments having the hole size of 2, 3, 4, 5 mm, a plane plate with varying number of holes which is 1, 2, 4, 8 arranged in three different arrangements shapes *i,e* square, triangular and random pitch. There is no significant effect of pitch of the holes in electrode on CRE and location of hole of hole of electrode does not affect performance. Effect of the distance between the holes in the electrode was investigated by keeping the distance between the holes in the electrode at 1 and 1.5 cm and it was found that there is no effect of the distance between the holes in the electrode on the CRE. It was found that the efficiency of the electrocoagulation process increases with the use of the punched electrode compared with the plane electrode due to the higher current discharge from the punched electrode [13].

Akanksha (2013) has compared electrocoagulation for the three different metals iron, aluminum, and stainless steel for the treatment of textile wastewater. Used six electrodes are used and tested for the different voltage and operation time for the removal of Color and COD. Maximum COD removal observed at 14V, 80min for aluminum and stainless steel were 92.97% and 87.23%, respectively. Maximum color removal observed at 10V, 20min for aluminum 96.22%, also stainless steel maximum removal observed at 12V, 80min which is 89.29%. Maximum COD removal was 90.12% at 8V at 80min and color removal was 99.46& at 14Vfor 80min. Energy consumption for iron, aluminum, and stainless steel electrode was 0.0866 kWh/kg of COD, 0.3974 kWh/kg of COD and 1.2318 kWh/kg of COD [14].

Hossain (2013) studied the impacts of current density, operation time and pH of textile wastewater by iron electrodes in bipolar arrangement and double connection for the textile wastewater. The increase of current density from 50 to 125 A/m^2 COD and turbidity removal efficiency also in¬creases, if the current density exceeds 95 A/m^2 then electrodes start to decay quickly is observed. Operating time at 50 min the removal of COD and turbidity is 79.86% and 96.88%, respectively. The COD removal is higher at neutral pH, than at pH values of 5 – 6 [15].

Demirci (2015) has investigated the different electrode connections for the treatment of textile wastewater by using aluminum metal electrode. The electrodes are arranged in monopolar parallel, monopolar series and bipolar parallel arrangements the efficiency of the arrangement is checked for the removal of the color and turbidity from wastewater. Maximum turbidity 75.5% removal obtained in MP-P arrangement, and color removal 73.6% in BP-P also, minimum electrode consumption observed in MP-P arrangement which is 0.551g for 60 min. Maximum removal of COD and Turbidity are found in Aluminum electrode and Color removal in iron. MP-P is preferred for its low-cost treatment. The turbidity removal efficiency increased sharply during 40 min for all arrangements. BP-P has higher voltage values during electrolysis and MP-P is the most cost-effective arrangement. Maximum turbidity 75.5% removal obtained in MP-P arrangement, and color removal 73.6% in BP-P also, minimum electrode consumption observed in MP-P arrangement which is 0.551g for 60 min. Maximum removal of COD and Turbidity are found in Aluminum electrode and Color removal in iron. MP-P is preferred for its low-cost treatment [16].

2.5 Leachate

Shivayogimath (2013) tested the leachate collected from the Bagalkot Municipal Solid waste site by the use of four aluminum electrodes at distance of 1.5cm. Removal efficiencies of COD and Turbidity checked for pH (5.8, 4, 8), Electrolysis time (5, 10, 15, 20, 25, 30, 35, 40 min), & Voltage (3, 6, 9V). Maximum removal of COD is observed at 9V, 35 min which is 95.8% at pH 5.8. Maximum removal of Turbidity is observed at 9V, 35 min which is 96.6% at pH 5.8.

The results of the study showed that EC technology could be applied for the cost-effective treatment of landfill leachate [17].

Rabahi (2016) compared the EC technique and chemical coagulation for the leachate without correction of the pH Aluminum and Aluminum Sulphate is used for the respective techniques. The research aims to remove the total organic carbon, Inorganic carbon, Total carbon, and COD from leachates. In the case of EC maximum amount of COD removal is 61% after 150min of operation time, TOC 56% after 90min, Total carbon 46% for 120min, Inorganic carbon 39% for 120min. where, in chemical coagulation, 3.5% Total organic carbon, 7% COD removed for 48mg and 40mg of aluminum is added [18].

2.6 Distillery wastewater

The Distillery wastewater is generally characterized by high BOD and high suspended solids, it also contains some amount of nitrogen in it.

Den (2016) has performed the EC process on the distillery wastewater by use of the four Aluminum electrodes. The author observed the effect of the current density on the removal of COD, Nitrate, and Phosphate. The system having the two different current densities which are $36A/m^2$ and $22A/m^2$ for the pH 3. The maximum removal of COD is observed for the $36A/m^2$ of current density which is 60% for the electrolysis time of 20min also final pH change is increased in small amount. 26% of nitrate removal is obtained at the current density of $36Am^2$ and 20% is removed for the current density of the $22A/m^2$. Also, 61% of nitrate removal is obtained at the current density of $36Am^2$ and 18% is removed for the current density of the $22A/m^2$ [19].

Farshi (2013) has tested the anaerobically treated distillery wastewater by electrocoagulation method by electrocoagulation method for the removal of color and COD. Aluminum and Stainless steel are used as anode and cathode electrodes respectively. Various current densities (2, 4, 8 Amp/dm^2) are tested for one hour operation time. Electrode distance varied from 1cm to 3cm, initial pH (2– 10) and electrolysis time (1hr - 6hrs). High current density $8A/dm^2$ removes 80% color and 36.67% COD. An optimum pH 4 was found and color removal was 94% and COD removal was 77.5%. Optimum electrode distance was found out to be 1cm, which removes Color 97.7% & COD 68.8%. For all optimum conditions the COD removal is 67% and Color removal was 98.3% [20].

Khandegar (2014) has examined the COD removal from the distillery wastewater for the current density, electrolysis time and pH of wastewater. An experiment conducted at four different pH (4, 5, 6, 7.2), three different current density (12.5, 14.7, $17.9A/m^2$) for two pairs of aluminum and iron. COD removal efficiencies 84.6% and 76.9% are obtained at 7.2 pH for Al-Al and Fe-Fe electrode respectively at a current density of $14.7A/m^2$ for 3hr of operation time. At current density $17.9A/m^2$ for 3hr removes 98% and 84.5% for Al-Al and Fe-Fe pair. It was found that about $375Rs/m^2$ is required for treatment of distillery spentwash containing initial COD Concentration of 52000mg/L [21].

2.7 Livestock wastewater

Feng (2007) has tested the EC for the low current (less than 1Amp) and soluble electrodes (mild steel and aluminum electrode) seven electrodes is arranged in the monopolar parallel arrangement and electrodes is maintained at a 1cm distance. pH of the tannery wastewater is increasing as the operation time increases, pH variation is small in case of Aluminum compared to Mild steel. 50% and 58% COD removal is observed in Aluminum and Mild Steel electrode for 1A at 60min. A concentration of TOC was decreased rapidly in Aluminum electrode for just 15min wherein Mild Steel it decreased gradually up to 60min. Removal of Sulfide is found to be very less in case of an Aluminum electrode, where in case of Mild Steel electrode it is about 96.7% for 60min. A concentration of Ammonia is decreased gradually for both electrodes, maximum removal is an aluminum electrode 34.50% [22].

Jose (2016) perform EC on livestock wastewater for a variable distance between electrodes and pH using the aluminum electrodes. An experiment is conducted at pH of 4, 7, and 8 and for electrode distance of 2, 3, 4, and 5 cm. Removal is above 80% at initial pH of 4 and 7, independently of distance. For initial pH 8 and 5cm distance shows 67.21% COD removal. 90.16% COD removal is observed under the optimum condition at pH 7, distance 2cm, Voltage 50V and an electrolysis time of 30min [23].

Joseph (2017) treated the wastewater from abattoir using two iron electrodes for turbidity removal with deciding factors such as pH, current intensity, electrolysis time, settling time, temperature, power consumption, a mass of electrode dissolved. At pH 2 removal efficiency of turbidity is 62.01% for 2.5A current, Effluent pH after EC treatment was found to increases. Optimum removal efficiency for turbidity is obtained at 30min for 2.5A current is 65.65%. A higher degree of settling was observed in the first 30 min but the optimum condition was found in 60 min for 2.5A current which is 73.72%. EC process increased by increasing solution temp, optimum removal of 93.69% was obtained at 600C. At optimum condition turbidity removal efficiency, 0.55kWh/L power consumption [24].

2.8 Oily wastewater

The oily wastewater is mainly consist of the free oil which is found in high concentration, also it consists of Emulsified oil, some phenolic compounds, suspended solids, and BOD.

Sekman (2011) has treated the oily wastewater from port waste reception facilities by electrocoagulation method by use of four aluminum electrodes arranged at a 1.6cm center to center distance. The aim of the study to remove the suspended solids, COD and O&G for the operating parameters like pH, Current density and electrolysis time. An experiment is conducted for four different current density (8, 12, 16, 24mA/cm^2) and electrolysis time (5, 10, 20, 30min) for pH of 6.7. 98.8% of SS is removed for both 16 and 24mA/cm^2 for 5 and 10min respectively. For the first 5 min COD removal is between 61 to 91% for all current density and maximum for 20min which is 93% except for 8mA/cm^2. Maximum removal rate 93.2% for O&G removal observed for 8mA/cm^2 for 30min. Amount of sludge produced increased with increased with an increasing removal rate of SS, COD, and O&G [25].

Salameh (2015) has aimed to remove TSS and COD from olive mill wastewater by EC process by a combination of six iron and aluminum electrodes. 82.2% of TSS and 38.5% COD is removed for the pH 6 in 60 min in Aluminum electrode for the Current density of 30 mA/cm^2. Also, 74.2% of TSS and 42.3% COD is removed for the pH 6 in 60 min in Aluminum electrode for the Current density of 30 mA/cm^2. By coupling the Aluminum and iron electrode, 82.5% of TSS and 47.5% of COD was removed at 45 mA/cm^2 [26].

El-Hosiny (2017) treated oil produced wastewater using eight aluminum electrodes for removal of TOC, TSS, and TDS for pH, current density and flow rates. Maximum removal of pollutant is obtained at pH 6 for the constant flow rate of 60ml/min and the current density of 48A/m^2. Removal efficiency increased from 38% to more than 96% with an increase in current density from 16 to 80A/m^2 for pH 7. For pH and current density 80A/m^2, with flow rate 60ml/min removes 87.5-99.5% of pollutants. Electrical energy consumption was about 1.38Kwh/m3 and operation cost per m3 was 0.3US$ [27].

3. CONCLUSION

In recent years Electrocoagulation is evolved as a promising treatment method for treatment of any kind of wastewater over conventional and chemical coagulation method. It is observed that in the past 10 years it is effective for removing pollutants mainly Chemical Oxygen Demand, Biochemical Oxygen Demand, Suspended Solids, Turbidity, Color, Nitrate, etc. The operation parameters of the electrocoagulation process such as Electrolysis time, Current Density, Conductivity of solution, Electrode arrangement, type of electrode material, and Electrode gap are tested for the different combination for the optimum removal of pollutants. EC method will be effectively used where less space is available to treat with the minimum treatment cost. From the above literature, it's concluded that the Electrocoagulation process is termed as the promising, modern and effective for the wastewater treatment.

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