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Electrocoagulation of Wastewater from Agro-based Industries: A Review

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***Abstract*— In India, there are many agro based industries such as sugar, distillery, textile, dairy etc. Huge quantity of wastewater is generated from these industries. Effluents generated from these industries are characterized by high COD value. In developing countries water is the most essential but inadequate resource. So to overcome this scarcity of water resource recycling of wastewater is one of the solutions. Now a day's different conventional methods are used to treat wastewater generated in these industries. The currently available conventional treatment consists of physical, chemical and biological methods. Further these methods have stringent requirement of pretreatment. These processes have high initial as well as operation and maintenance cost. Therefore, there is need of single treatment to treat wastewater. In this view, Electrocoagulation (EC) technique would play a major role in purification of wastewater. EC has been tested successfully for almost all types of wastewater. EC provides a relatively compact and all in one treatment alternative. EC is worth considerable because of its various advantages such as no chemicals addition, simple equipment, easy operation and decreased amount of sludge. This article aims to raise awareness of EC process by reviewing various studies on electrocoagulation of agro based industrial wastewater.**

Index Terms*— *Agro based industries, Conventional treatment, Electrocoagulation, Water and wastewater.

I. INTRODUCTION

The total availability of water resources is currently under stress due to climatic changes, continuous increase in population and rapid growth of industrialization. Water plays an important role in the natural cycles of various ecosystems in environment. The available fresh water on the surface of the earth is rare resource, which is only 3% of the water that exists on the earth [19]. Agriculture and industry have conventionally been viewed as two separate parts both in terms of their characteristics and their role in economic growth [17]. Agriculture has been considered as the assurance of the first stage of development, while the degree of industrialization has been taken to be the most appropriate indicator of a country's progress along the development path. Agro-based industries are those industries which have either direct or indirect links with agriculture. India is an agricultural country. In India, there are many agro based industries such as sugar, distillery, textile, dairy etc. From these industries large quantity of wastewater is generated. The composition and quantity of agro-industrial wastes depends upon sources of raw material, nature of products, operations and processing methods [17]. Effluents generated from agro based industries are characterized by high chemical oxygen demand (COD) [15].

The disposal of these effluents in the environment will lead to cause surface as well as ground water contamination and different environmental problems such as ecosystem imbalance, eutrophication, and human health [5]. For protection of environment, Indian government prepared very stringent rules and regulations for the effluent discharge. Therefore, appropriate treatment methods are required to meet effluent discharge standards [3]. India is one of the fastest developing countries in the world; water scarcity is major future and current challenge. So to overcome this scarcity of water resource recycling of wastewater is one of the solutions. Recycling of wastewater is one of the main components of cleaner technology and which is widely accepted as an effective tool to save environment [17].

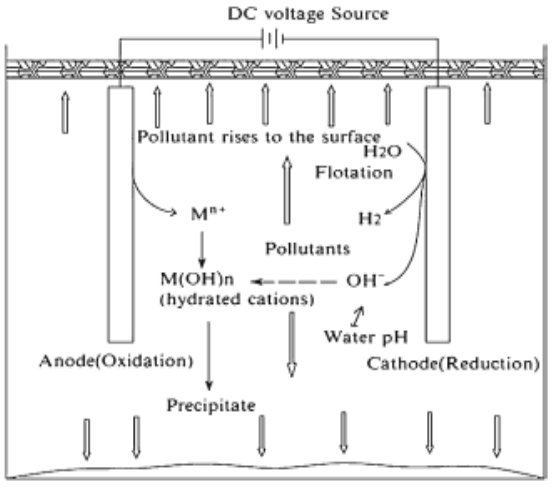
Wastewater generated from these industries is treated by conventional methods of treatment. The currently available conventional treatments consist of physical, chemical and biological methods. The commonly used conventional biological treatments need large area and they are time consuming treatments [3]. From such treatment toxic elements present in wastewater are not removed effectively and some of the soluble organic compound goes untreated in this treatment process. However, there is no single process that can satisfy all requirements according to the variable nature of the wastewater [11]. Under these conditions, new advanced technology i.e. Electrocoagulation (EC) would help to treat agro based industrial wastewater. EC process is playing an important role in the treatment of wastewater by virtue of various benefits. As compared with traditional treatment methods, EC provides a relatively compact and all in one treatment alternative [7]. EC technology seems to be feasible and cost effective alternative in wastewater treatment and this technology has excellent future because of numerous advantages. Electrocoagulation is still under trial and optimization, and has many operational challenges to make it commercially viable. This article aims to raise awareness of EC process by reviewing various studies on electrocoagulation of agro based industries mainly sugar, distillery, textile and dairy.

II. BASICS OF ELECTROCOAGULATION

The main principle of electrocoagulation (EC) technique comes from "electrolysis". Electrolysis is a process in which oxidation and reduction reaction occurs when electric current is applied to an electrolytic solution [21]. EC system consists of an anode and cathode electrode which is connected to external DC power supply. These electrodes are submerged in aqueous solution which is being treated. EC is a process in which the anode material undergoes oxidation while cathode material undergoes reduction. When anode material undergoes oxidation, there is production of various monomeric and polymeric metal hydrolyzed species. In an EC process the coagulating ions are produced 'in situ' and it involves five successive stages: (i) Production of destabilization agents such as Al and Fe ions by electrolytic oxidation of the 'sacrificial electrode' that neutralize the electric charge of the colloidal particles. (ii) Destabilization of the contaminants, particulate suspension, and breaking of emulsions. (iii) Aggregation of the destabilized phases to form flocs [12].(iv) Formation of OH^- ions, Formation of H_2 and O_2 gas at cathode and anode resp. (v) Removal of colloids by sedimentation or floatation [20].

The operation of EC depends on the nature of wastewater, the electrolyte used, type and arrangement of the electrode and current supply. The EC treatment can be carried out in both batch and continuous mode, but the efficiency of process depends upon the flow rate, mixing conditions, residence time, and characteristics of wastewater [14]. EC technique combines function and advantages of the conventional coagulation, flotation and electrochemistry [4]. There are many benefits of electrocoagulation process which include: environmental compatibility, versatility, energy efficiency and cost effectiveness [10]. It was tested successfully for treating almost all type of wastewater such as sugar industry effluent, distillery spentwash, dairy industry effluent, textile wastewater, landfill leachate etc.

There are different factors which have an effect on the efficiency of the EC process such as electrode material, electrode distance, electrode arrangement, pH of solution, current density, detention time and supporting electrolyte.



A schematic representation of electrocoagulation process

(Source: Sahu et al., (2013))

III. CONVENTIONAL TREATMENTS

Conventional techniques adopted to treat the agro based industrial wastewater are physical, chemical and biological methods.

A. Physical Methods

They were the first treatment methods to be used to treat wastewater. Different methods are involved such as sedimentation, screening, filtration, aeration, skimming, flotation, equalization and degasification.

B. Chemical Methods

Chemical methods are those in which removal of pollutants are brought about by chemical activity. These methods are usually used in conjunction with physical methods and biological methods. Commonly used chemical methods are coagulation, chlorination, ozonation, neutralization, adsorption and ion exchange.

C. Biological Methods

Biological methods are those in which removal of pollutants are brought about by biological activity. These methods further classified in aerobic and anaerobic process.

IV. PREVIOUS WORKS ON ELECTROCOAGULATION

A. EC of Sugar Industry Wastewater

Sahu et al., (2016) have worked on "Treatment of wastewater from sugar process industry by electrochemical and chemical process". In this study, wastewater samples were collected from Bhoramdev sugar industry Ltd. Kavardha (India) and its electrocoagulation treatment was carried out. These experimental studies were carried in both batch and continuous mode. It is reported that the performance of EC depends on current supply, nature of wastewater, arrangement of the electrode and electrolyte used including its operation. In this study electrolyte used was sodium sulphate (Na_2SO_4). At the optimum conditions such as density 178A/m^2, pH 7.5, aluminum electrode distance of 20mm and electrolyte concentration of 0.5M, COD was reduced by 84% and the colour reduction was 88% in batch process. Continuous process with volumetric flow rate of 0.375dm^3/h showed reduction in COD of 61% and colour removal 65% under optimum condition. In this study it is stated that the minimum space between electrodes were require to enhance flotation process and addition of electrolyte increase the effectiveness of process. To improve the treatment process, poly aluminum chloride was used as a coagulant. The combination showed COD reduction of 98% and colour removal of 99.5% at pH 7.5. The settling and filtration characteristics of sludge and slurry were found to be good at pH 7.5.

Varhade et al., (2014) have carried work on "Comparative study on the performance of various electrodes for removal of COD from sugar mill wastewater". In this experimental study, wastewater sample from sugar industry at Devhada (India) was treated by electrocoagulation. These experimental studies were conducted in lab scale batch EC reactor in which different types of electrodes such as iron, copper, stainless steel and aluminum were used separately. These experiments

were carried in rectangular EC reactor having capacity of 2 liter. In this EC reactor, 4 to 6 electrodes were placed having fixed gap of 1cm and electrode dimension were used are 9cm x 11cm x 1.5mm having effective surface area 9900 mm^2. These experimental studies were conducted to optimize the parameters such as electrolysis time (ET), voltage and type of electrode. In this study, initial characteristic of effluent such as BOD (1420 mg/L), COD (3300 mg/L) and TDS (2000mg/L) were observed. These experiments were conducted at 1.67A to 3A using 4 and 6 electrodes. At 1.67A, using 4 electrodes the voltage was found 7.4, 7.7, 9 and 10.4 for Cu, Fe, Al and stainless steel resp. similar experiments were conducted at 3A using 6 electrodes, the maximum voltage was found for aluminum. In this study, COD removal has been considered as an important parameter. In this study, the effectiveness of various electrodes was compared and it was found that, the COD removal efficiency varied as Al>Cu>SS>Fe. This study conclude that, at optimal condition (pH 6, voltage 14V, and electrolysis time of 20 min and 6 aluminum electrodes), 56% removal efficiency for COD was achieved.

Shivayogimath and Jahagirdar (2013) have carried work on "Treatment of sugar industry wastewater using electrocoagulation technique". In this study, wastewater samples were collected from sugar industry and its electrocoagulation treatment was carried out. These experimental studies were carried out in batch mode reactor having capacity of 1 liter with bipolar configuration of EC process. In this EC reactor, four iron electrodes were placed having fixed gap of 1cm. The dimensions of the electrodes were used are 5cm x 5cm x 1mm. In this EC reactor magnetic stirrer was used to maintain homogenous mixing of the reactor content. These experimental studies were conducted to optimize the various parameters such as electrolysis time (ET), pH and voltage. In this study, initial characteristic of effluent such as BOD (2250 mg/L), COD (6400 mg/L) and turbidity (249.1 NTU) were observed. Initially, these experiments were carried out without adjusting pH of raw wastewater (at pH 5) with varying voltages. This study states that, at optimal condition (pH 6, voltage 12V and electrolysis time of 4 hr), 92.8% removal efficiency for COD and 92.4% removal efficiency for turbidity were observed.

B. EC of Distillery Industry

Wagh and Nemade (2016) have worked on "Treatment of distillery spentwash by using chemical coagulation (CC) and electrocoagulation (EC)". In this study, wastewater samples were collected from distillery industry and its electrocoagulation treatment was carried out. These experimental studies were carried in batch mode. These EC experiments were performed in a beaker taking 1000 ml spentwash. In this EC experiments combination of different electrodes were used such as aluminum-aluminum (Al-Al) and iron-iron (Fe-Fe). Electrodes were used in this EC experiments having dimension of (135mm x 25mm x 2mm) and dipping area of electrode was 2750 mm^2. In this EC experiments, direct current was applied in the range of 20V to 30V. These experimental studies were conducted to optimize the parameters such as electrolysis time (ET), voltage, pH and type of electrode. In this study comparison of chemical coagulation and electrocoagulation were done. Different dosage of coagulants such alum (1gm to 4gm) and lime (3gm to 12gm) were used. It is found that alum coagulation is more appropriate than lime coagulation. In this study, 66.27% removal efficiency for COD was achieved using alum at pH 5. In this study, it is observed that, efficiency of aluminum electrodes was found good as compared to iron electrodes. It is reported that, at optimal condition pH 3, voltage 30V, and electrolysis time of 150 min, 85.7% removal efficiency (aluminum electrode) for COD and 73.17% removal efficiency of colour were observed. This study conclude that electrocoagulation method is effective than chemical coagulation for removal of COD from spentwash.

Santosh et al., (2014) have carried work on "Comparative assessment of iron and aluminum electrode for treatment of distillery spent wash by electrocoagulation method". In this experimental study, wastewater sample from distillery industry was treated by electrocoagulation. These experimental studies were conducted in lab scale batch EC reactor of capacity of 2 liter in which different types of electrodes such as iron and aluminum were used separately. In this EC reactor, two electrodes were placed having fixed gap of 3cm and electrode dimension were used are 150mm x 50mm x 5mm.These experimental studies were conducted to optimize the parameters such as electrolysis time (ET), voltage, pH and type of electrode. In this study, initial characteristic of effluent such as COD (134000 mg/L), BOD (59072 mg/L), TDS (12300mg/L), colour (316000 Pt-Co) and turbidity (15880 mg/L) were observed. In this study it is observed that, efficiency of aluminum electrodes was found good compare to iron electrodes. This study states that, at optimal condition pH 9, voltage 15V, and electrolysis time of 90 min. for aluminum electrodes removal efficiencies for COD, BOD, TDS, colour and turbidity were observed as 98.39%, 97.57%, 83.91% ,97.64% and 98.85% respectively.

C. EC of Textile Industry Wastewater

Shivprasad and Bhagwat (2017) have carried work on "Electrocoagulation to treat textile wastewater: A comparative study of electrodes". In this experimental study, raw textile wastewater samples were collected from zenith textiles Ltd., Nanjanagudu, Karnataka (India). These samples were collected from equalization tank. In this study, initial characteristic of effluent such as COD (6000 mg/L) and colour (2868 Pt-Co) were observed. These experimental studies were conducted in lab scale batch EC reactor of capacity of 4.5 liter in which different types of electrodes such as copper, aluminum and iron were used separately. In these experiments, anode and cathode electrodes were connected in monopolar connection arrangement at a fixed gap of 3cm. These experiments were carried at 4V, 8V and 12V with variable electrolysis time (10 to 50 minutes). In this EC reactor magnetic stirrer was used to maintain homogenous mixing of the reactor content. These experimental studies were conducted to optimize the various parameters such as electrolysis time (ET), pH and voltage. This study states that, efficiency of iron electrodes is good compare to other electrodes. For iron electrodes, at optimal condition (pH 8, voltage 12V and electrolysis time of 30 minute), 89% removal efficiency for COD and 96% removal efficiency for colour were observed.

Patel et al., (2010) have worked on "Studies on Removal of Dyes from wastewater using Electrocoagulation Process". They used electrocoagulation technique for the removal of colour and COD from dye solutions containing Direct Black 22 and Acid Red 97 using batch process. For batch, the process effect of operational parameters such as current density, initial pH of the solution, time of electrolysis and electrode materials were studied to attempt the maximum reduction of COD and colour. Different electrodes were used such as Iron and Aluminum with D.C. current. From the experiment, they found three important conclusions. First was the treatment of degradation of dyes by electrocoagulation has been found to be pH dependent. Second was in almost neutral medium, pH 8, COD and Colour removal efficiencies of Aluminum and iron electrodes are higher than those of all pH. Third was comparing overall performance of Iron and Aluminum electrodes, Iron electrodes give higher efficiency for COD and colour removal.

D. EC of Dairy Industry Wastewater

Krishna et al., (2017) have worked on "Dairy wastewater treatment using electrocoagulation technique" The wastewater for this study was collected from Manmull product dairy (Karnataka). These experimental studies were carried out in batch mode reactor having capacity of 1liter with monopolar configuration of EC process. These experiments were carried with different voltages, varying inter electrode spacing and pH. For each voltage at every 15minutes intervals samples were taken and analyzed for COD, TSS, TDS, oil and grease and efficiency was studied using iron electrode. It was reported that at pH (7.5), voltage (30V) and electrolysis time (90minute) the maximum removal efficiency for COD, TSS, and TDS was 80.4%, 85.1%, and 83.4% respectively. It was reported that the removal efficiency of 91.4% was obtained for oil and grease at an optimum voltage 30V and contact time 30min.It is also stated that the removal efficiency increases when there is increase in voltage, electrolysis time and decreases with increase in electrode spacing.

Aitbara et al., (2014) studied "Continuous treatment of industrial dairy effluent by electrocoagulation using aluminum electrodes". This experimental study was conducted in lab scale continuous EC reactor in which aluminum electrodes were used. This experiment was carried in cylindrical vessel having capacity of 1 liter. In this EC reactor, two parallel plate aluminum electrodes were placed having fixed gap of 1cm. In this study, initial characteristic of effluent such as BOD (1270mg/L), COD (2300mg/L) and turbidity (1037NTU) were observed. This paper states that, at optimal condition i.e. flow rate 1.75mL/min, pH 7.03, current density 15mA/cm^2 and electrolyte support KCL (0.02M) the removal efficiency for BOD (97%), COD (92%) and turbidity (99%) were observed.

Conclusion

- Some of the toxic pollutants from agro based industries are not removed by traditional conventional methods. Also these methods require large area. Therefore a compact and effective treatment is required to treat agro based industrial wastewater.

- In this view, electrocoagulation (EC) process is one of the alternatives available to treat agro based industrial wastewater and many of the researchers are working on this EC process.

- It is found that most of the researchers have done their EC study in batch mode (lab scale) and very few researchers have done their EC study in continuous-flow systems. Continuous flow EC system should be applied more in future studies in order to apply EC process on field scale.

- In the studies discussed above it is found that use of aluminum electrodes in EC process gives better result compared to other electrodes. From above study it is found that effectiveness of EC process depends on various parameters such as pH of wastewater, type of electrode, inter electrode spacing, conductivity of wastewater, current density and detention time.

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