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Treatment of Wastewater by Electro coagulation: A Review

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***Abstract* —: Worldwide scarcity of water is tending people to reuse the recycled wastewater. This can also be achieved at the industrial level. Treatment of industrial wastewater can be done by selection of the suitable and efficient method for any particular industry. In this paper, review has been done on the treatment of industrial wastewater by Electro coagulation individually and also in combination of various treatment processes. Literature shows that Electro coagulation can be the good option for the treatment of wastewater from various industries.**

Keywords: **Water scarcity, wastewater, Electro coagulation, Electrolysis, Electrode arrangements.**

I. INTRODUCTION

The treatment of wastewater involves many challenges that are not limited to the technical objectives of good water quality and solid/liquid separation. In developing a wastewater treatment method, its overall environmental impact, usefulness in various industrial applications, ease of installation and operation, energy efficiency, and cost-effectiveness must be considered [1]. There are numerous wastewater treatment units are employed around the world, each having its advantages and disadvantages. The aim of the study is to investigate the use of electro coagulation, an eco-friendly alternative to chemical coagulation and other treatment processes that require large areas for treatment facilities and staff.

II. ELECTROCOAGULATION

A. Theory of electro coagulation

Electro coagulation (EC) is a unique method for water and wastewater treatment that is based on the electrochemical dissolution of sacrificial metal electrodes into soluble or insoluble species that improves the coagulation, the precipitation or adsorption of colloidal contaminants [2]. In an Electro coagulation process the coagulating ions are generated continuously and it consists of three consecutive steps:

(i) Coagulant formation by electrolytic oxidation of the sacrificial anode.
(ii)Destabilization of the pollutants, particulate suspension, and emulsion breaking
(iii) Aggregation of the destabilized phases to form flocs.

The destabilization mechanisms of the contaminants, particulate suspension, and emulsion breaking have been summarized as follows:

1. The diffuse double layer compression around the charged species by the ions produced by oxidation of the sacrificial anode.
2. Neutralization of charge of the ionic group in wastewater by counter ions formed by the electrochemical dissolution of the sacrificial electrode. These counter ions decrease the electrostatic inter
3. Particle repulsion to such level that the Van der Waals attraction predominates, as a result cause coagulation in the solution. Result of the process is a zero net charge.
4. Formation of floc as a result of coagulation creates a blanket of sludge that entraps and bridges colloidal particles still remaining in the solution. The hydroxides, oxyhydroxides and solid oxides give active surfaces for the adsorption of the polluting species [3].

B. Electrochemical Reactions in Electro coagulation Process

When Iron and Aluminum are used as an electrode material the reaction are as follows [4]:

1. Iron Electrode:
   Anode: $Fe \rightarrow Fe^{2+} + 2e^-$
   Cathode: $2H_2O + 2e^- \rightarrow H_2 + 2OH^-$
   Overall: $Fe^{2+} + 2H_2O \rightarrow H_2 + Fe(OH)_2\downarrow$

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or
Anode: $Fe \rightarrow Fe^{3+} + 3e^-$
Cathode: $H_2O + 3e^- \rightarrow 1.5H_2 + 3OH^-$
Overall: $Fe^{3+} + 3H_2O \rightarrow 1.5H_2 + Fe(OH)_3\downarrow$

2. Aluminum electrode :
Anode: $Al \rightarrow Al^{3+} + 3e^-$
Cathode: $H_2O + 3e^- \rightarrow 1.5H_2 + 3OH^-$
Overall: $Al + H_2O \rightarrow H_2 + Al(OH)_2\downarrow$

General Equation in Electro coagulation:
At Anode: $M \rightarrow M^{n+} + ne^-$
At Cathode: $2H_2O + 2e^- \rightarrow H_2 + 2OH^-$
Overall: $M^{n+} + nH_2O \rightarrow M(OH)_n + nH^+$

C. Various Treatment Parameters in Electro coagulation (EC) process

There are various treatment parameters effects on efficiency of the Electro coagulation in elimination of the contaminants from water or wastewater are as follows [5]:

1. Material of the electrodes can be Iron, Aluminum and/or inert material. Iron and Aluminum ions and hydroxides have different chemistries and applications.
2. PH of the solution influences the dissolution of Aluminum electrodes and affects the ζ potential of the colloidal particles and also on the speciation of metal hydroxides in the solution.
3. The amount of electrochemical reactions taking place on the electrode surface is proportional to Current density.
4. Treatment time is relative to the amount of coagulants formed in the Electro coagulation system and other reactions taking place in the system.
5. Temperature has an effect on formation of floc, conductivity of the solution and reaction rates. Depending on the pollutant, increasing temperature can have either good or bad effect on removal efficiency.
6. Electrode potential defines which reactions occur on the electrode surface.
7. Concentration of the pollutants affects the removal efficiency since coagulation does not follow zero th-order reaction kinetics but rather pseudo second or first-order kinetics.
8. Inter-electrode distance may have effect on efficiency of the treatment and electricity consumption.

Electro coagulation can effectively remove the metals, suspended particles, clay minerals, organic matters, and oil and greases from a various industrial effluents [3].

D. Design of the EC cell

In an EC process the electrode assembly is typically connected to a DC source externally. The quantity of electricity passed through the electrolytic solution is responsible for the amount of metal dissolved or deposited. A simple relationship between current density (A/cm^2) and the amount of substances (*M*) dissolved (g of *M*/cm^2) can be derived from Faraday's law:

$$w = \frac{itM}{nF}$$

where *w* is the quantity of electrode material dissolved (g of *M*/cm^2), *i* the current density (A/cm^2), *t* the time in second; *M* the relative molar mass of the electrode concerned, *n* the number of electrons in oxidation/reduction reaction, *F* the Faraday's constant, 96,500 C/mol.

It is expected that there should be an agreement between the calculated quantities of material dissolved as a result of passing a specific amount of electricity and the experimental quantity determined. Usually a good agreement is achieved although significant error may be occur if proper consideration is not done on the geometry of the electrode arrangement and the optimum conditions of operation of the Electro coagulation unit. One area of improbability is in the measurement of potential of the EC cell. The calculated potential is the summation of three components:

$$\eta AP = \eta\kappa + \eta Mt + \eta IR$$

where ηAP is the applied over potential (V), $\eta\kappa$ the kinetic over potential (V), ηMt the concentration over potential (V), ηIR is the over potential due to solution resistance or IR-drop (V). The IR-drop is related to the distance (*d* in

cm) between the electrodes, surface area (A in m^2) of the cathode and specific conductivity of the solution (κ in mS/m) and current (I in A) by the equation [6].
ηIR = $Id\ A\kappa$

The IR-drop can be minimized easily by decreasing the inter electrode distance and increasing the area of cross section of the electrodes and the specific conductivity of the solution. Concentration over potential (ηMt, V), also called as diffusion over potential or mass transfer, is because of the change in analyte concentration happening near the electrode surface due to electrode reaction. The variations in electro active species concentration between the bulk solution and the electrode surface cause this over potential. This condition takes place when the electrochemical reaction is adequately quick to lower surface concentration of electro active species under that of the bulk solution. When reaction rate constant is much lesser than the mass transfer coefficient then the concentration over potential is negligibly less. By increasing the masses of the metal ions transported from the anode surface to the bulk of the solution the concentration over potential (ηMt, V) can be reduced and can be accomplished by increasing the turbulence of the solution. At a higher velocity by passing electrolyte solution from anode to cathode mechanically it can also be overcome. Kinetic over potential has its origin in the activation energy barrier to electron transfer reactions.

The activation over potential is mainly high for evolution of gases on certain electrodes. There is an increase in both kinetic and concentration over potential with the increase in current. However, the effects of these changes need to be explored for particular types of physical and chemical group in aqueous solution. The complete effects of the electric field gradient on the related surface and solution reactions must also be clearly explained. The effect of pH and electrochemical potentials on both solution phase as well as interfacial reactions should be clearly understood for optimization of the performances of EC systems.

To achieve the maximum efficiency, it is important to design the EC cell. While designing EC unit, the following factors must be taken into consideration [7]:

a. The IR-drop between the electrodes must be kept at minimum value.
b. gathering of O_2 and H_2 gas bubble nucleates at the electrode surfaces must be minimized;
c. Impediment to mass transfer through the spaces between the electrodes must be minimized.

The IR-drop depends on [8]:

a. The inter electrode distance.
b. The conductivity of the electrolyte solution
c. The geometry of the electrode.

The errors due to IR-drop can be decreased in three different ways:

a. Use of high conductivity solution.
b. Decreasing the inter electrode distance.
c. Develop an electronic means to compensate for IR-drop (feedback action of potentiostat).

The mass transport can be improved by increasing the turbulence level in the flow through an EC reactor. The increase in turbulence level also reduces the passive layer formation near the electrode plates. Oxygen and hydrogen gases are evolved at the anode and the cathode in the form of gas bubble nucleates. These gas bubbles are insulating spheres which will increase the electrical resistance of the cell if they are allowed to accumulate at the electrode surfaces and, as a result, more electricity is to be used to get the optimum removal efficiency. To sweep out the bubbles, the electrolyte flow around the electrodes should be increased to minimize their accumulation [3].
The main process in Electro coagulation unit are shown in fig 1

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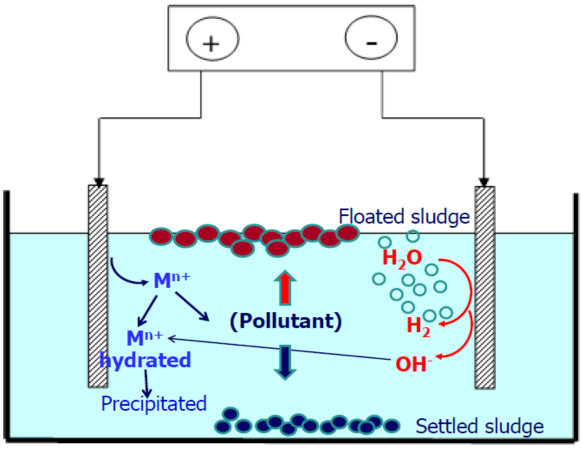

Fig. 1 Main process in Electro coagulation [9]

E. Arrangement of Electrode

In Electro coagulation the arrangement of electrode can be done in following three ways:

a. ***Monopolar electrodes in parallel connections***

Monopolar electrode connected in parallel arrangements is shown in Fig .2

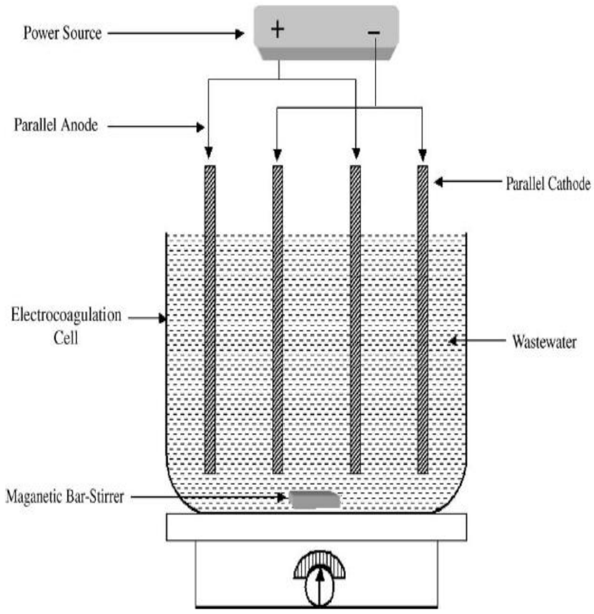

Fig.2 Monopolar electrodes in parallel connections [10]

Monopolar electrodes in parallel connections are a most simple arrangement of an EC cell. It consists of pairs of conductive metal plates positioned in between two parallel electrodes and a dc power supply. In the experimental set up a resistance box regulates the current density and a multimeter to read the current values. The conductive metal plates are usually known as 'sacrificial electrodes' which may be made up of the same or of dissimilar materials [10] *(Pretorius et al, 1991)*.

b. ***Monopolar electrodes in series connections***

Monopolar electrode connected in series arrangements is shown in Fig .3

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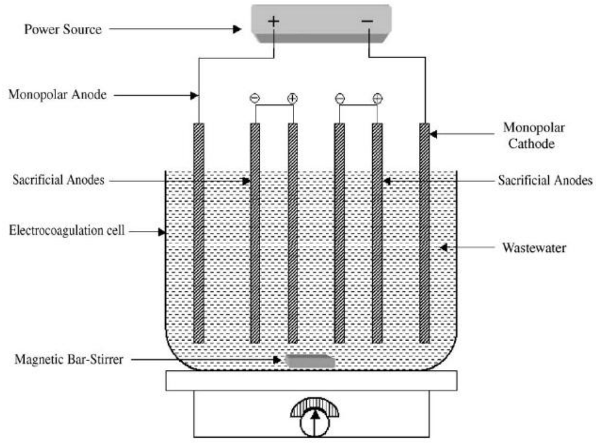

Fig 3.Monopolar electrodes in series connections [10]

This cell arrangement provides a simple set-up; the sacrificial electrodes are placed between the two parallel electrodes without any electrical and only two monopolar electrodes are connected to the power supply without any connections between the sacrificial electrodes which helps in easy handling. As current is passed through the pair of electrodes, the neutral sides of the conductive plate will be changed to charged face, which have opposite charge compared to the nearby parallel side. The sacrificial electrodes in this case are also called bipolar electrodes [10].

c. *Dipolar electrodes in parallel connections*

Dipolar electrode connected in parallel arrangements is shown in Fig .4

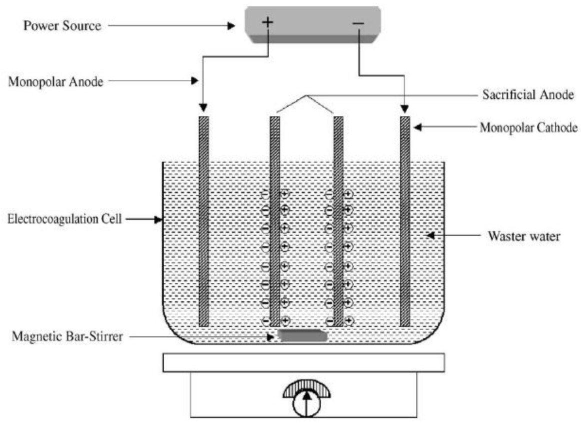

Fig 4.Dipolar electrodes in parallel connections [10]

This cell arrangement provides a simple set-up, which facilitates easy maintenance. In this arrangement the sacrificial electrodes are positioned between the two parallel electrodes without any electrical connection. Not more than two monopolar electrodes are connected to the electric power supply without any interconnections among the sacrificial electrodes. The neutral sides of the conductive plate will be changed to charged sides when current is passed through the two electrodes. This side has opposite charge contrast to the corresponding side near it. The sacrificial electrodes in this scenario are called as bipolar electrodes [10].

F. Advantages of EC

1. EC requires simple equipment and is easy to operate.
2. EC cell has no moving parts and the electrolytic processes are controlled electrically, thus requiring less maintenance.
3. Wastewater treated by EC gives pleasant, clear, colorless and odorless water.
4. Sludge formed by EC is composed of mainly metallic oxides/hydroxides so it tends to be readily settable and easy to de-water therefore it is a low sludge producing technique

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5. Flocs formed by EC are similar to chemical floc; moreover that EC floc tends to be much larger, contains less bound water and is acid-resistant and more stable.
6. There is no use of chemicals in EC process, so there will be less risk of secondary pollution as unlike the chemical coagulation in which chemical substances added at high concentration.
7. The gas bubbles generated at the time of electrolysis can take the pollutants to the top from where it can be separated easily.
8. The Electro coagulation can be suitably used with the help of other renewable sources of energy such as solar or wind in rural region where power is not easily available [11].

G. Disadvantages of EC

1. Viscous hydroxide may be likely to solubilize in some cases.
2. The sacrificial anodes are dissolved into solution due to oxidation, and need to be replaced at regular interval.
3. The electricity may be not easily available and expensive in some area.
4. Efficiency of the electro coagulation unit decreases due to an impermeable oxide film formed on the cathode.
5. Conductivity of the wastewater suspension must be high [11].

III. INDUSTRIAL APPLICATION

From the literature survey of earlier work done in Electro coagulation and its integration with other treatment processes it is seen that these methods are useful in the treatment of wastewater from various industries.

Electro coagulation (EC) treatment is applied widely in the numerous industries such as textile, potato chips manufacturing [12] [13], paint manufacturing [14], distillary *[15]*, chemical mechanical polishing (CMP) [16], tannery *[17]*, vegetable oil refinery wastewater (VORW) [18], paper and pulp [19] pharmaceutical [20] other industries successfully. Results show that EC is very effective in the removal of COD and solids from most variety of wastewater.

Some literature shows the use of Electro coagulation with hydrogen peroxide and ozone in combination for the treatment of wastewater. [21], has used the electrochemical treatment of alcohol distillery wastewater by electro coagulation with and without the presence of H_2O_2. According to the results obtained, electro coagulation (EC) alone was not very effective and Electro Fenton (EF) i.e. electro coagulation with H_2O_2 was found to be more efficient than EC alone for the treatment of alcohol distillery wastewater which has high concentration of refractory organic matters. [22] in their work makes a comparison between electro coagulation (EC), photo electro coagulation, peroxi-electrocoagulation and peroxi-photoelectrocoagulation processes in the removal of chemical oxygen demand (COD) from pharmaceutical wastewater. Results showed that under the optimum operating conditions the best COD removal efficiency was found in the peroxi-electrocoagulation i.e. Fenton oxidation combined with Electro coagulation. Also [23] in year *2011* investigated the hybrid technique of electro coagulation assisted with ozone for color and COD removal in distillery effluent. The result showed that the hybrid technique was more effective than electro coagulation and ozonation alone.

IV. CONCLUSION

Previous studies shows that electro coagulation has proven to be a good alternative to conventional coagulation which introduce chemical in to the effluent and biological treatment process which has its own limitation as they requires specific conditions, thus have limitation in treating various wastewaters with high pH and toxicity. When integrated with the other treatment processes such as Ozonation, Fenton oxidation, Adsorption etc, Electro coagulation shows better efficiency in removal of color, Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD) and other impurities from wastewater.

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