

# A Review of Electrocoagulation Process for Wastewater Treatment

SANJAY S<sup>1</sup>, HARSHITA S RYAGI<sup>2</sup>, HARSHITH H J<sup>3</sup>, RAKESH H<sup>4</sup>

<sup>1</sup>Assistant Professor, Department of Civil Engineering, AIET, Mijar, Karnataka, India.

<sup>2</sup>UG Scholar, Department of Civil Engineering, AIET Mijar, Karnataka, India.

<sup>3</sup> UG Scholar, Department of Civil Engineering, AIET Mijar, Karnataka, India.

<sup>4</sup> UG Scholar, Department of Civil Engineering, AIET Mijar, Karnataka, India.

## ABSTRACT

*Electrocoagulation is a complex process with a multitude of mechanisms operating synergistically to remove pollutants from the water. A wide variety of opinions exist in the literature for key mechanisms and reactor configurations. A lack of a systematic approach has resulted in a myriad of designs for electrocoagulation reactors without due consideration of the complexity of the system. A systematic, holistic approach is required to understand electrocoagulation and its controlling parameters. This will enable a priori prediction of the treatment of various pollutant types.*

**Keywords:** *Electrocoagulation, electroflotation, wastewater, Water treatment.*

---

## 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 employed around the world, each having its advantages and disadvantages. The aim of the study is to investigate the use of electrocoagulation, an eco-friendly alternative to chemical coagulation and other treatment processes that require large areas for treatment facilities and staff. Effluents from many industries are now one of the major sources of water pollution which represent important environmental problems. These pollutants in water cause considerable damage to the aquatic environment and significant source of environmental pollution. It contains several harmful chemicals that are toxic to biological life.

## ELECTROCOAGULATION

Electrocoagulation process involves oxidation and reduction reaction in which destabilization of contaminants (suspended, emulsified, or dissolved) happens because of application of electric current to the electrolytic solution. EC unit consists of an electrolytic cell and metal (Al or Fe) electrodes which are connected to an external power supply. The conductive metal plates are well known as sacrificial electrodes which are made up of same or completely different materials as anode or cathode. In the EC process, anodic dissolution generates *in situ* coagulants along with hydroxyl ions and hydrogen gas at the cathode. These *in situ* coagulants cause the formation of flocs within the sort of metal (Al or Fe) hydroxides and/or polyhydroxides. The hydrogen gas generated at the cathode brings flocs at the water surface by providing further buoyancy.

## ELECTROCHEMICAL REACTIONS IN ELECTRO COAGULATION PROCESS

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

### 1. Iron Electrode:

Anode:  $\text{Fe} \rightarrow \text{Fe}^{2+} + 2\text{e}^-$  Cathode:  $2\text{H}_2\text{O} + 2\text{e}^- \rightarrow \text{H}_2 + 2\text{OH}^-$  Overall:  $\text{Fe}^{2+} + 2\text{H}_2\text{O} \rightarrow \text{H}_2 + \text{Fe}(\text{OH})_2 \downarrow$  or  
Anode:  $\text{Fe} \rightarrow \text{Fe}^{3+} + 3\text{e}^-$  Cathode:  $\text{H}_2\text{O} + 3\text{e}^- \rightarrow 1.5\text{H}_2 + 3\text{OH}^-$  Overall:  $\text{Fe}^{3+} + 3\text{H}_2\text{O} \rightarrow 1.5\text{H}_2 + \text{Fe}(\text{OH})_3 \downarrow$

### 2. Aluminum Electrode:

Anode:  $\text{Al} \rightarrow \text{Al}^{3+} + 3\text{e}^-$  Cathode:  $\text{H}_2\text{O} + 3\text{e}^- \rightarrow 1.5\text{H}_2 + 3\text{OH}^-$  Overall:  $\text{Al} + \text{H}_2\text{O} \rightarrow \text{H}_2 + \text{Al}(\text{OH})_3 \downarrow$

General Equation in Electro coagulation:

At Anode:  $\text{M} \rightarrow \text{M}^{n+} + n\text{e}^-$

At Cathode:  $2\text{H}_2\text{O} + 2\text{e}^- \rightarrow \text{H}_2 + 2\text{OH}^-$  Overall:  $\text{M}^{n+} + n\text{H}_2\text{O} \rightarrow \text{M}(\text{OH})_n + n\text{H}^+$

## 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  $\zeta$  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].

## 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 ( $A/\text{cm}^2$ ) and the amount of substances ( $M$ ) dissolved ( $g$  of  $M/\text{cm}^2$ ) can be derived from Faraday's law:  $w = \frac{M}{zF} \cdot i \cdot t$  where  $w$  is the quantity of electrode material dissolved ( $g$  of  $M/\text{cm}^2$ ),  $i$  the current density ( $A/\text{cm}^2$ ),  $t$  the time in second;  $M$  the relative molar mass of the electrode concerned,  $z$  the number of electrons in oxidation/reduction reaction,  $F$  the Faraday's constant,  $96,500 \text{ C/mol}$ . 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  $\eta_{AP}$  is the applied over potential (V),  $\eta_{\kappa}$  the kinetic over potential (V),  $\eta_{Mt}$  the concentration over potential (V),  $\eta_{IR}$  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 ( $\kappa$  in  $mS/m$ ) and current ( $I$  in A) by the equation [6].  $\eta IR = Id A \kappa$  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 ( $\eta Mt$ , 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 ( $\eta Mt$ , 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]:

- The IR-drop between the electrodes must be kept at minimum value.
- gathering of O<sub>2</sub> and H<sub>2</sub> gas bubble nucleates at the electrode surfaces must be minimized;
- Impediment to mass transfer through the spaces between the electrodes must be minimized.

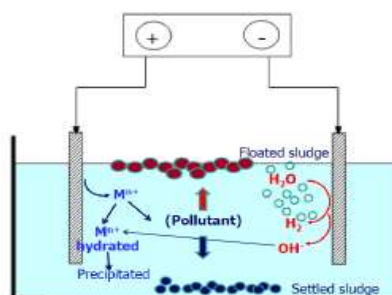
The IR-drop depends on [8]:

- The inter electrode distance.
- The conductivity of the electrolyte solution
- The geometry of the electrode.

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

- Use of high conductivity solution.
- Decreasing the inter electrode distance.
- 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

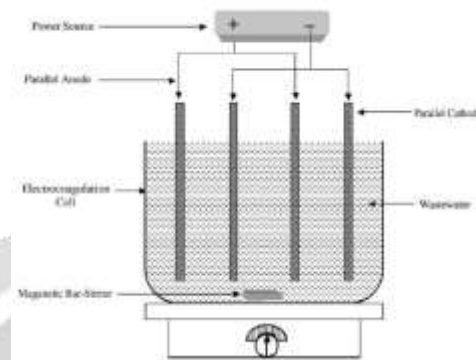


**Fig. 1 Main process in Electro coagulation**

## Electrode Arrangement

In the EC process, electrode material and type of electrode connection play a major role in the cost analysis.

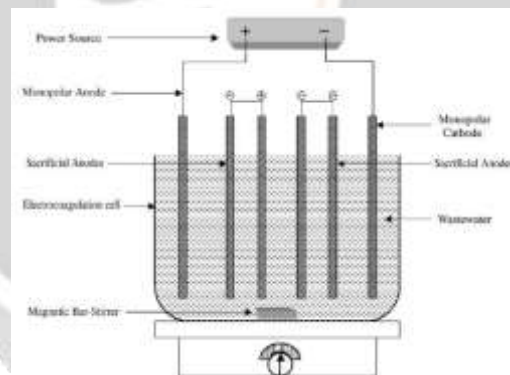
### a. Monopolar electrodes in parallel connections:



**Fig.1 Monopolar electrodes in parallel connections**

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 millimeter 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.

### b. Monopolar electrodes in series connections:



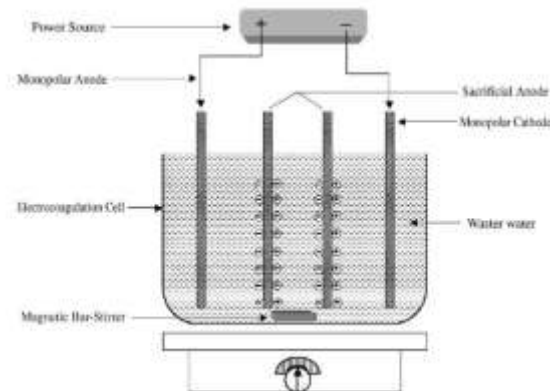
**Fig 2.Monopolar electrodes in series connections**

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

### c. Dipolar electrodes in parallel connections:

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.



**Fig 3. Dipolar electrodes in parallel connections.**

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].

### 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 settleable and easy to de-water therefore it is a low sludge producing technique.

### 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].

### 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.

## REFERENCES

- [1] W. Hirzallah, Effectiveness of Electrochemical Treatment of Municipal Sewage, Department of Building, Civil and Environmental Engineering, Concordia University Montreal, Quebec, Canada, 2011.
- [2] P.K. Holt, G.W. Barton, C.A. Mitchell, The future for electro coagulation as a localized water treatment technology, *Chemosphere* 59, 355–367, 2005.  
ISSN: 2319-5967 ISO 9001:2008 Certified International Journal of Engineering Science and Innovative Technology (IJESIT) Volume 5, Issue 3, May 2016 110
- [3] Mohammad Y.A. Mollaha, P Morkovskyb, A.G. Gomesc Jewel, M. Kesmezc, J. Pargad, D.L. Cockec, Fundamentals, present and future perspectives of electro coagulation, Elsevier, 2004.
- [4] D. O. Siringi, P. Home, J. S.Chacha, E. Koehn, Is Electro coagulation (EC) A Solution to the Treatment of Wastewater and Providing Clean Water for Daily Use. *ARPN Journal of Engineering and Applied Sciences*. Vol. 7, No. 2, 2012.
- [5] M. Vepsäläinen, Electro coagulation in the treatment of industrial waters and wastewaters, 2012.
- [6] A. Vik, D.A. Carlson, A.S. Eikum, E.T. Gjessing, *Water Res.* 18 (11), 1355, 1984.
- [7] A.B. Paul., Proceedings of the 22nd WEDC Conference on Water Quality and Supply, New Delhi, India, p. 286, 1996
- [8] Laboratory Techniques in Electro analytical Chemistry, 2nd ed., Marcel Dekker, New York, 1996.
- [9] S Hirunmasuwan and B Punpeng, Water Purification by Electro coagulation, Thai Water 2013: Water for the Future, BITEC, Bangkok, Thailand, 2013.
- [10] W.A. Pretorius, W.G. Johannes, G.G.Lampert, *Water South Arica* 17 (2), 133, 1991.
- [11] M.Y.A Mollah, R. Schennach, J.R. Parga, D.L. Cocke, Electro coagulation (EC) — science and applications, *Journal of Hazardous Materials*, Volume 84, Issue 1,P. 29–41, 2001
- [12] M. Kobya, O.T. Can, M. Bayramoglu, Treatment of textile wastewaters by electro coagulation using iron and aluminum electrodes, *Journal of Hazardous Materials(B)*100, 163–178, 2003
- [13] M. Kobya, H. Hiza, E. Senturka, C. Aydinera, E. Demirbasb, Treatment of potato chips manufacturing wastewater by electro coagulation, *Desalination* 190, 201–211, 2006
- [14] A. Akyol, Treatment of paint manufacturing wastewater by electro coagulation, *Desalination* 285, 91–99, 2012
- [15] U.T. Un, A.S. Koparal, U.B. Ogutveren, Electro coagulation of vegetable oil refinery wastewater using aluminum electrodes, *Journal of Environmental Management* 90, 428-433, 2009
- [16] V. Khandegar and A.K. Saroha, Electrochemical Treatment of Distillery Spent Wash Using Aluminum and Iron Electrodes, *Chinese Journal of Chemical Engineering*, 20(3) 439— 443, 2012
- [17] N. Drouichea, N. Ghaffourb, H. Lounicic, M. Mameric, Electro coagulation of chemical mechanical polishing