



An Overview Of Electrochemical Coagulation Technology For Treatment Of Industrial Wastewater

GROUP INFO:

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Abstract :70% of the Earth's surface is covered by water, but only 0.3% of total water is potable. Rapidly growing population and industrialization have raised serious problems for the world. It is difficult to clean polluted waters, because of the many problems faced by applications of time-consuming traditional treatment methods. The electrochemical coagulation method comes to rescue with its exceptional efficiency.

Electrochemical coagulation technology is a method of treating wastewater using electricity. Which makes it more effective and economical than traditional methods. This advanced method has the advantage of removing the smallest colloidal particles compared with conventional activated sludge process and other technologies. Along with this, the electrocoagulation process is flexible according to the intensity of impurities present in wastewater by changing the parameters affecting it.

This review paper reviews and discusses the mechanism of electrocoagulation process, and discusses the parameters affecting the rate of electrocoagulation efficiency along with the rate of impurity removal by electrodes in different conditions.

Keywords: Wastewater, Electrocoagulation, Electrodes, Adsorbent, Coagulant, Treatment, Impurities, BOD, COD.

I. INTRODUCTION:

Nature has always paid the price of human interference by various means. Discharged effluents from industries causes unbearable water pollution, it can be measured by the various parameters as biological oxygen demand (BOD), chemical oxygen demand (COD), total solids (TS), total suspended solids (TSS), total organic carbon (TOC), pH, organic, non organic matters, color, odor, etc.

To reduce the contamination from water, there are different methods developed according to the type of wastewater and the nature of the contaminants present in them. Thermal degradation, physicochemical, chemical method, Various oxidation, reduction methods, microbiological methods, enzymatic decomposition method are few methods which are used to treat wastewater. Every method has its novelty and highest efficiency in their respective areas of treatment according to the need of the treatment to deal with a particular type of impurity.

Electrochemical coagulation is a method used to treat wastewater by applying electric currents through wastewater; it was patented by Dietrich in 1906. The main aim was to remove heavy cations from the wastewater and destroy the microorganisms. Later, it developed haphazardly, observing its tremendous advantages and large capacity to treat water for various purposes.

It is an advanced method that works on a molecular level to separate impurities from water by the process of ionization. In this method, two metal electrodes dips into wastewater up to required limit to generate a circuit to pass an electric current through them using an electric source having high capacity to hold voltage as per scale of the project.

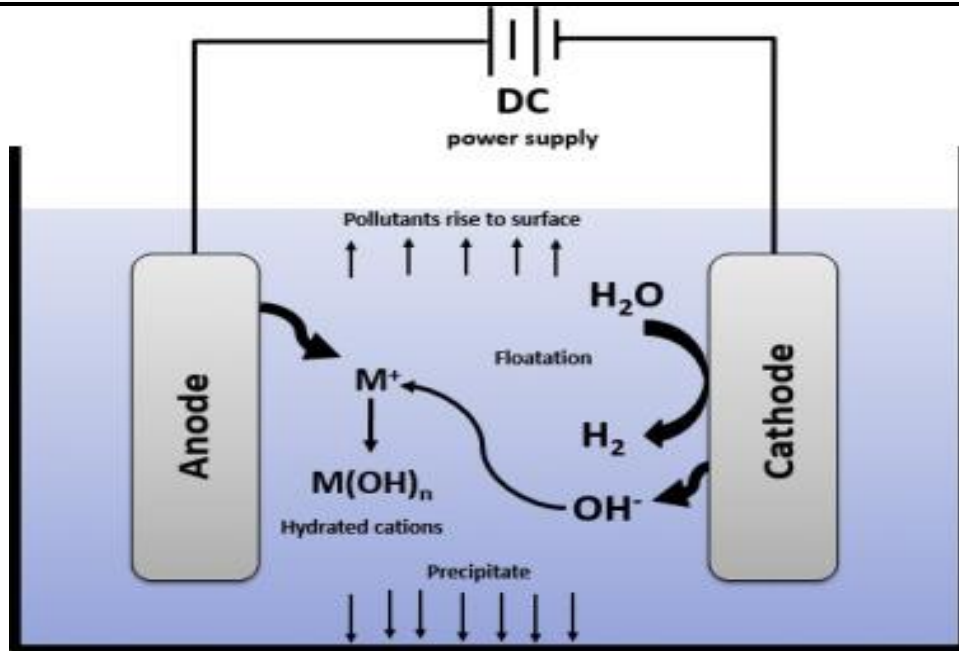


Fig: Basic Structure of Electrochemical Coagulation Process in tank

Source: <https://images.app.goo.gl/qrZDYtoDdTFMwF4r7>

Addition of small electric current through the wastewater leads to the process of ionization, where electrons get separated from their outer orbit, generating the electric charge over impurities. Charged impurities get attracted to the electrodes dipped in the wastewater for causing oxidation and reduction processes on either ends of the electrodes completing the circuit flow. Dipped electrodes react with these impurities, generating the sludge with electric double layer formation which gets settled at the bottom of the tank.

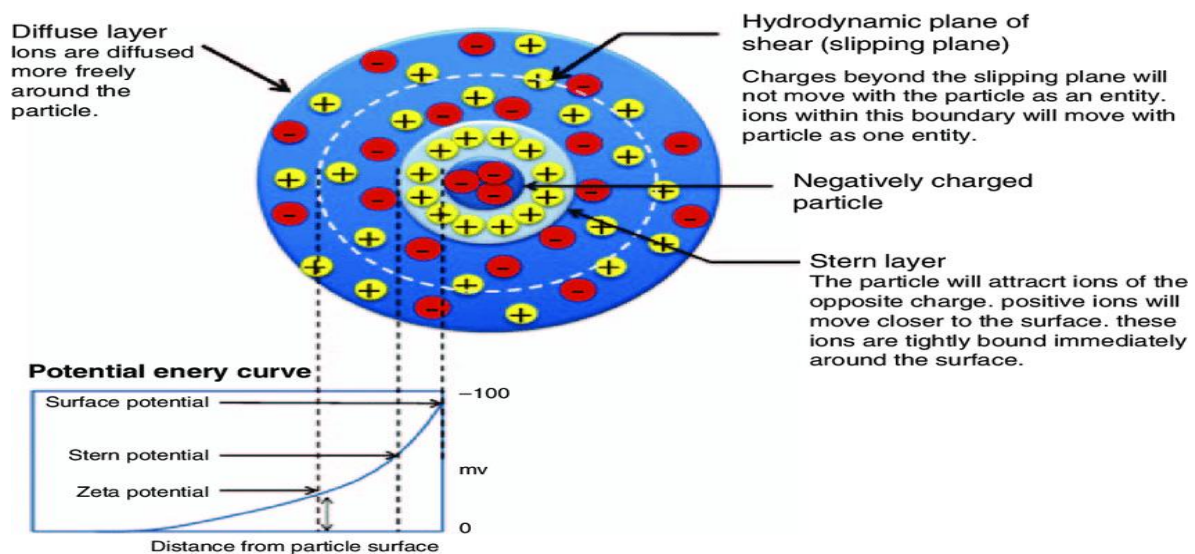


Fig: Formation of electric Double Layer

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Electricity generates metal ions at cathode of the electrode and free electrons at the anode causing bubbling in wastewater. Water molecules at anode generate hydrogen ions H⁺ and hydroxyl OH⁻ ions. Hydrogen ions react with each other to form hydrogen gas at the cathode of the system. Metal ions from the electrode react with OH⁻ ions and produce floc molecules. The floc molecules are destabilized molecules by their ionic nature and get adsorbed on metallic positive ions of the electrode to produce macro sized floc particles by a process of electric double layer adsorption process and settle down by gravity force, and light particles float on wastewater. [3,4,9]

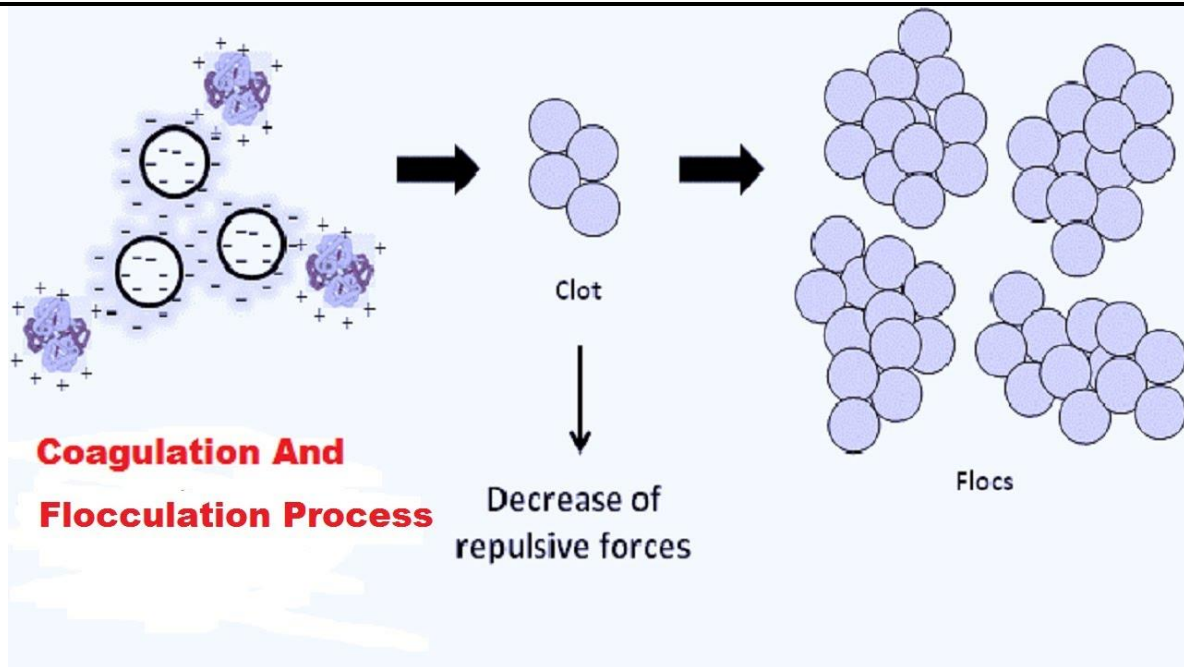


Fig: Generation of Floc molecules

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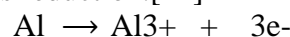
II. MECHANISM OF ELECTRO-CHEMICAL COAGULATION PROCESS:

1. Electrochemical coagulation technology gained popularity and attracted attention because of its efficiency with constantly improving advantages in the field, also it is widely discussed by authors all over the world. It is a complex procedure where electrolysis of wastewater is done with systemic conditions and in presence of definite electrodes and coagulants. In this process, an electric circuit is created between wastewater, where all crucial procedures take place. The entire procedure divides into four sections where, step by step, major events form, they are:
 - a. Electrolytic reaction at electrodes
 - b. Formation of coagulant in wastewater
 - c. Generation of electric double layer
 - d. Adsorption and floc generation.[14]

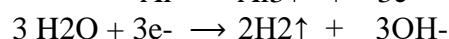
1.1 Electrolytic reaction at electrodes: During electrolytic reactions, electrolysis of water takes place at cathode and anode of the selected electrodes. Depending upon the material of the electrodes, they release the free electrons and get ionized, generating metal ions at anode. Example: Aluminum electrode releases three electrons because it has three free electrons in its last orbit forming an excellent quality of electrode for treatment of industrial wastewater where high efficiency is needed. Anode sacrifices its metal ion for production of free electrons and positively charged ions. While at cathode, water gets ionized, forming hydroxyl ions and hydrogen ions. Two molecules of hydrogen react with each other, forming hydrogen gas H₂. Hydrogen gas easily escapes as bubbles. [15,17]

Free electrons generated through this reaction continue the flow of electricity and the positive metal ion sacrificed from the electrode causes decomposition of the anode electrode. Every time anode sacrifices its metal to keep generating metal ions as it gets oxidized, means at anode oxidation process occurs and at cathode where production of hydrogen gas takes place undergoes reduction.[11]

Reaction at Anode:



Reaction at Cathode:



Overall Reaction:



1.2 Formation of Coagulant: Coagulant is generated by chemical reaction between hydroxyl ions and the sacrificed metal ion to form a complex compound of metal hydroxide. These compounds are negatively charged and have high masses. Because of their heavy negative charges, the buffer condition in the wastewater gets disturbed, causing them to destabilize from their original position. These destabilized particles seek for opposite charged particles to neutralize and act as a catalyst in the formation of the floc molecule. [8,10]

1.3 Electric Double Layer: In the process of formation of electric double layer generation, metal hydroxyl ions cause a highly destabilized environment for the generation of metal ions and the impurities which are getting ionized by the electricity. Similar to metal ions, impurities also break down in free electrons and destabilized ions. These ions generated from impurities have positive charges and some negative charges. [14,15]

Negatively charged particles of impurities get attracted towards the positively charged metal ions. The number of positively charged metal ions is high in comparison to negatively charged so, they get adsorbed over the positively charged metal ions forming a thin layer of densely charged negative impurities.

These adsorbed molecules lead to an increase in the electric field, causing other positively charged impurities to get absorbed, coating it with a second layer of the positively charged impurity, which further attacks negatively charged impurities. This continuous process leads to formation of electric double layer adsorption.[9, 17]

1.4 Adsorption and floc generation: The continuous formation of electric double layer leads to the gain of the weight of the structure, causing it to get settled at the bottom of the tank or float because of their lack of formation of bulky molecules. This way, they can be easily removed from the existing wastewater efficiently. [13, 18]

III. PARAMETERS AFFECTING ELECTROCHEMICAL COAGULATION:

Electrochemical Coagulation process depends on parameters which can be adjusted according to the need of the project or the concentration of the impurities.

1. **Current Density:** High current density causes the decomposition or corrosion of the electrodes, causing them to reduce in their size. With an increase in the current density, the rate of removal of contaminants will be improved because of the higher amount of metal ions generated by its application, which causes rapid decomposition of electrodes too. Higher amounts of metal ion generated created a destabilized environment resulting in the production of the high amount of floc generation[4, 7, 14]. Current density is found to be the most influential parameters of electrochemical coagulation process in removal TD, COD, and BOD, where the rate of contaminant removal gets increased as the current density increases, but up to a certain limit; normally, this limit is seen to found between 25-30 mA/cm², means after this limit if current density increases, it doesn't affect the rate of removal of contaminants and remains constant for further increment. It is also seen that higher current density increases the formation of hydroxyl metal ion, which acts as a catalyst in the process of electrochemical coagulation. The current density is the only parameter which can be directly controlled by the needs of the projects. [10, 13, 19]
2. **pH:** Generally, it is seen that the pH of the wastewater is higher than normal water. The role of pH in this process lies in the smooth conduction of the electrolysis process. It is preferred that, the range of pH between 4 to 11 to treat the textile industry as the wastewater generated from it has a high concentration of the strongly acidic and basic properties, but for other industries it's taken between 5 to 8 because between these range production of the hydroxyl metal ions rises to its higher limits to form a floc molecules[2,3]. pH below 4 is critical for handling ducting the electrochemical coagulation process and when pH is greater than 8 causes problems in smooth operation of the electrolysis process, hydroxyl ion causes hindrance by generating an excess amount of bubbles of hydrogen gas. To maintain pH at a particular range, buffer solutions were adding in wastewater during the procedures. The rate of removal of impurity is higher in acidic or alkaline medium than neutral as formation of ions is easy. [12, 17]
3. **Temperature:** It is seen that the efficiency of the removal of turbidity from wastewater in the process of electrochemical coagulation is increased by slight rise in the temperature. This increased efficiency can be explained by the development of a favorable environment for the easy transfer of the ions. the formation of metal ions at anode, which causes bulk, resulting in a decrease in viscosity of the aqueous medium of the wastewater. It is observed that the rate of removal of impurity increased by 29% at 293K temperature. Higher temperature of the wastewater also helps in formation of bulky floc molecules. [5,8,11]

4. Voltage: In all electrolysis processes, voltage acts as a key factor because the rate of electrolysis and flow of electrons to complete the circuit depends on it. The required time of electrolysis will be increased if the voltage gets reduced and the rate of removal of impurities will also slow down. It also shows that it will affect the rate of production of coagulant, formation of bubbles and the growth of the floc molecules.[1,2,5]
5. Material of Electrode: Material of the electrodes and its arrangements are one of the most crucial factors affecting the rate of electrolysis and the rate of removal of impurity. Material of the electrodes are commonly selected according to the objectives of the project to gain the desired results based on the efficiency of them to treat the wastewater and the cost of the plant. Aluminum and iron electrodes give best results on the field, both of them release three electrons to generate an ion[7,8]. Copper is considered as an ideal electrode, because of its tremendous capacity to remove impurity from wastewater but its efficiency in cost creates a huge problem in its application on site. It is considered as the best electrode, which gives the maximum number of free electrons for the generation of the floc[3]. Carbon is non metal but still widely used for the electrocoagulation process. As non metal, the corrosion of carbon electrodes is less than the other metal electrodes available in the market. In the case of removing COD from industrial wastewater, a combination of iron and aluminum electrodes removes 71% colors and 69% COD. [3,5,11, 14, 18]
6. Electrode material is highly important for the chemical reaction occurring in the electrolysis process. Where and where aluminum dissolves to generate Al^{+++} ions. Which is the highly active coagulant for the process of electrochemical coagulation, whereas iron electrode dissolves and generate Fe^{++} and Fe^{+++} both ions from which Fe^{++} is a weak coagulant and generates precipitate in the wastewater which needs to be filtrate afterwards[3, 16]. Aluminum electrodes are especially used for removal of color from wastewater there as iron electrodes remove COD and phenol from wastewater more effectively than aluminum electrodes. For removal of heavy metals, arsenic, phenol, nickel, a combination of iron and aluminum electrodes do the highest removal efficiency. [2, 7, 9, 16]
7. Time of operation: Time of electrocoagulation is another important factor which affects integrally on its efficiency of removal of the impurity. Reaction time is an operational parameter which can increase and reduce according to the concentration of impurity present in wastewater[1, 4]. To remove, TS, COD and BOD minimum 15 to 30 minutes is necessary to remove all impurities during the period of electrolysis. During this time, hydroxyl ions from wastewater generated by electrolytic reaction get combined to the ionized impurities to generate floc molecules to settle down. The COD removal of wastewater is directly proportional to the rate of efficiency of the process[6,17].
8. Inter Electrode Distance: In the process of electrochemical coagulation process, the distance between electrodes plays a significant role, as the distance between them reduces the rate of impurity removal decreases, to get maximum high results, electrodes should be arranged in parallel series and placed not too far from each other. In cases of increased distances between electrodes, ionic transfer of free electrons and metal ions caused hindrance because of the bubbling of the generation of hydrogen gas. [17, 19]

IV. CONCLUSION:

Electrochemical coagulation is a revolutionary process universally used as an alternative to commonly applied activated sludge process and any other methods in industrial wastewater treatment. It is a perfectly eco-friendly process and treats wastewater, generating no pollution and hazard to the environment. This process is capable of removing heavy metal, colloidal particles, organic, non organic impurities, emulsifiers, color, BOD, COD, etc. It's immensely advanced and recommended as the cheapest and cost effective method till available to treat wastewater.

Different electrode materials give different percentages of COD, BOD, turbidity, and ammonia removal, but among those copper electrodes gives the best result but the cost of copper avoided the application of it on field. While, considering the field application of electrodes, Al and Fe electrodes give best results as both releases three electrons each and under high voltage and current density Fe and indeed releases four electrons. All parameters play an important role in the functioning of the electrochemical coagulation process to get the best results in desired time. It can be successful in times of urgency and addition of coagulants can still be an additional benefit for getting results.

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