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Use of Electrocoagulation for Waste Water Treatment

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Abstract: *The electrocoagulation (EC) process is an electrochemical means of introducing coagulants and removing suspended solids, colloidal material, and metals, as well as other dissolved solids from water and wastewaters. The EC process has been successfully employed in removing pollutants, pesticides, and radionuclides. This process also removes harmful microorganisms. More often during EC operation, direct current is applied and electrode plates are sacrificed (dissolved into solution). The dissolution causes an increased metal concentration in the solution that finally precipitates as oxide precipitates. Due to improved process design and material of construction, the EC process is being widely accepted over other physicochemical processes.*

Keywords: Waste Water Treatment, Electrocoagulation, Electrolysis, COD

I. Introduction

1.1 Wastewater

Water is natural resource which is necessary for life. It is available in various sources like rivers, streams, lakes and oceans. Through the last century, fresh water has been depleted enormously due to the explosion of human population and eco-unfriendly activities. The disposal of human waste in water bodies causes severe threats to the environment which affects all kinds of living organisms. In order to save water bodies, we need to understand the sources of wastewater and its polluting components. Domestic, industrial and agricultural sectors are the three major sectors of wastewater. These wastewaters are rich in organic and inorganic contents. This wastewater can be reused, if treated suitably, by removing the different pollutants. It is necessary to first know the wastewater components so that suitable technologies can be used for water treatment before it is released back into water bodies or recycled for further use.

Untreated wastewater could contain biological, chemical, and physical pollutants. chemical or physical pollutants would include heavy metals (chromium, lead, and mercury), organic particles (hairs, food, feces, vomit, and plant material), soluble organic material (urea, drugs, and pharmaceuticals), macro-solids (sanitary napkins, dead animals or plants, condoms, diapers, and toys), emulsions (paints, adhesives, oils, and mayonnaise), and toxins (pesticides, herbicides, and poisons), among others.

Biological pollutants, on the other hand, would include bacteria (Salmonella, Campylobacter, Shigella), viruses (rotavirus, hepatitis, enterovirus), protozoa (Entamoeba sp., Cryptosporidium sp., and Giardia sp.), and helminths (roundworm, hookworm, and whipworm). Wastewater could also contain non-pathogenic organisms such as arthropods, insects, and fishes.

1.2 Effects of Wastewater

The impact of wastewater is devastating, to say the least. It adversely impacts the environment and ends up ruining the ecological balance. It’s impact on human health is equally alarming.

While it may seem fine for industrial plants or manufacturers to dispose of two inert chemicals, when those chemicals are mixed the result could be a serious pollutant to the water supply. As streams, rivers, and oceans become polluted, aquatic life can suffer as well as humans.

A. Contamination of Habitat and Water

The first and the most pronounced impact of wastewater is the fact that it ends up contaminating and eventually destroying the natural habitats. Over time, the wildlife residing in these habitats are affected as they are under the exposure of harmful chemicals borne by the water. So, wastewater doesn't just destroy habitats, but it also ends up killing the animals living there.

B. Degradation of Soil

Very often, farmers reuse and treat wastewater only to use it in their agricultural facilities. Sadly, the various methods of treating water aren't always effective, resulting in the degradation of soil. This usually happens when harmful chemicals make their way through the agricultural soil. The underlying chemicals will affect the speed and process of irrigation, causing fewer crops to yield at a significantly slower pace. These crops, when consumed by humans, can lead to a range of diseases.

C. Squalor

Wastewater is one of the worst sources and carriers of diseases. According to a report from the World Health Organization, more than 3.4 million people die each year from a waterborne disease. Besides the diseases wastewater carries, the combination of human waste, solvents, and paints create fumes that aren't only putrid but they also expose people to harmful fumes. There's a real danger when you inhale sewage gas.

D. It Contains Harmful Substances

The composition of wastewater may include heavy metals, pathogens, salts, toxic chemicals, oil and grease, solids, nutrients, sludge, acids and bases, toxic organic compound, organic and inorganic materials. This effluent poses numerous hazards for humans, animals and the environment as a whole. It can be toxic, corrosive, reactive, acidic and ignitable.

1.3 Treatment Methods

Purpose to remove the contaminants from water so that the treated water can meet the acceptable quality standards

A. Physical Treatment

- Based on exploitation of the physical properties of the contaminants
- Simplest form of treatment
- Screening
- Sedimentation
- Flotation
- Filtration

B. Chemical Treatment

- Utilize the chemical properties or of the added reagent
- Precipitation
- Coagulation
- Disinfection

C. Biological Treatment

- Biochemical reaction
- Biological filtration
- Activated sludge process

D. Combination of Physical and Chemical Treatment

- Air stripping
- Carbon adsorption

- Oxidation and reduction
- Ion exchange
- Membrane process like RO, electro dialysis

1.4 Analytical Methods

A. COD

Oxidizing bacteria of the BOD tests are replaced by a strong oxidizing agent ($K_2Cr_2O_7$) under acidic condition (FAS). A sample of the waste water containing organic matter is mixed with as excess of potassium dichromate and sulphuric acid and the mixture is heated under total reflux conditions for a period of 2 hours.

During digestion, chemically oxidisable organic material reduces a stoichiometrically equivalent amount of dichromate, the remaining dichromate is titrated with standard ferrous ammonium sulphate solution.

The amount of potassium dichromate reduced gives a measure of the amount of oxidisable organic material. The COD test does not distinguish between organic materials that are biodegradable and those that are not, and, hence, gives a measure of the total oxidisable organic material in the sample. Due to this, the COD test results are higher than those of BOD tests carried out on the same sample.

B. TOC

TOC test is based on the oxidation of the carbon of the organic matter to carbon dioxide, which is measured by a non-dispersive infrared analyzer. Alternatively, the carbon dioxide can be reduced to methane, which is then measured by flame ionization detector.

In this test, a few micro-litres (5 to 10μl) of the aqueous sample are injected into a combustion tube containing a catalyst and heated at 900 in a constant flow of air. Water is vaporized and the carbonaceous matter is oxidized to CO_2 and steam.

Outside the combustion tube, the steam is condensed and removed. CO_2 is swept in to a non- dispersive infrared analyzer, which measures the amount of CO_2. The concentration of CO_2 is directly proportional to the concentration of total carbon present in the original sample and it include both organic and inorganic carbon. Inorganic carbon can be measured separately using acid catalyst at 150, which is below the temperature at which organic matter is oxidized. Organic carbon content can then be obtained by subtracting the inorganic carbon from the total result.

C. Electrocoagulation

Basically, electrocoagulation means solidifying, or semi-solidifying, a solution of liquid and suspended solids by passing an electrical current through it. The current creates an extreme temperature, which is concentrated in the liquid, coagulating it.

History

Electrocoagulation has a long history, the first plant was built in London in1889 for the treatment of sewage where electrocoagulation treatment was employed via mixing the domestic wastewater with saline water (Kabdash et al.). The principle of electrocoagulation was first patented in 1906 by A.Edietrich and were used to treat bilge water from ships (Ahmed Samir Naje et al.). In 1909, J.T. Harries received a patent for wastewater treatment by electrolysis using sacrificial aluminum and iron anodes in the United States

Process

Electrocoagulation is an electrochemical technique for treating wastewater using electricity instead of expensive chemical reagents. An electrocoagulation process has been attracted a great attention on treatment of industrial wastewater because of the versatility and environmental compatibility. This technique has several advantages as compared to conventional methods in terms of use of simple equipment, ease of operation, less treatment time, reduction or absence of chemicals addition. Moreover, an electrocoagulation process provides rapid sedimentation of electro generated flocs and a less amount of sludge production. Electrocoagulation has the advantage of removing the smallest colloidal particles compared with traditional flocculation coagulation, such charged particles have a greater probability of being coagulated and destabilized because of the electric field that sets them in motion.

The system uses electro coagulation enhanced filtration technique to remove total suspended solids, heavy metals, emulsified oil, heavy bacteria and other contaminants from water this system is suited for applications such as oil and gas produced water, mine process water, industrial storm water, waste water and construction storm water. The process consists of three key steps electrocoagulation, solid separation and filtration depending on the influent water characteristics. Prior to treatment water is collected in source for processing through the system. A power supply, the electrocoagulation cell housing and electrocoagulation electrodes was water passes through the EC cell multiple reactions take place simultaneously first on the surface on the anode a metal ion is driven into the water. Second on the surface of the cathode water is hydrolyzed into hydrogen gas and hydroxide groups and the third the electrons free flow from the cathode to the anode which destabilizes the surface charges on suspended solids and emulsified oils as the reaction begins metal ions complex with hydroxyl groups and form large flocks that include metals and other contaminants. Suspended solids and emulsified oils are readily entrained within the flock because of the disabled eyes surface charges. Finally the hydrogen gas bubbles help to separate and lift the blocks these cooperative reactions are what make the easy process so effective and efficient. As water leads the EC system it enters the series settling tank, here the effect of the electrocoagulation reaction are further accelerated. The flocks generated during the electrocoagulation process begin to react with each other and form larger flocks that can float or settle out of the water column. Finally water enters the last compartments of the settling tanks and is directed to the filtration system. As water enters the media filtration system it slows down through a bed of glass media, larger particles are trapped on the top of the media bed as effluent water exits the filter at the bottom. The media filter is periodically back washed to the source to reduce operator maintenance if enhanced filtration is required, ultra filtration technology can be utilized in place of media filtration to provide 10x improvement in filtration.

II. Experimental Setup

Electrolysis is a process in which oxidation and reduction reactions take place when electric current is applied to an electrolytic solution. Electrocoagulation is based on dissolution of the electrode material used as an anode. This so called "sacrificial anode" produces metals ions which act as coagulant agents in the aqueous solution. At its simplest, an electrocoagulation system consists of an anode and a cathode made of metal plates, both submerged in the aqueous solution being treated. The electrodes are usually made of aluminum, iron or stainless steel, because these metals are cheap, readily available, proven effective and non-toxic. Thus they have been adopted as the main electrode materials used in electrocoagulation system. An electrocoagulation system may contain either one or multiple anode-cathode pairs and may be connected in either a monopolar or a bipolar mode. Generally, three main processes occur serially during electrocoagulation:

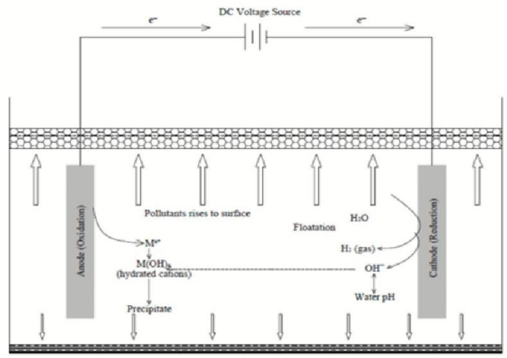
1. Electrolytic reactions at electrode surfaces,
2. Formation of coagulants in aqueous phase,
3. Adsorption of soluble or colloidal pollutants on coagulants, and removal by sedimentation or floatation,

Electrocoagulation is the technique to creates a mixture of the suspended, dissolved or emulsified particles in aqueous medium using electrical current causing production of metal ions at the expense of sacrificing electrodes (anode) and hydroxyl ions as a result of water splitting. Metal hydroxides are produced as a result of EC and acts as coagulant/flocculant for the suspended solids to convert them into flocs of enough density to be sediment under gravity. The electrical current provides the electromotive force to drive the chemical reactions to produce metal hydroxides. Dissociation of water by EC generate hydroxide ions which are known as one of the most reactive aqueous radical species and this radical has the ability to oxidize organic compounds because of its high affinity value. The generated hydroxides or polyhydroxides have strong attractions towards dispersed particles as well as counter ions to cause coagulation. The gases evolved at the electrodes are also helpful to remove the suspended solids in upward direction Following reactions are carried out at different electrodes

Anode: $Me - 3e \rightarrow Me^{3+}$ (Me – MOC of electrode) Alkaline condition: $Me^{3+} + 3OH^- \rightarrow Me(OH)_3$

Acidic condition: $Me^{3+} + 3H_2O \rightarrow Me(OH)_3 + 3H^+$ $2H_2O - 4e \rightarrow O_2 + 4H^+$

Cathode: $2H_2O + 2e \rightarrow H_2 + OH^-$



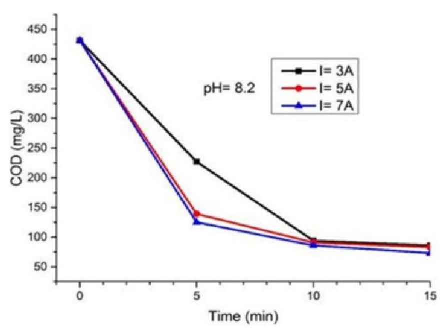
2.1 Effect of Parameters on Electrocoagulation

A. Electrode Arrangement

In the EC process, electrode material and type of electrode connection (monopolar series and bipolar parallel) play a major role in the cost analysis. In the EC process, electrode materials define the type of electrochemical reaction that will occur in the EC processes. Al or Fe plate can be used as the anode and inert material such as steel, stainless steel, platinum coated titanium etc. can be used as cathode. In few cases, similar material is used for the anode and cathode. An EC system can include either one or multiple anode-cathode pairs and may be connected in either a monopolar or a bipolar mode.

B. Effect of Electrolysis Time

Electrolysis time also has significant effect on pollutant removal efficiency of electrochemical coagulation method. It defines the amount of coagulant formed and cost of the process. An increase in electrolysis time up to the optimum level increases the pollutant removal efficiency but it does not increase beyond optimum level. The actual fact is that at constant current density coagulant formation increases with an increase in electrolysis time which leads to increased removal efficiency.

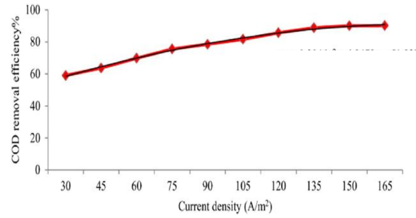


C. Inter Electrode Distance

In the EC process, inter-electrode distance plays an important role on EC potential because the electrostatic field depends on the distance between the anode and the cathode. An optimum distance between electrodes provides maximum pollutant removal efficiency. Minimum inter-electrode distance provides low pollutant removal efficiency. The more the inter electrode distance the slower the movement of the generated ions.

D. Effect of Current Density

One of the most significant operational parameters in electrocoagulation process is current density i.e. current per area of the electrode. According to the literature a wide range of current densities applied between 1-100 mA/cm2 depending on the case study. The separation processes which involves flotation cells or large settling tanks requires high current density.



E. Effect of pH

The pH of the solution determines the conductivity of the solution, the electrode dissolution, and formation of hydroxides in the electrocoagulation process. Various empirical studies show that at high current efficiency using aluminum electrodes occurs at either acidic or alkaline condition than at neutral conditions. The nature of the pollutants determines the EC efficiency, however near pH 7 pollutant removal was found best.

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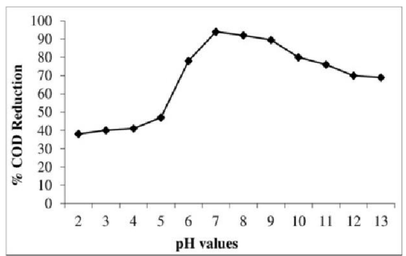
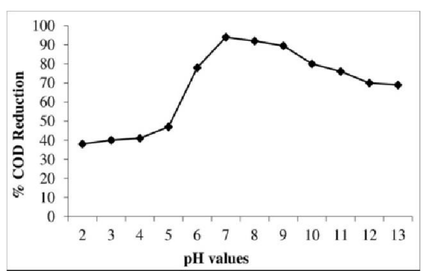


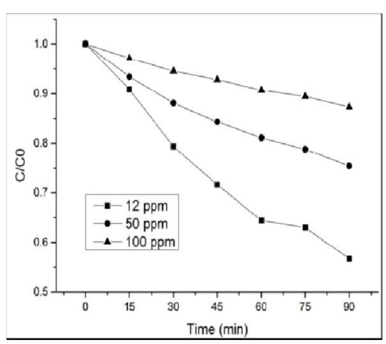
F. Effect of Temperature

Temperature significantly influences the pollutant removal efficiency by using EC process. Temperature can have a positive or negative effect on electrochemical coagulation process, therefore in an EC process which is carried out at ambient temperature. The increase in temperature decreases the pollutant removal efficiency due to the decrease in metal hydroxide formation



G. Effect of Initial Pollutant Concentration

The initial pollutant concentration is also considered as one of the effective parameters in pollutant removal by electrochemical coagulation. According to literature an increase in initial pollutant concentration (by keeping other parameters constant) reduces the pollutant removal efficiency of EC process. This is due to the circumstance that at fixed operating parameter the amount of coagulant generated will be fixed which is insufficient to form floc with high pollutant concentration.



2.2 Benefits of Electrocoagulation Process

1. EC involves artless equipment and is easy to work.
2. EC requires low investment, maintenance, energy, and treatment costs.
3. EC treated wastewater furnish pleasant, odorless, clear and colorless water.
4. EC is a low sludge producing process. EC generated Sludge is mainly composed of metallic oxides/hydroxides.
5. There are no additional chemicals required in EC process.
6. Flocs formed by EC are similar to chemical flocs. EC flocs are much larger in size, enclose less bound water and are acid-resistant and more firm.
7. The reuse of EC produced effluent contributes to a lesser water recovery cost because it contains a lesser amount of total dissolved solids (TDS) as related with chemical treatments.
8. The gas bubbles generated at the time of electrolysis can proceeds the pollutants to the top of solution from where it can be separated without difficulty.
9. EC provides greater efficient pH range and pH neutralization result and can be suitably used with other renewable sources of energy.

2.2 Disadvantages of Electrocoagulation Process

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

III. Conclusion

This paper has given a review of the successfully electrocoagulation application, for the removal of specific problematic factors (likewise COD). The interest is double: economic and environmental.

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