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Efficient Removal of Chlorinated Toxic Pollutants from Industry Wastewater Using Electrochemical Processes

Mukesh Kumar

Guest Faculty, Department of Chemistry, Maltidhari College Naubatpur, Patliputra, University

ABSTRACT

Due to their durability and bio accumulative capacity, the ever-increasing discharge of chlorinated hazardous contaminants from industrial sources presents a major environmental concern. An integrated electrochemical treatment procedure followed by improved post-treatment techniques is the subject of this work, which aims to efficiently remove chlorinated pesticide industrial wastewater (PIW). Using conventional physicochemical techniques, we analyzed wastewater samples taken from an industrial location. The electrochemical oxidation process was improved using a range of pH settings and reaction periods with a variety of electrode materials (Fe, SS, Ti, and Al) as part of the core treatment. The electrochemical system was observed for pollutants degrading every ten minutes and powered by a controlled direct current source (up to 84V). The treated effluents were subjected to further processing steps including activated carbon filtration, photochemical oxidation, and son chemical treatment (33 kHz ultrasonic bath, 1255 W) in order to improve mineralization and finish breaking down the remaining organics. Chlorinated pollutants were degraded more efficiently using the integrated strategy. The calculation of removal efficiencies using APHA standards shows that this combined treatment technique has the ability to effectively remediate industrial effluents contaminated with persistent organic pollutants.

Keywords: Water Reuse, Recycling, Environmental Engineering, Wastewater Treatment, Electrocoagulation.

I.INTRODUCTION

Industrialization has made huge strides in improving the efficiency of production and boosting the economy, but it has also done a lot to damage the environment, especially through the pollution of Industrial Wastewater. Chlorinated organic toxins are one of the most dangerous poisonous chemicals that businesses release into the environment and into people's bodies. Some examples of these chemicals are trichloroethylene, dichlorobenzene, chlorophenols, and polychlorinated biphenyls (PCBs). They are very stable, stay in the environment for a long time, and don't break down naturally. Most of the time, they come from industries like petrochemicals, fabrics, agrochemicals, wood and paper, and medicines. When chlorine toxins get into water, they can cause cancer, mutations, and problems with hormones. Because of this, they need to be removed completely and effectively before wastewater is released or used again. Physical, chemical, and biological processes used in traditional treatment often aren't able to break down these tough substances completely, which results in only partial breakdown and the production of harmful leftovers. Because of this, the look for technologies that are more effective, long-lasting, and scalable has grown over the last few decades. In this situation, electrochemical treatment technologies like electro-oxidation and electrocoagulation are getting more and more attention because they work well, are safe for the environment, and can be used in a variety of situations. In electrochemical processes, electricity is used to power redox reactions on the electrodes' surfaces. These reactions change complex organic pollution into less dangerous substances like carbon dioxide, water, and mineral salts. One of the best things about electrochemical oxidation is that it can make strong oxidants like hydroxyl radicals (•OH), ozone, and active chlorine species without adding any other chemicals. These oxidants can break even the most stable C-Cl bonds in chlorinated chemicals, which can lead to mineralization or a lot of purification. Electrocoagulation, on the other hand, creates coagulant species on-site, usually iron or aluminum hydroxides, which remove pollution by clumping together and sinking to the bottom. Combining the two methods makes the removal of chlorine pollutants more effective while also lowering the amount of sludge made and the complexity of the process.

The conditions for how electrical treatment works are also very flexible. You can fine-tune things like the current density, the material of the electrodes, the makeup of the liquid, and the pH to get the best decay rates and energy use. In addition, the process has become much more selective, durable, and active thanks to the creation of new anode materials. Because they are chemically stable and have a high oxygen over potential, electrodes like boron-doped diamond (BDD), mixed metal oxides (MMO), and titanium-based alloys can break down chlorinated organics more quickly. Also, new types of reactors have been made, like flow-through cells, packed-bed reactors, and three-dimensional electrode systems, to get around problems with mass transfer and make the process bigger for use in industry. These new developments make it more likely that electrochemical systems can be used in a wide range of businesses to treat wastewater on-site. Even though these things look good, there are still problems with how energy-efficient, cheap, and likely it is that halogenated byproducts will form during partial oxidation. Studies show that if the treatment is not carefully tuned, chlorinated chemicals that don't break down all the way can turn into more dangerous intermediates like chlorinated acetic acids and chloroform. A lot of study has been done on how to combine electrochemical processes with methods that work well together, like biological treatment, membrane filtering, advanced oxidation processes (AOPs), and adsorption. It has been shown that hybrid systems not only remove pollutants more effectively, but they also use less energy and make the electrochemical system last longer. Also, adding green energy sources like sun and wind to electrolytic reactors is being looked into as a way to make these treatment methods even more environmentally friendly and long-lasting.

The focus on cycle economies and strict environmental laws around the world have made people even more likely to use modern wastewater treatment systems that make sure that waste water is safely released and water is reused. Electrochemical methods are a good way to reach these goals, especially for businesses that make small to medium amounts of wastewater with a wide range of contaminants. As pollution and a lack of clean water continue to be problems around the world, it is very important to have cleaning methods that are effective, autonomous, and strong. Electrochemical technologies are at the heart of this change. They promise to get rid of harmful pollutants like chlorinated organics quickly and effectively, and they also offer a long-term solution for managing industrial water. Because of these things, the study's main goal is to look into how electrochemical processes work, how well they work, their pros and cons, and how they treat chlorine harmful pollutants from Industrial Wastewater. The study's goal is to give a full picture of the present and future of electrochemical technologies by looking at recent progress in electrode creation, reactor design, and mixed treatment systems. It also stresses the importance of improving and standardizing operating factors to make sure safe and effective breakdown of pollutants, reducing the production of byproducts, and enabling large-scale use in a wide range of industrial settings. The results will give us important information for making production better and for making sure that commercial wastewater cleaning methods last.

II.LITERATURE REVIEW

Ahmed, Menatalla et al., (2022) New improvements in the ways that wastewater is treated have made it possible to get rid of many harmful toxins very efficiently. Even so, some methods work better than others at getting rid of certain contaminants. We went over all the new developments in getting rid of harmful pollutants from Industrial Wastewater using Fenton-based processes, hybrid systems like electrically-enhanced membrane bioreactors (eMBRs) and an integrated eMBR-adsorption system, as well as membrane technologies and adsorption. The most important parts of each technology are compared, and new changes to traditional treatment methods and the limits of modern treatment systems are pointed out. It's also talked about how to get new toxins out of wastewater, like medicines.

P.V., Nidheesh et al., (2020) It is hard to treat mixed Industrial Wastewater because it is so complicated. This paper looks closely at how electrochemistry is used to treat mixed Industrial Wastewater. Specifically, it looks at electrocoagulation and indirect electrochemical oxidation processes by studying how to remove color and COD. Both methods work better when the pH of the wastewater is low. It was found that a monopolar connection was better at getting rid of COD and color in wastewater than a bipolar connection. The monopolar connection got rid of up to 55% of COD and 56% of color. The bipolar connection, on the other hand, got rid of 43% of COD and 48% of color at a pH of 6.5 and a voltage of 1.5 V over the course of 1 hour of electrolysis. The COD and color removal rates of the indirect electrochemical oxidation process with graphite electrodes were 55% and 99.8%, respectively, after 1 hour of electrolysis at pH 7.7, 4 V, and 1 g L{^{2} of NaCl. This study also shows how important electrolytes are in the indirect electrochemical oxidation process, since adding sodium chloride from the outside made both COD removal and color removal much more effective.

Gracepavithra, Kirubanandam et al., (2020) more and more people are interested in new pollutants, and environmental scientists have been looking at the most cutting edge solutions for these pollutants. The main focus of this work is on using a specially built three-phase three-dimensional electrode reactor to remove sulphonamide from water. Batch tests have been used to study things like pH, particle electrode concentration, starting content of sulphonamide, and the applied voltage. At 12 V, pH 3, and 15 g of particle anode in an electrochemical cell, sulphonamide was taken away in 60 min. After gathering information, it was decided that the electrochemical generator works better when the amount of pollution goes down and the voltage is set at 12 V. We used SEM-EDS and FTIR to learn more about SASP, which stands for Sulphuric acid-activated Strychnos potatorum particle electrodes. This reactor followed the pseudo-second-order ($R^2 > 0.96$) and Langmuir–Hinshelwood processes ($R^2 = 0.9504$) for getting rid of sulphonamide. This newly created three-dimensional reactor is a good way to get rid of all the harmful pollutants in wastewater, and it can be used instead of the current method.

Damaraju, Madhuri et al., (2017) Manufacturing sectors make new chemicals every day, and these chemicals end up in wastewater from homes and businesses. Because of this, garbage is changing into something more complicated. The new pollutants get past the systems that clean the water and end up in the bodies of water that receive them. India's wastewater treatment plants still report discharge data in terms of biological oxygen demand (BOD) and chemical oxygen demand (COD) at the ppm level. However, at the ppb level, these new pollutants, many of which don't break down, can be harmful and even cause cancer. So, it is very important to find other ways to get rid of these dangerous chemicals in wastewater or to improve the ones that are already in place. In this study, the electrocoagulation process' ability to remove carbon that doesn't dissolve was tested in a lab setting using real wastewater. The wastewater came from a sewage treatment plant that treats wastewater from homes as well as wastewater from chemical, bulk drug, and related businesses. The wastewater sample in this study was tested for total dissolved solids (TDS) and total organic carbon (TOC). It was then treated organically with aerobic bacteria in a respirometer. The sample was checked for TDS and TOC and then put in a lab-scale electrocoagulation setup after the oxygen uptake graph reached a peak, which meant that the biological process had stopped. Iron and aluminum electrodes were used in the study, and the system's ability to get rid of stubborn carbon and TDS was looked at in terms of response time. The results showed that electrocoagulation might be a good way to get rid of carbon that is hard to dissolve in wastewaters after biological treatment.

Feng, Yujie et al., (2016) this article talks about new research in environmental electrochemistry and how it might help make the environment better for uses in wastewater cleaning. Several processes, such as electrochemical oxidation, electrochemical reduction, and electrocoagulation, electrocoagulation/flotation, electro dialysis, and electrochemical advanced oxidation processes, can get rid of or change most environmental pollutants into materials that are not harmful. There are specific examples of how the different processes can be used to remove pollutants and reuse wastewater. There are also calls for more study and improvements so that these electrochemical processes can be used in the real world.

Pulkka, Susanna et al., (2014) it has been shown that electrochemical processes like electrocoagulation, electro-oxidation, and electro reduction can remove different types of anionic pollution from water and garbage. To get an adaptable environment, electrochemical processes can either directly change pollutants or change the redox state of the environmental material. This study is about how electrocoagulation, electro-oxidation, and electro reduction can be used to get rid of different anions from water. These anions include cyanide, fluoride, nitrate, nitrite, phosphate, and sulfate. The best conditions for treating the anions that were studied in each electrochemical method are talked about. An outline of the electrochemical methods used to get rid of anions is given, along with examples of their use and results from experiments. Based on the research that was looked at, it is clear that these ways have a lot of promise for getting rid of anionic pollutants in water. But the hardest thing about this area of study is figuring out how to use these methods in the real world on a business level so that pollution control is better.

III.MATERIALS AND METHODS

Collection of Samples

The industrial location was used to obtain the sample of industrial wastewater. According to the "Standard Methods for Examination of Water and Wastewater," the physicochemical analysis of the wastewater samples was conducted.

- Electrochemical treatment of chloro Industrial Wastewater

Each experiment was done three times to assess the treatment effectiveness of the chloropesticide wastewater using the electrochemical device. Reaction time, pH, electrode material (Fe, SS, Ti, and Al), and other factors were all taken into account during the optimization studies.

A 0.1N/1.0N HCl or 0.1N/1.0N NaOH solution was used to alter the pH. An 84V DC power supply unit (APLAB regulated DC power supply L6403) was used to connect the working electrodes. In order to determine the amount of residual metal, samples were taken at 10-minute intervals. To further remove any leftover organic matter from Industrial Wastewater, carbon filtration, photocatalysis, and sonication were used to mineralize the wastewater. Additional treatment of this EC effluent was carried out using sonication and photo catalysis.

- **Sonochemical reactor**

A 3.3 L ultrasonic bath (Model No. EN-30-US, Enertech Electronics Pvt. Ltd., Bombay, India) equipped with a high-frequency Mosfet-based electronic ultrasound generator made up the experimental setup.

Operating at a frequency of 33 kHz in either continuous or pulse mode (five seconds on and one second off), the ultrasonic bath consists of two piezo-ceramic transducers integrated into the base of a stainless-steel tank. The calorimetric technique was used to compute the power output of the ultrasonicator, which was 1255 W.

- **Photo chemical reactor set-up**

A cylindrical photo-reactor with a capacity of 1 L was used for the tests. A quartz tube was used to cover the reactor, preventing it from coming into direct touch with the aqueous solution that flowed via an annulus at the vessel's axis between its inside and outside surfaces.

Carbon filtration

A bed of activated carbon was used in the carbon filtering process to eliminate impurities and pollutants. Activated charcoal weighing 3 grams and a 150 cc sample were also included. An experiment was conducted by dispersing 150 ml of charcoal in a shaking incubator for 30 minutes.

Removal percentage calculation

We used the APHA standard procedures to quantify the decrease of pollutants, and we used equation (1) to compute the % elimination. Where C0 represents the starting concentration and Ct represents the ending concentration.

IV.RESULTS AND DISCUSSION

Effect of The Electrochemical Method For The Treatment Of Chloropesticide Wastewater

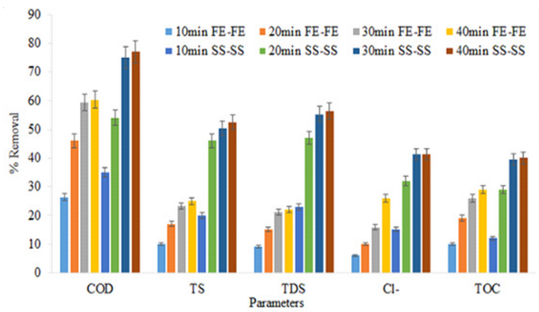

Figure 1: Effect of electrochemical reaction time on Industrial Wastewater treatment.

Using Fe-Fe and SS-SS electrodes, researchers have examined the reaction time for treating industrial wastewater at various reaction time intervals ranging from 10 to 40 minutes. As shown in Figure 3, the maximal percentages of COD, TS, TDS, Cl-, and TOC elimination were 60%, 25%, 22%, 26%, and 29% for the Fe-Fe electrode, and 77%, 52%, 56%, 41%, and 40% for the SS-SS electrode, respectively, after 40 minutes. It is possible that the passivation layer on the electrode material is to blame for the fact that the percentage removal rate has not grown to a significant range from 30 to 40 minutes (figure 1).

Effect of Electrode Material On Industrial Wastewater Treatment

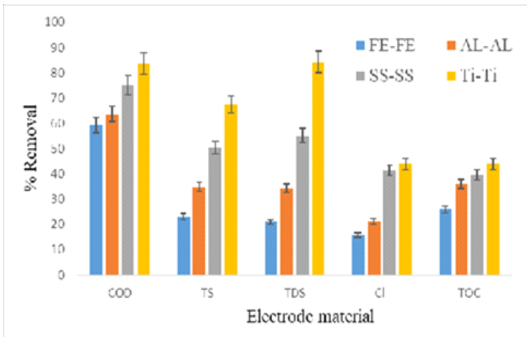

Figure 2: Effect of electrode material on Industrial Wastewater treatment.

To determine the coagulant affinity, it is necessary to know the electrode material. Iron, aluminum, stainless steel, and titanium have all been extensively evaluated for their efficacy. Therefore, our research made use of these materials. The impact of the electrode material on the treatment of industrial wastewater is shown in Figure 4. Ti-Ti electrodes have been shown to be the most effective at removing metals. Consequently, these electrodes were thought to be the most suitable option. The greatest percentages of COD, TS, TDS, Cl-, and TOC elimination over the 30-minute reaction time using Ti-Ti electrodes were 83%, 67%, 84%, 43%, and 43%, respectively (figure 2). The efficient production of OH radicals released from the surface of the Ti might be the cause of this. Compared to Ti electrodes, the amount of OH radicals released by iron and aluminum electrodes is smaller because these materials sacrifice and release coagulants. According to this research, Ti is an effective material for treating industrial wastewater that contains organic compounds.

Effect Of Ph On Industrial Wastewater Treatment.

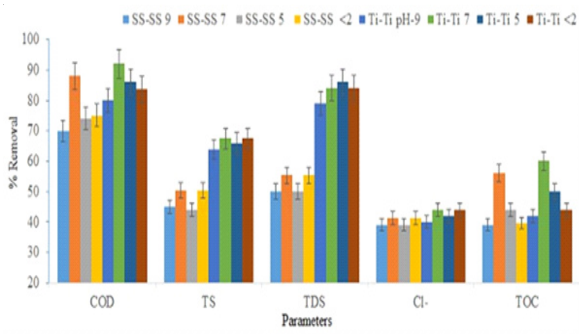

Figure 3: Effect of pH on Industrial Wastewater treatment

According to the results of this investigation, the removal effectiveness was highest under neutral circumstances (figure 3). When using Ti-Ti electrodes at pH 7, the maximum removal of COD, TS, TDS, Cl-, and TOC was 92%, 67%, 84%, 43%, and 60%, respectively. When using SS-SS, the maximum removal was 88%, 50%, 55%, 41%, and 56%.

Since chemical addition was required for sample neutralization, additional cutting-edge procedures including sonication and light catalysis were investigated as potential alternatives.

Effect Of Aop (Ultra Sonication, Photo Catalysis) On Industrial Wastewater

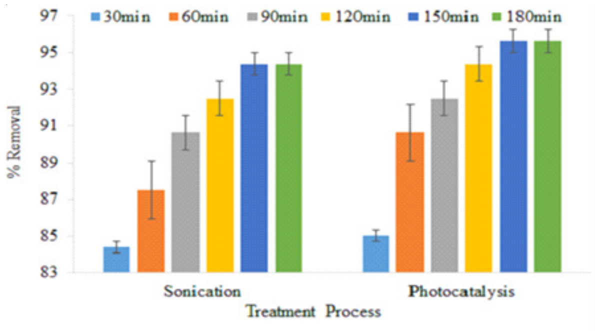

Figure 4: Effect of AOP (Ultra Sonication, Photo catalysis) on Industrial Wastewater

Figure 4 shows that the Industrial Wastewater was effectively treated using sonochemical and photochemical degradations. The elimination of COD was enhanced from 83% to 95% using the photochemical method and from 83% to 94% using the sonochemical approach. The photochemical hydroxyl radical may be to blame for this, as it outperforms the sonochemical method.

V.CONCLUSION

The application of electrochemical processes for the efficient removal of chlorinated toxic pollutants from Industrial Wastewater presents a promising alternative to conventional treatment methods. Electrochemical oxidation and electrocoagulation have demonstrated high effectiveness in degrading persistent chlorinated compounds without generating secondary pollutants. The performance of these systems largely depends on the choice of electrode materials, operating conditions, and wastewater composition. Notably, advanced electrodes such as boron-doped diamond and titanium-based oxides have significantly improved pollutant degradation rates and energy efficiency. Moreover, electrochemical processes are highly adaptable and can be easily integrated into existing treatment plants, making them suitable for decentralized and on-site applications. Their eco-friendly nature, minimal chemical use, and ability to target a broad spectrum of contaminants enhance their appeal in Industrial Wastewater treatment. Continued innovation in reactor design, process modeling, and renewable energy integration is expected to further lower operational costs and carbon footprints. Overall, electrochemical technologies offer a sustainable, scalable, and effective approach to addressing the growing challenge of chlorinated pollutant removal in industrial effluents.

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