Electrochemical Treatment for Municipal Wastewater: Parametric Optimization Through Response Surface Methodology

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Abstract*—. Electrochemical treatment process is one of the efficient techniques for municipal wastewater treatment. Central Composite Design (CCD) under Response Surface Methodology (RSM) is utilized to optimize the process variable such as pH: (3→11), Time: (20→100 min) and Electrolyte Concentration: (0.03→0.07 mol/min) during treatment of municipal wastewater using electrochemical treatment. The study is focused on the removal of chemical oxygen demand (COD) from municipal wastewater. CCD predicted maximum COD removal efficiency is observed 70.01 % at optimum operating conditions like pH: 6.83, Time: 74.8 min and electrolyte concentration: 0.05 mol/min.

Keywords: Municipal wastewater, Chemical oxygen demand Electrocoagulation.

I. INTRODUCTION

India's urban centers are bursting at the seams, leading to a surge in wastewater generation. Homes, industries, and businesses pump out massive amounts of used water, creating a complex problem for public health and the environment. This "grey tide" carries a mix of pollutants that, if left untreated, can wreak havoc. The numbers are staggering. As of 2019, India gushes out over 61,998 million Liters of wastewater daily but can only treat a fraction (23,277 MLD) – leaving a massive, untreated gap (1). This gap translates to trouble: polluted water bodies, damaged ecosystems, and the potential spread of waterborne diseases. A NITI Aayog report paints a grim picture: only 37% of urban sewage gets treated, contaminating rivers, lakes, and groundwater. Smaller towns, lacking proper infrastructure, face the brunt of this neglect, with their water quality suffering the most. But India isn't sitting idle. Recognizing the urgency, the government has launched initiatives like Namami Gange, which aims to clean the iconic Ganges River by tackling various pollution sources, including municipal wastewater. Swachh Bharat Abhiyan, the Clean India Mission, also tackles wastewater woes, aiming to improve sanitation infrastructure and treatment facilities across the country, ultimately aiming for "Open Defecation Free" status. In essence, India is grappling with a complex wastewater management challenge. Its rapidly growing cities produce vast amounts of untreated sewage, public health and the environment. However, initiatives like Namami Gange and Swachh Bharat Abhiyan offer hope, aiming to turn the tide and ensure cleaner water for future generations (2). Municipal wastewater is a complex mixture whose composition is intricately influenced by several factors, including geographical location, population density, and industrial. activities (3). Among its key constituents, the organic component, comprising proteins, carbohydrates, and fats derived from human waste, food remnants, and household substances,

plays a pivotal role in contributing to both biological and chemical oxygen demand. Nitrogen and phosphorus, originating from sources like human waste, detergents, and agricultural runoff, constitute the nutrient content in wastewater (4). Elevated levels of these nutrients pose the risk of eutrophication, potentially leading to algal blooms and oxygen depletion in water bodies (5). Pathogenic microorganisms, including bacteria, viruses, and parasites entering wastewater through human and animal faces, underscore the necessity for effective treatment to prevent the spread of waterborne diseases (6). Municipal wastewater also harbours a diverse array of chemicals from industrial discharges and household products, encompassing pharmaceuticals, personal care items, and cleaning agents. Furthermore, suspended particulates such as grit, debris, and organic matter necessitate physical treatment processes for removal. Lastly, the inorganic salt and mineral content in wastewater, originating from household water usage and industrial discharges, further contributes to its intricate nature (7). Understanding these diverse components is vital for implementing effective wastewater treatment strategies tailored to specific environmental and human contexts. The resolution to this challenge lies in the advancement of sanitation technologies aimed at reclaiming nutrients from municipal wastewater. By repurposing these nutrients for irrigating agricultural crops, we can address issues related to water shortages, nutrient exhaustion, and waste management. Electrocoagulation (EC) has emerged as a noteworthy and effective alternative in the treatment of domestic wastewater, gaining prominence over the last few decades. This method utilizes the application of an electric current to destabilize and coagulate suspended particles and pollutants in wastewater, presenting a sustainable approach to address various water quality challenges. The versatility, high efficiency, and environmental friendliness of the electrocoagulation process have positioned it as a promising technology for the removal of diverse contaminants. In the past decades, electrocoagulation has demonstrated its effectiveness in treating different types of wastewater. Notably, it has proven successful in the removal of contaminants such as lignin, phenol, heavy metal ions, and anionic dyes (8). The process involves the introduction of metal cations, usually derived from sacrificial anodes, into the wastewater. Under the influence of an electric current, these metal cations neutralize charged particles, leading to the formation of flocs that can be easily separated from the water. One of the key advantages of electrocoagulation is its ability to address a wide range of water quality issues. It has been particularly successful in the removal of organic substances like lignin and phenol, which are commonly found in domestic wastewater. Additionally, the process has shown efficacy in treating wastewater containing heavy metal ions and anionic dyes, showcasing its versatility in handling diverse contaminants. The high efficiency of electrocoagulation is underscored by its ability to achieve substantial reductions in various wastewater parameters. Suspended solids (SS), total dissolved solids (TDS), chemical oxygen demand (COD), and biological oxygen demand (BOD) are significantly reduced through electrocoagulation processes. This contributes to improved water quality and aligns with environmental standards for discharged effluents (9). One primary objective of electrocoagulation is its elimination of the need for chemical additives, except for potential sodium chloride (NaCl) supplementation, rendering the EC process an environmentally friendly or 'green technology.' Essentially, the only 'chemical' involved is the 'electron,' mitigating the risk of secondary pollution. Moreover, the versatile nature of the EC process extends to enhancing both groundwater and surface water in various locations. This versatility translates to ease of application, diminished sludge generation, and the absence of a requirement for additional chemicals. The EC process has demonstrated successful applications in addressing diverse water treatment challenges (10). The electrochemical treatment process combines coagulation, adsorption, absorption, precipitation, and flotation processes, with a focus on electrocoagulation for wastewater pollutant removal. This involves oxidation, flocculation, and flotation, with the addition of chloride salt leading to chlorine gas formation for disinfection. Electrochemical technologies, like microbial fuel cells (MFCs), are explored for energy extraction from organic pollutants in wastewater, generating usable forms like electrical power and chemicals (e.g., hydrogen peroxide, methane). Advanced anode materials, such as antimony-doped tin oxide and lead dioxide, enhance oxidation efficiency.

II. Materials And Method

A. Material

The electrochemical consists of a power supply, Cathode is made up of iron plate and Anode is Aluminum. Size would be the same 1 mm thickness with sheet area is 19 cm^2. The photoelectrochemical cell is made up of acrylic glass having dimensions 15 cm length, 10 cm width, and 12 cm height. One magnetic stirrer was also utilized in the experiment.

B. Sampling and Characterization

The municipal waste sample utilized in the investigation was obtained from the local sewage system. The chemical oxygen demand (COD) and pH of this municipal waste sample were assessed. A freezer was utilized to store the municipal waste effluent. Prior to commencing the experiments, the samples were permitted to equilibrate to room temperature and the pH was adjusted accordingly.

C. Methodology

The use of a magnetic stirrer significantly enhances the performance of electrocoagulation by promoting uniform mixing, facilitating mass transfer, aiding floc formation, and preventing electrode fouling. Electrocoagulation utilizes aluminum and iron electrodes to purify water by inducing metal ions to form flocs, effectively trapping impurities. The process begins with submerging sacrificial electrodes into the municipal wastewater and applying a direct current (DC) voltage, prompting the release of metal ions. These ions trigger chemical reactions, leading to the creation of insoluble hydroxide precipitates, known as flocs, which efficiently capture suspended particles, emulsions, and dissolved pollutants present in the water. Maintaining optimal (3-6) pH levels and current densities is critical to enhance treatment efficiency and minimize electrode corrosion. Continuous agitation within the reactor ensures uniform dispersion of metal ions, fostering floc development. Once flocs have sufficiently grown, the electrocoagulation process is stopped, allowing the flocs to settle. Supplementary treatments like pH adjustment or additional filtration may be employed to further refine water quality. Regular upkeep of the electrodes and monitoring of system performance are essential for sustained effectiveness. Proper disposal of any resulting waste or byproducts is necessary to adhere to environmental regulations. By following these steps, electrocoagulation using aluminum and iron rods provides reliable and efficient water treatment, effectively addressing various contaminants to meet quality standards shown in figure 1.

Anode: $2Al(s) + 6OH^{-}(aq) \rightarrow 2Al(OH)_3(s) + 6e^{-}$

Cathode: $2Fe^{2+}(aq) + 2e^{-} \rightarrow 2Fe(s)$

Overall: $2Al(s) + 6OH^{-}(aq) + 2Fe^{2+}(aq) \rightarrow 2Al(OH)_3(s) + 2Fe(s)$

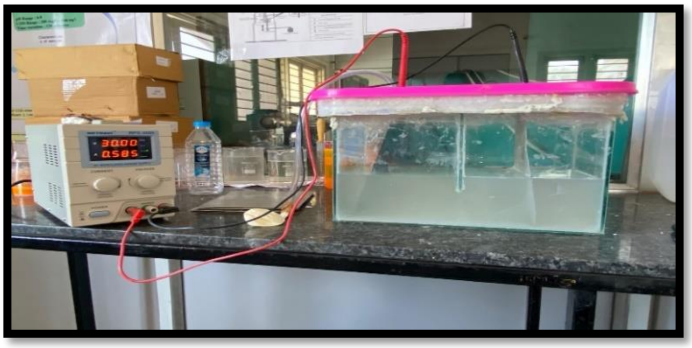


Figure 1 Electrochemical Treatment

D. Experimental Design Using CCD tool for electrochemical Treatment of Municipal wastewater.

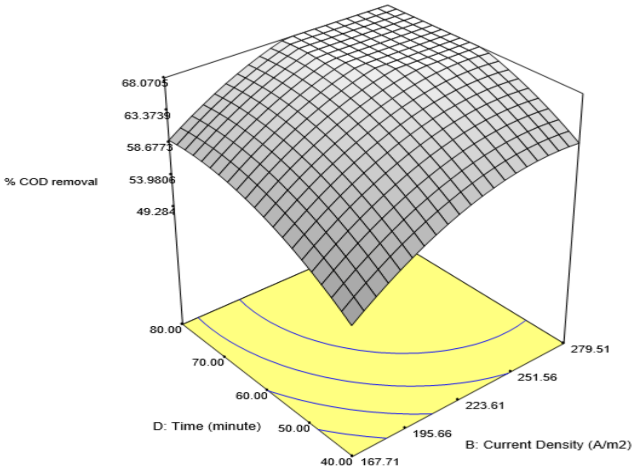
The provided table 1 presents experimental data or simulation results pertaining to a study involving four key parameters: pH (X1), Current Density (CD) in Amperes per square meter (A/m²) (X2), Electrolyte concentration in moles per liter (mol/L) (X3), and Time in minutes (X4). Each row in the table corresponds to a distinct combination of values for these parameters. Notably, the pH (X1) values range from 3 to 11 in increments of 2, while the Current Density (X2) increases from 111.80 to 335.42 A/m² across the rows. Additionally, Electrolyte concentration (X3) shows a progression from 0.03 to 0.07 mol/L, and Time (X4) increases from 20 to 100 minutes. The table does not explicitly state the dependent variables being measured, necessitating. further context for full interpretation. Nonetheless, the structured variation of these parameters likely reflects a systematic exploration of their effects on a particular process or system.

Table 1. Operating Parameters for electrochemical treatment

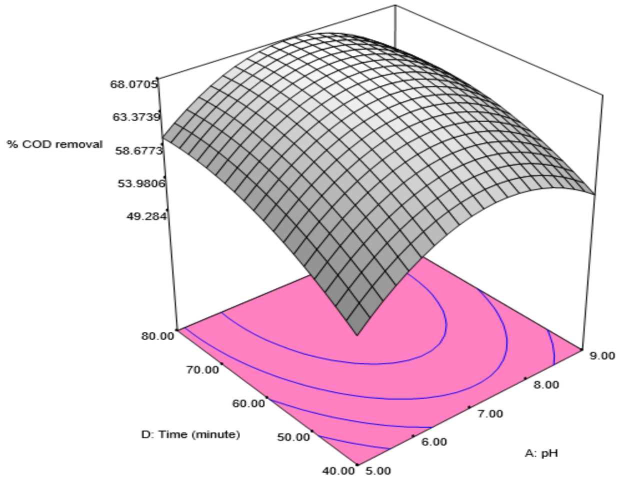
Parameter			
X_1	X_2	X_3	X_4
pH	CD (A/m^2)	Electrolyte concentration $(\frac{mol}{L})$	Time (min)
3	111.80	0.03	20
5	167.71	0.04	40
7	223.61	0.05	60
9	279.51	0.06	80
11	335.42	0.07	100

E. *Effect of pH, time, and Electrolyte Concentration (mol/L)*

The effect of pH (3-11), time (20-100), and electrolyte concentration (0.03- 0.07 mol/L) during electrical treatment was investigated for % COD removal as shown in figure 2(a, b & c). Maximum %COD removal was observed 70.01% at optimum operating conditions as mentioned in Table 2. Optimum amount of electrolyte concentration gives maximum removal efficiency as shown in figure.



a



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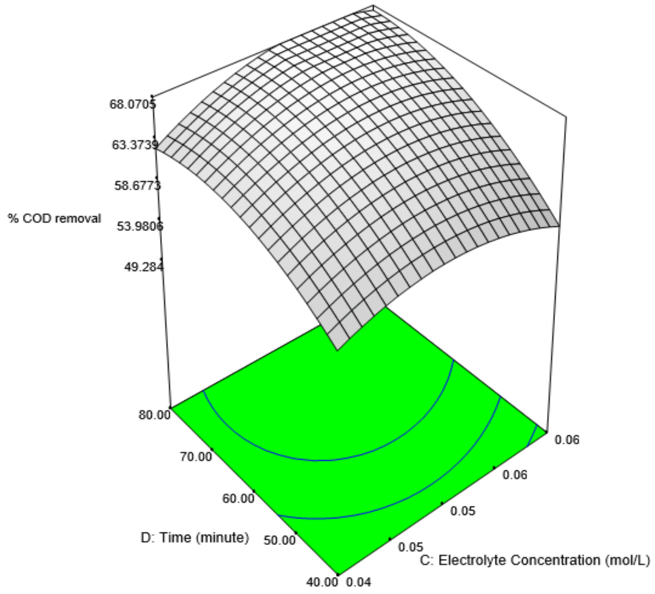

Figure 2. Effect of %COD removal and Current density (A/m2) (b) Effect of pH and %COD removal (c) Effect of time and electrolyte Concentration (mol/L)

III. Result and discussion

A. *Optimization*

The presented table 2 delineates experimental observations conducted on a process, evidently involving the removal of Chemical Oxygen Demand (COD), across various operational conditions. Each row corresponds to a distinct experimental run, characterized by specific parameter settings. These parameters include pH, expressed in standard units, Current Density (CD) denoted in Amperes per square meter (A/m²), Electrolyte Concentration measured in moles per liter (mol/L), and Time denoted in minutes (min). Notably, the process efficiency, quantified as the percentage removal of COD, is recorded for each experimental condition. The table provides insight into how alterations in pH, CD, Electrolyte Concentration, and Time influence the efficiency of COD removal, thus offering valuable data for further analysis and process optimization endeavors.

Table 1 Optimum operating conditions predicted by software for electrochemical treatment.

pH	CD (A/m^2)	Electrolyte Conc^n (mole/L)	Time (min)	% Removal of COD	
				CCD (Pre.)	Test Run
6.83	267.07	0.05	74.80	70.01	64.6

IV. Conclusion

The electrochemical process in treating municipal wastewater has proven to be highly efficient compared to other treatment methods. Through the application of central composite design (CCD) within the response surface methodology (RSM), it has been determined that this process is well-suited for optimizing key variables such as pH, treatment duration, and electrolyte concentration (expressed in mole/L) during the treatment of municipal wastewater using electrochemical techniques. The CCD has predicted optimal operating parameters for pH, treatment duration, and electrolyte concentration to be 6.83, 267.07 A/m², and 0.05 mole/L respectively, showcasing the potential for effective wastewater treatment through meticulous process optimization.

References

1. Schellenberg, T., Subramanian, V., Ganeshan, G., Tompkins, D., & Pradeep, R. (2020). Wastewater discharge standards in the evolving context of urban sustainability–The case of India. Frontiers in Environmental Science, 8, 30.
2. Aayog, N. I. T. I. (2018). Composite water management index: A tool for water management.
3. Tchobanoglus, G., Burton, F., & Stensel, H. D. (2003). Wastewater engineering: treatment and reuse. American Water Works Association. Journal, 95(5), 201.
4. Henze, M., Gujer, W., Mino, T., & Van Loosedrecht, M. (2006). Activated sludge models ASM1, ASM2, ASM2d and ASM3.
5. Mara, D., & Horan, N. J. (Eds.). (2003). Handbook of water and wastewater microbiology. Elsevier.
6. Halden, R. U. (2014). On the need and speed of regulating triclosan and triclocarban in the United States.
7. Tchobanoglous, G., Stensel, H. D., Tsuchihashi, R., Burton, F., Abu-Orf, M., Bowden, G., & Pfrang, W. (2014). Wastewater engineering: treatment and resources recovery. Metcalf and Eddy Inc.
8. Akbal, F., & Camcı, S. (2011). Copper, chromium and nickel removal from metal plating wastewater by electrocoagulation. Desalination, 269(1-3), 214-222.
9. Al Aji, B., Yavuz, Y., & Koparal, A. S. (2012). Electrocoagulation of heavy metals containing model wastewater using monopolar iron electrodes. Separation and Purification Technology, 86, 248-254.
10. Aswathy, P., Gandhimathi, R., Ramesh, S. T., & Nidheesh, P. V. (2016). Removal of organics from bilge water by batch electrocoagulation process. Separation and Purification Technology, 159, 108-115.