ESKİŞEHİR TECHNICAL UNIVERSITY JOURNAL OF SCIENCE AND TECHNOLOGY
A- APPLIED SCIENCES AND ENGINEERING

Estuscience – Se, 2025, 26 [1] pp. 14-27 , DOI: 10.18038/estubtda.1547245

RESEARCH ARTICLE

DETERMINATION OF THE PERFORMANCE OF THE ELECTROCOAGULATION PROCESS IN THE TREATMENT OF WASTEWATER FROM THE CERAMIC INDUSTRY

Esra FINDIK [1, *], Merve SÖZDER [2]

[1] Environmental Engineering, Faculty of Engineering, Eskisehir Technical University, Eskisehir, Turkey
ekacar@eskisehir.edu.tr - 0000-0002-4867-9572

[2] Eskisehir Technical University, Faculty of Engineering, Environmental Engineering, Eskisehir, Turkey
mrvsozder@gmail.com - 0009-0006-4252-3573

Abstract

The ceramic industry produces wastewater containing organic and inorganic pollutants. Traditional treatment methods are costly and complex. Electrocoagulation technology provides an effective treatment by precipitating pollutants through electrochemical reactions. In this thesis, wastewater samples taken from a ceramic factory in Kütahya were treated using the electrocoagulation method. The study considered current densities (1mA/cm², 2mA/cm², 4mA/cm², 10mA/cm²), electrode types (Iron, Aluminum, Iron-Aluminum), and different experiment durations (15 min, 30 min, 45 min, 60 min, 75 min), analyzing turbidity, suspended solids (SS), chemical oxygen demand (COD), and heavy metals. The results of measurements were compared with the Water Pollution Control Regulation (WPCR), showing that the treated wastewater met discharge criteria. When examining the effect of current density and electrode type on treatability, the best removal was found to be at 4 mA/cm² with an iron electrode. Parameters exceeding discharge limits in raw wastewater, such as suspended solids (SS), were reduced by 98.5% at 4 mA/cm² using the iron electrode. The Chemical Oxygen Demand (COD) was diminished by 85.7% at 4 mA/cm² with the iron electrode. For turbidity removal, a 99.94% success rate was achieved using the iron-aluminum electrode at 4 mA/cm². Heavy metal analyses for Zn, Pb, and Cd showed concentrations below WPCR discharge limits. However, in further processed wastewater, the best Pb removal was observed with the iron electrode at 4 mA/cm², and the best Cd removal was achieved with the aluminum electrode at 1 mA/cm². The data obtained were from laboratory-scale experiments, and it is recommended that the method be tested in pilot and full-scale systems. This will permit an evaluation of the efficacy and suitability of the method in actual, real-world contexts.

Keywords

SS Removal,
Turbidity Removal,
Electrocoagulation,
COD Removal,
Ceramics Industry

Time Scale of Article

Received :10 September 2024
Accepted : 07 February 2025
Online date : 25 March 2025

Abbreviations

WPCR: Water Pollution Control Regulation
SS: Suspended Solids
COD: Chemical Oxygen Demand
EC: Electrocoagulation

*Corresponding Author: ekacar@eskisehir.edu.tr

1. INTRODUCTION

The ceramic industry is a widely active sector in our country, and large amounts of wastewater are generated during ceramic production processes. The direct discharge of wastewater into the receiving environment without prior treatment can result in significant environmental issues. Therefore, the treatment of wastewater generated from production processes using appropriate methods is of significant economic and environmental importance [1].

Electrocoagulation (EC) is an advanced electrochemical treatment method that relies on the production of coagulant agents within the system through electrochemical reactions triggered by electric current passing through electrodes. These coagulants aid in the removal of contaminants by promoting their precipitation. The sludge resulting from the electrocoagulation process is easily settleable and dewaterable. The efficiency of the EC method has been proven, and it is relatively easy to implement. The numerous advantages of electrocoagulation, such as the minimal or negligible need for chemical additives, simple equipment requirements, reduced labor needs, applicability small areas, and lack of secondary pollution, distinguish this method from others. The aforementioned advantages have prompted a surge in research activity pertaining to electrocoagulation in recent years [2].

Within the scope of this study, the state of the ceramic industry in Turkey, its wastewater, production processes, the characteristics of post-process wastewater, environmental impacts, and regulatory requirements were examined. Additionally, experiments were conducted to improve the efficiency of removing discharge parameters from ceramic industry wastewater using the electrocoagulation method. In these experiments, the effects of three main parameters (current density, different experimental durations, and electrode type) on the treatment of ceramic industry wastewater by electrocoagulation were investigated [3].

In order to evaluate the effect of current density on treatment, the system was evaluated using iron, aluminum, and iron-aluminum electrodes at different current densities. The effect of electrode type on the treatment performance was examined using aluminum, iron, and iron-aluminum electrodes at different current densities.

In all the studies conducted, the parameters that must be adhered to in order to comply with discharge limits were measured in the influent waters. These values were then compared with the discharge standards in our country in order to evaluate the applicability of the method. Additionally, the electrical voltage and current intensities applied during the system operation were recorded, and comments were made on the treatability at different energy levels [4].

The electrocoagulation (EC) method has emerged as an effective and economical solution for the treatment of industrial wastewater. Özyonar et al. (2012) investigated the treatability of textile industry wastewater using the EC process and achieved removal efficiencies of up to 83% for total organic carbon (TOC), up to 73% for chemical oxygen demand (COD), up to 98% for color, and up to 99% for turbidity. These results demonstrate the high efficiency of the EC method in removing pollutants from textile wastewater [5].

Emir (2015) reported the removal of over 99% of suspended solids in wastewater from a ceramic factory, as well as high removal rates of heavy metals, including cadmium, zinc, and lead. The study identified iron electrodes and a current density of 1 mA/cm^2 as the most economical option, highlighting that the use of supporting electrolytes did not offer a cost-effective advantage [6].

In a study on the removal of methylene blue using sequential electrocoagulation and dried banana peel adsorption, it was observed that up to 99% of the colour was removed. The study utilised current densities ranging from 2.5 to 10 mA/cm^2, with the highest removal observed at 10 mA/cm^2.

Additionally, the effect of inlet concentration on removal efficiency was examined, and it was found that higher removal efficiency was achieved at lower concentrations. [7].

A study conducted by Camcıoğlu (2016), the effects of the EC method on paper industry wastewater were evaluated, showing a 9.96% increase in COD removal and a 37.49% reduction in energy consumption under controlled conditions [8].

Öztürk (2018) investigated the effects of different electrode types and geometries on the treatment of marble processing wastewater and found that Monopolar Al-Fe electrodes achieved the highest suspended solids removal, while Monopolar Al-Al electrodes provided the highest turbidity removal [9].

In anaother experimental study, the optimal working conditions for decolourisation of a synthetic dye solution with a concentration of 50 mg/L were identified. The experimental conditions, which were found to be optimal, included a current density ranging from 30 to 37.5 mA/cm^2, a conductivity value of 1 mS/cm, and a pH value of 7.5 at 25°C for both Al and Fe electrodes.In addition to these findings, a real textile wastewater sample was examined under conditions analogous to those of the synthetic dye solution, employing a batch EC reactor. The dye removal rate was found to be 80% with real wastewater, with an energy consumption of 9.16 kWh/m^3[10].

Kasaplar et al. (2019) achieved removal efficiencies of 50% COD and 46% suspended solids in the treatment of automotive industry wastewater using the EC method [11].

Öztürk (2019) examined the combination of EC and electrooxidation methods for the electrocatalytic degradation of phenol, achieving over 98% removal of phenol and conversion of by-products to carboxylic acids [12].

Salah et al (2022) investigate the removal of Disperse Blue 3 from aqueous solutions by electrocoagulation with Al and Fe electrodes. The effects of the operation parameters on the process are examined, including the electrocoagulation time, current density, initial pH, salt concentration, the distance between electrodes, and initial dye concentration. The results of the study demonstrated that the removal efficiency of Disperse Blue 3 increased from 22% to 90% when the electrocoagulation time was extended from 5 to 70 minutes, and from 67% to 96% when the electrocoagulation time was decreased from 5 to 60 minutes for Al and Fe, respectively [13].

Akkaya and Üçgül (2023) evaluated the effectiveness of the EC method in treating high dye concentration textile wastewater using solar energy and achieved 92% COD and 95% color removal with a 15-minute process at 1A current. These studies reveal that the EC method offers high efficiency and economic advantages for treating various industrial wastewaters, demonstrating significant potential for environmental sustainability [14].

2. MATERIALS AND METHODS

This study investigated the performance of the electrocoagulation method for the treatment of wastewater from the ceramic industry. The raw wastewater used in the study was obtained from a ceramic factory operating within the boundaries of Kütahya province. The characterization of the wastewater is detailed in Table 1.

Table 1: Initial Measured Values

Parameter	**Value**
SS	8941,5 mg/L
COD	140,20 mgO_2/L
Pb	0,0014 mg/L
Zn	0,1982 mg/L
Cd	-
Ph	8,53
Turbidity	15170 NTU

A Statron power supply, with an input voltage of 220 V, a voltage range of 0-300 V and an output current of 0-4 A, was utilised in the electrocoagulation configuration. Additionally, aluminum, iron, and iron-aluminum electrodes with dimensions of 3.8 x 5.8 cm were employed. The electrodes were connected using insulating serum caps, nuts, rubber seals, washers, and metal plates, and were arranged in a monopolar configuration to ensure that successive electrodes were charged with different loads. A burette stand was used to keep the electrode bundle at a fixed height, and a 600 mL beaker was chosen as the reactor. A magnetic stirrer were used to facilitate mixing within the system as illustrated in Figure 1.

Figure 1. Electrocoagulation Experimental Set-Up

Filter paper, filtration apparatus, and a precision balance were used for the analysis of suspended solids (SS). Samples were dried in an oven and then stored in a desiccator. pH measurements were performed using a Thermo Scientific pH meter, while Chemical Oxygen Demand (COD) analyses were conducted with a thermoreactor and glassware. Metal analyses were carried out using an Agilent 8800 ICP-MS device.

2.1 Determination of the Effect of Electrode Types on Purifiability

In this study on the treatment of ceramic industry wastewater using the electrocoagulation method, comprehensive experiments were conducted to determine the effects of different electrode types on treatability. The experiments were carried out using various reaction times and current densities, and each combination was repeated with different electrode types. At the end of the experiments, parameters such as suspended solids (SS), turbidity, and chemical oxygen demand (COD) were measured, and treatment efficiencies were calculated. The resulting data were compared with the discharge criteria specified in the Water Pollution Control Regulation (WPCR), and the suitability of the wastewater for discharge into the receiving environment was assessed.

2.2. Determination of the Effect of Test Time on Treatability

The aim of this study is to determine the effect of electrocoagulation (EC) treatment time on treatability. Treatability is typically regarded as a parameter that reflects the effectiveness of chemical and physical processes and directly impacts process efficiency. The contribution of treatment time to this effect is of significant importance, especially regarding the optimization of treatment processes. The objective of this study was to investigate the impact of alternative treatment times using the EC treatment method, and the resulting turbidity, as well as suspended solids (SS), chemical oxygen demand (COD), and heavy metal analysis data at the conclusion of the treatment time, with a view to optimising these factors. The goal is to reveal the changes in treatability and the impact of time on these changes, thereby contributing to the development of more efficient and effective treatment strategies.

2.3. The Effect of Current Density on Purification Performance in the Electrocoagulation Process

In order to gain a detailed understanding of the impact of current density on the efficacy of the electrocoagulation process, different current densities were applied to wastewater from the ceramic industry. The experiments were conducted using iron, aluminum, and iron-aluminum plates with an active area of approximately 100 cm^2, and current densities of 1, 2, 4, and 10 mA/cm^2 were employed. This study was conducted to determine and optimize the effects of various current densities on electrocoagulation performance.

3. RESULTS

3.1. Studies on the Performance of Iron Electrodes in the Electrocoagulation Process

- Turbidity Removal Studies: Turbidity experiments were conducted over a duration of 75 minutes. Samples were taken from the wastewater under treatment every 15 minutes, centrifuged for 5 minutes at 5000 rpm, and the turbidity values were then measured and recorded using a turbid meter (Figure 2, Figure 3, Figure 4, and Figure 5). The turbidity removal efficiency of the experiments conducted at different currents using the Fe electrode was calculated to be in excess of 99%. When examining the effect of current density and electrode type on treatability, it was concluded that the best removal was achieved at 4 mA/cm^2 with the iron electrode. Following a period of analysis, it was determined that a duration of 15 minutes would be adequate for the purposes of this investigation. Salah A.et al found the Fe electrode was found to be more successful than the aluminum electrode[13].

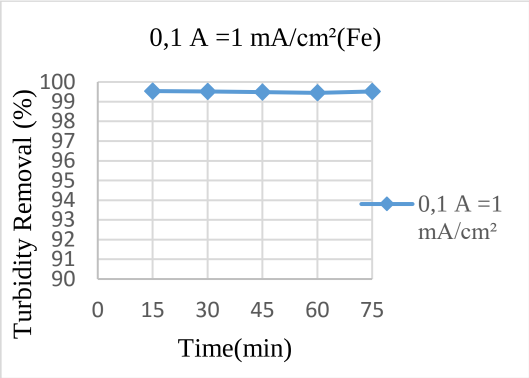


Figure 2. Turbidity values for 0,1A

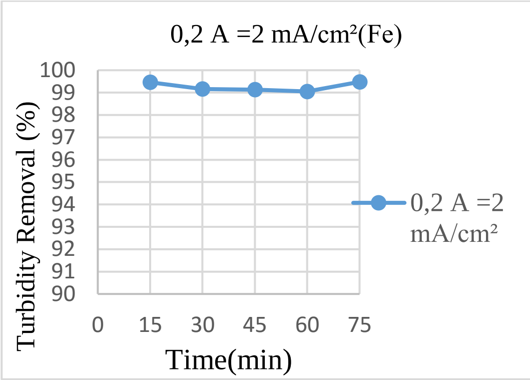


Figure 3. Turbidity values for 0,2A

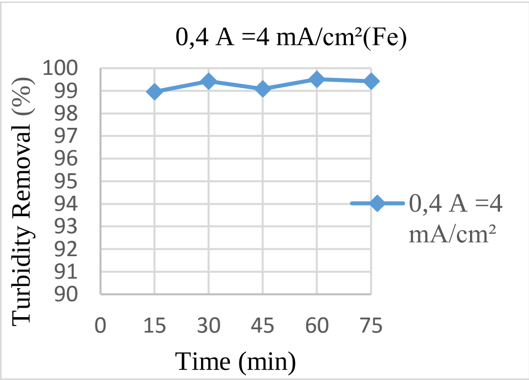


Figure 4. Turbidity values for 0,4A

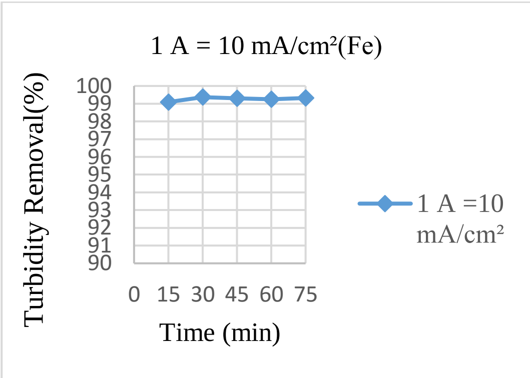


Figure 5. Turbidity values for 1A

- Suspended Solids Removal Studies: The electrocoagulation process aimed at determining the performance of different electrode types in suspended solids removal was carried out over a duration of 75 minutes. The removal efficiencies achieved with the iron electrode at the end of 75 minutes are as follows (Figure 6). The optimal suspended solids removal was observed at a current of 4 mA/cm², and when the current density attained 10 mA/cm², the efficiency declined from 98.5% to 87%.

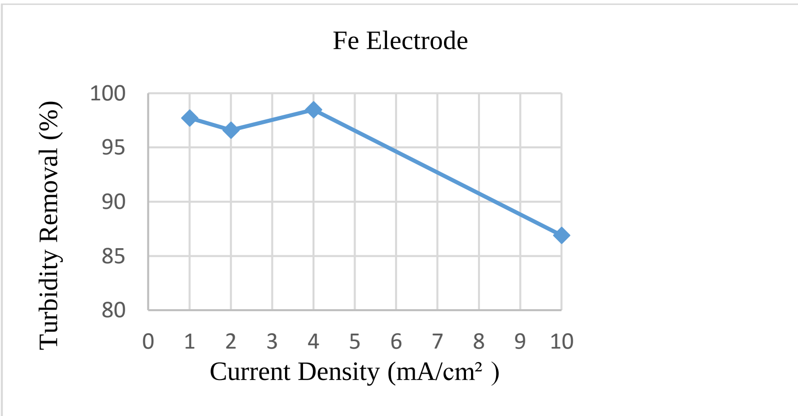


Figure 6. The Relationship Between Current Density and Suspended Solids Removal Using Iron Electrodes

- Chemical Oxygen Demand (COD) Removal Studies: In the electrocoagulation process conducted with ceramic industry wastewater, samples taken at the 75th minute were acidified and analyzed for Chemical Oxygen Demand (COD). The removal efficiencies achieved with the iron electrode at the end of 75 minutes are as follows (Figure 7). The optimal COD removal was achieved at a current of 4 mA/cm², with a 86% removal efficiency. When the current density was reduced to 0.1 mA/cm², the efficiency remained at 43%.

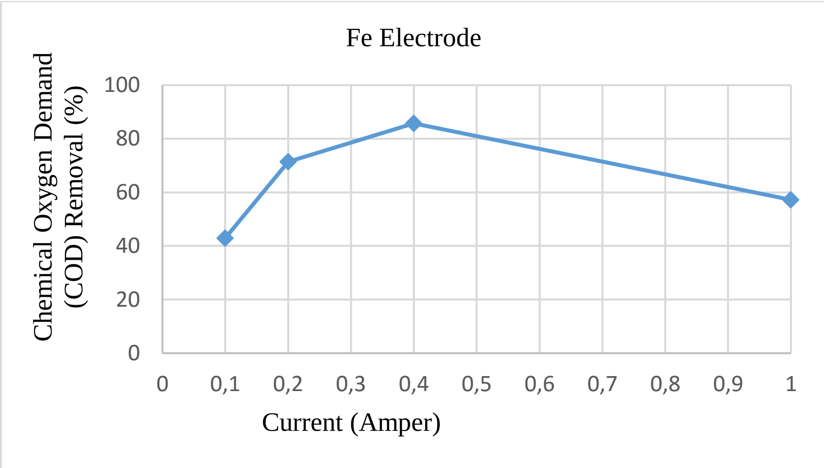


Figure 7. The Relationship Between Current Density and Chemical Oxygen Demand (COD) Removal Using Iron Electrodes

3.2. Studies on the Performance of Aluminum Electrodes in the Electrocoagulation Process

- Turbidity Removal Studies: Wastewater samples were processed at different current densities for 75 minutes, with samples taken every 15 minutes and centrifuged. Turbidity values measured with a turbid meter were recorded throughout the experimental period. The turbidity removal efficiency of the experiments conducted at different currents using the Aluminum electrode was calculated to be in excess of 99%. The graphs of turbidity removal efficiencies versus time for experiments conducted with aluminum electrodes at various current densities over 75 minutes are shown below (Figure 8, 9, 10 and 11).

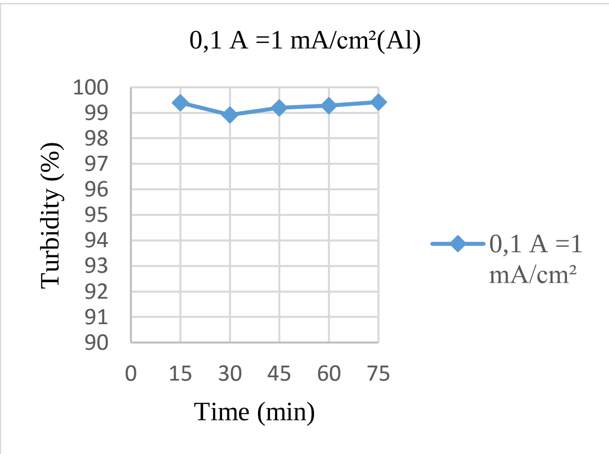


Figure 8. Turbidity values for 0,1A

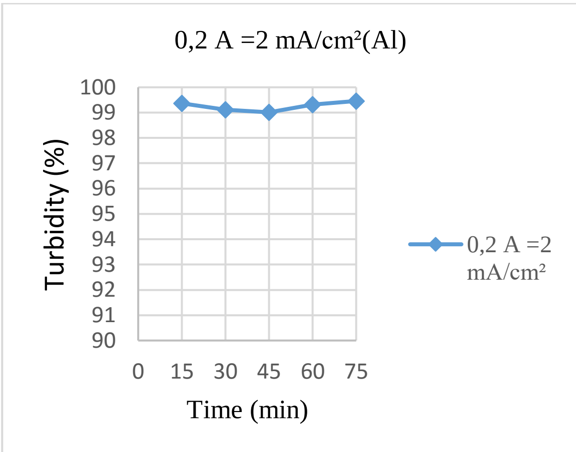
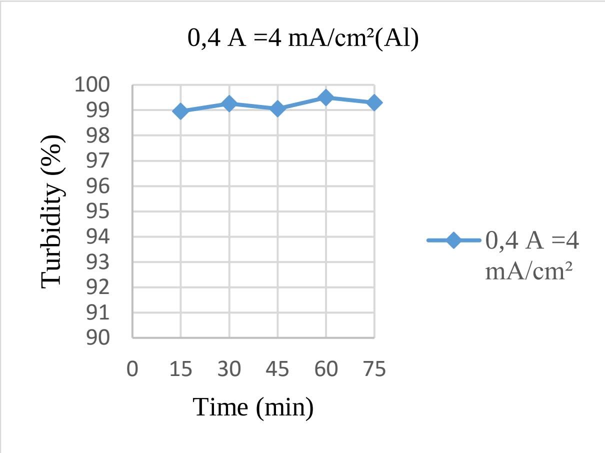


Figure 9. Turbidity values for 0,2A



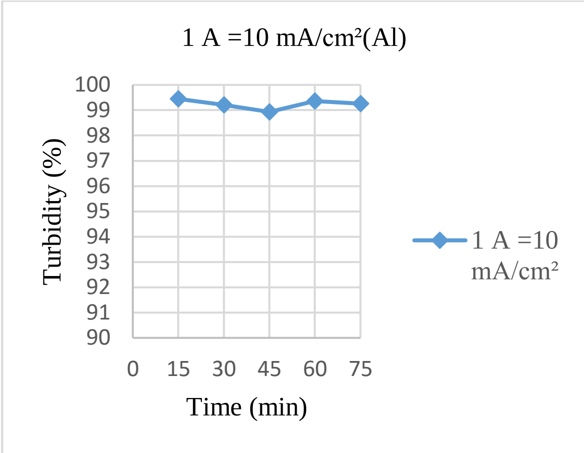


Figure 10. Turbidity values for 0,4A

Figure 11. Turbidity values for 1A

- Suspended Solids Removal Studies: The electrocoagulation process aimed at determining the performance of different electrode types in suspended solids removal was carried out over a duration of 75 minutes. The removal efficiencies achieved with the aluminum electrode at the end of 75 minutes are as follows (Figure 12). The optimal suspended solids removal was observed at a current of 1 mA/cm², and when the current density attained 0,2 mA/cm², the efficiency declined from 97.9% to 87,8%.

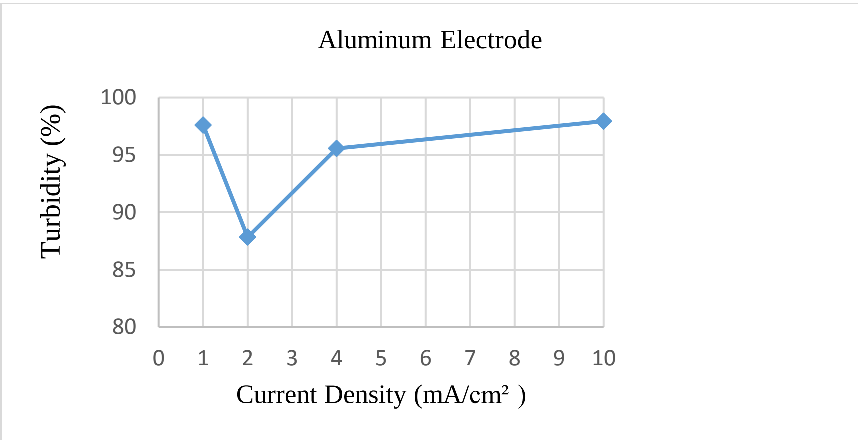


Figure 12. The Relationship Between Current Density and Suspended Solids Removal Using Aluminum Electrodes

-Chemical Oxygen Demand (COD) Removal Studies: In the electrocoagulation process conducted with ceramic industry wastewater, samples taken at the 75th minute were acidified and analyzed for Chemical Oxygen Demand (COD). The removal efficiencies achieved with the aluminum electrode at the end of 75 minutes are as follows (Figure 13). The optimal COD removal was achieved at a current of 0,4 mA/cm², with a 82,7% removal efficiency. When the current density was reduced to 0.1 mA/cm², the efficiency remained at 43%.

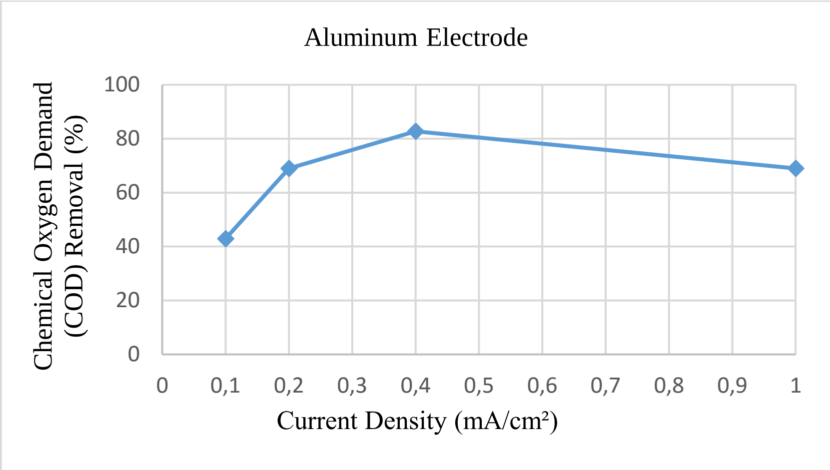


Figure 13. The Relationship Between Current Density and Chemical Oxygen Demand (COD) Removal Using Aluminum Electrodes

3.1.3. Studies on the Performance of Iron-Aluminum Electrodes in the Electrocoagulation Process

- Turbidity Removal Studies: Wastewater samples were processed at different current densities for 75 minutes, with samples taken every 15 minutes and centrifuged. Turbidity values measured with a turbid meter were recorded throughout the experimental period. The graphs of turbidity removal efficiencies versus time for experiments conducted with Iron-Aluminum electrodes at various current densities over 75 minutes are shown below (Figure 14,15,16 and 17). The turbidity removal efficiency of the experiments conducted at different currents using the Iron-Aluminum electrode was calculated to be in excess of 99,94%.

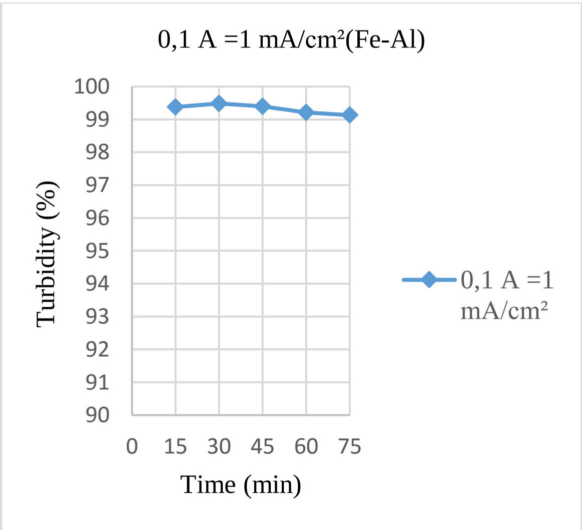


Figure 14. Turbidity values for 0,1A

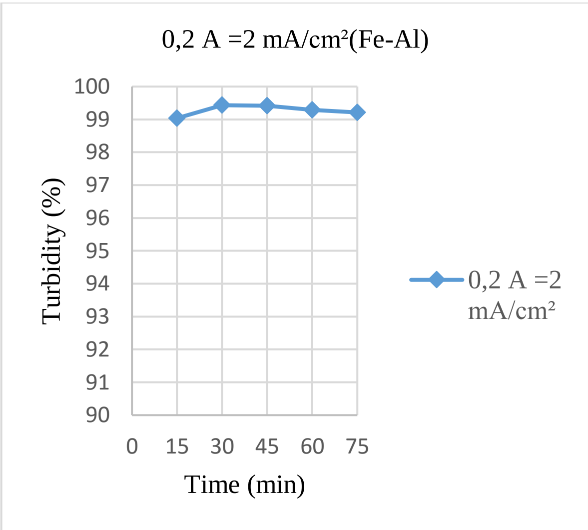
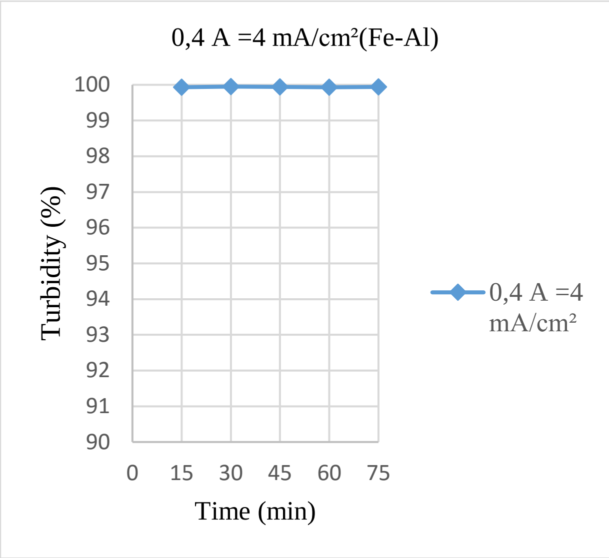


Figure 15. Turbidity values for 0,2A



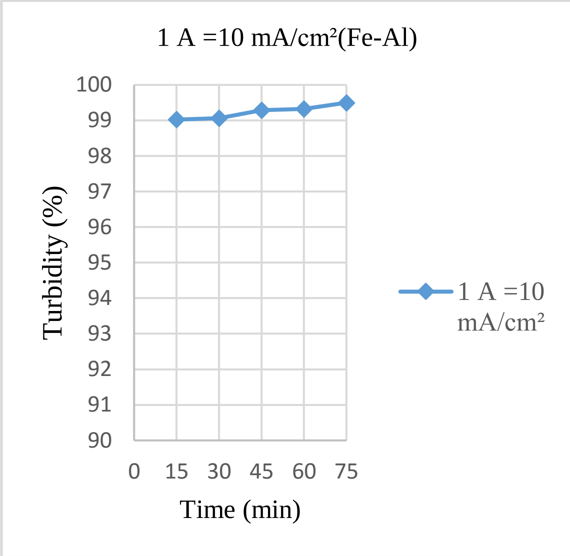


Figure 16. Turbidity values for 0,4A

Figure 17. Turbidity values for 1A

- Suspended Solids Removal Studies: The electrocoagulation process aimed at determining the performance of different electrode types in suspended solids removal was carried out over a duration of 75 minutes. The removal efficiencies achieved with the Iron-Aluminum electrode at the end of 75 minutes are as follows (Figure 18). The suspended solids removal efficiency of the experiments conducted at different currents using the Iron-Aluminum electrode was calculated to be in excess of 99%.

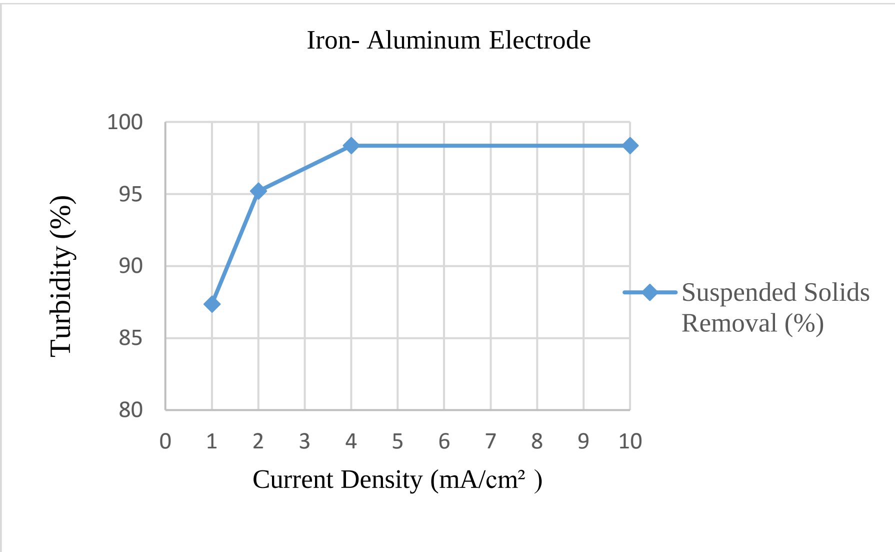


Figure 18. The Relationship Between Current Density and Suspended Solids Removal Using Iron-Aluminum Electrodes

- Chemical Oxygen Demand (COD) Removal Studies: In the electrocoagulation process conducted with ceramic industry wastewater, samples taken at the 75th minute were acidified and analyzed for Chemical Oxygen Demand (COD). The removal efficiencies achieved with the iron-aluminum electrode at the end of 75 minutes are as follows (Figure 19). The optimal COD removal was achieved at a current of 0,2-0,4 mA/cm², with a 85,7% removal efficiency.

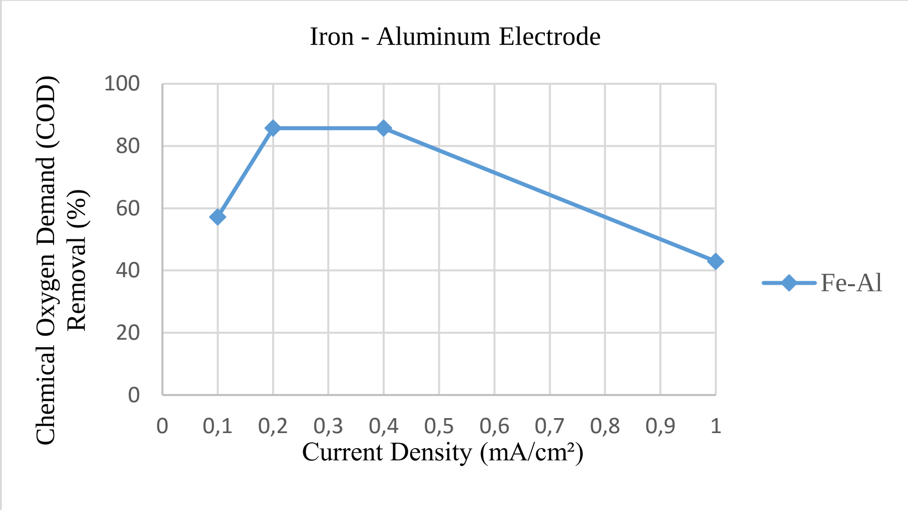


Figure 19. The Relationship Between Current Density and Chemical Oxygen Demand (COD) Removal Using Iron-Aluminum Electrodes

3.2. Effect of Electrode Type on Treatment Performance in the Electrocoagulation Process

- Turbidity Removal Studies: In the study, the effect of different electrode types on turbidity removal was investigated. The results of the experiments conducted with various electrodes are shown below (Figure 20).

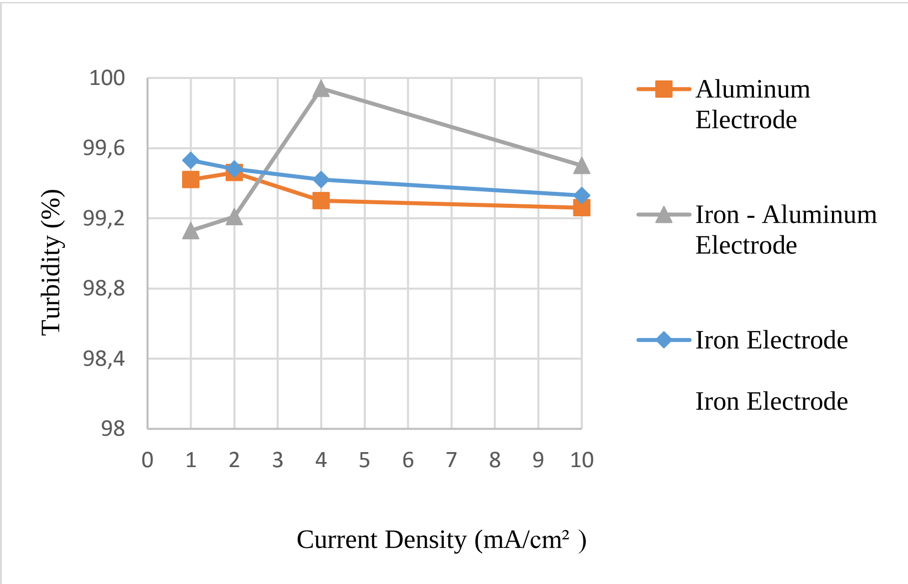


Figure 20. Relationship Between Turbidity Removal Performance and Electrode Types

- Suspended Solids Removal Studies: In the study, the effect of different electrode types on suspended solids removal was investigated. The experimental results are shown below (Figure 21).

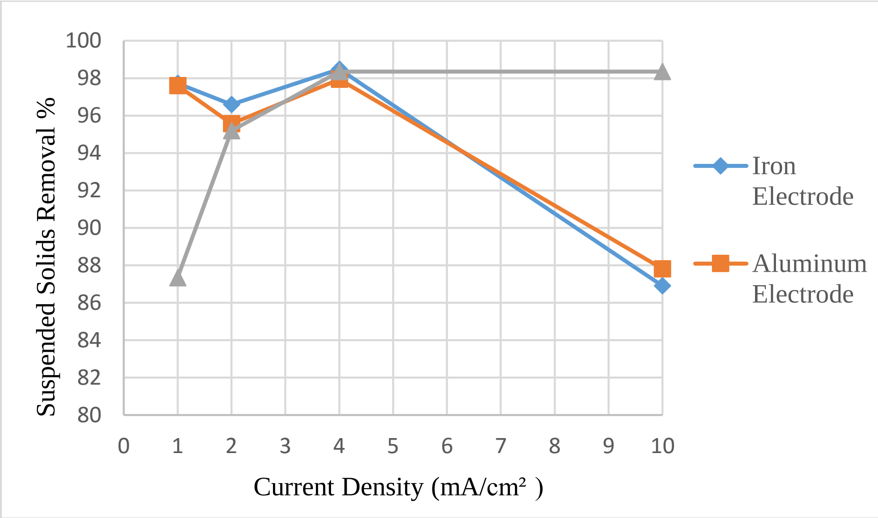


Figure 21. Relationship Between Suspended Solids Removal Performance and Electrode Types

- Chemical Oxygen Demand (COD) Removal Studies: According to the Water Pollution Control Regulation, the COD discharge limit for ceramic industry wastewater into receiving environments is 80 mg/L (Table 2). The COD concentration of the raw wastewater used in the experiments was determined to be 140.20 mg/L. In the study, wastewater samples were collected following a 75-minute treatment process at current densities of 1, 2, 4, and 10 mA/cm². The samples were acidified to below pH 2, allowed to settle, and then analyzed for COD using the supernatant. With the iron electrode, the electrocoagulation experiments resulted in a COD value reduced to 20 mg/L at a current density of 4 mA/cm², achieving a removal efficiency of 85.7%.

4. DISCUSSION AND CONCLUSION

In this study, the performance of the electrocoagulation method was evaluated using a wastewater sample from a ceramic factory in Kütahya Province. The study involved the use of different current densities (1 mA/cm², 2 mA/cm², 4 mA/cm², 10 mA/cm²), electrode types (Iron, Aluminum, Iron-Aluminum), and various treatment times (15 min, 30 min, 45 min, 60 min, 75 min) to analyze the turbidity, Suspended Solids (SS), Chemical Oxygen Demand (COD), and heavy metals in the ceramic industry wastewater. The effectiveness of the electrocoagulation method was assessed based on these parameters.

The experimental results indicate that the discharge standards set by the Water Pollution Control Regulation (WPCR) were met for all current densities. Due to the easily settleable nature of the ceramic industry wastewater, the highest turbidity removal efficiency was achieved within the early minutes of the experiment. The results of this study indicate that the optimal current density for the electrocoagulation process is 4 mA/cm².

In the pre-settled raw wastewater sample, the only parameter below the discharge limits was that of heavy metal levels. Heavy metal analyses were conducted after all electrocoagulation treatments. The electrocoagulation process achieved removal of Pb and Cd, further reducing these already below-limit heavy metals to even lower levels.

The characterisation results revealed that the concentration of suspended solids, a crucial parameter in the ceramic industry, exceeded the prescribed discharge limits. A removal efficiency of 98.5% was achieved using iron electrodes at a current density of 4 mA/cm².

Another parameter that exceed the receiving environment discharge standard in raw wastewater is COD. Experiments were conducted with iron, aluminum, and iron-aluminum electrodes at different current densities (1, 2, 4, 10 mA/cm²). Using iron electrodes, electrocoagulation experiments reduced COD to 20 mg/L at a current density of 4 mA/cm², achieving a removal efficiency of 85.7%.

The findings of the studies indicate that the electrocoagulation method could be an effective alternative to existing methods for treating ceramic industry wastewater.

The results of the experiments demonstrated that the standards set forth in the Water Pollution Control Regulation (WPCR) were met. When examining the effect of current density and electrode type on treatability, it was concluded that the best removal was achieved at 4 mA/cm² with the iron electrode. Parameters exceeding discharge limits in raw wastewater, such as Suspended Solids (SS), were removed by 98.5% at 4 mA/cm² current density in experiments using the iron electrode. Chemical Oxygen Demand (COD) was reduced by 85.7% at 4 mA/cm² current density in experiments using the iron electrode. In terms of turbidity removal 99.94% success rate was achieved using the iron-aluminum electrode at 4 mA/cm² current density.

ACKNOWLEDGEMENTS

This study was supported by the Scientific and Technological Research Council of Turkey (TÜBİTAK) under the 2209 program.

CONFLICT OF INTEREST

The authors stated that there are no conflicts of interest regarding the publication of this article.

CRediT AUTHOR STATEMENT

Esra Fındık: Methodology, Formal analysis, Writing – Original Draft, Writing – Review & Editing. **Merve Sözder:** Resources, Writing – Original Draft, Formal analysis.

REFERENCES

[1] Namal ÖÖ. Investigation of processes used in the treatment of textile industry wastewaters. Nevşehir J Sci Technol. 2017;6:388-396. doi:10.17100/nevbiltek.322169

[2] Houssini NS, Essadki A, Elqars E. Removal of reactive blue and disperse red dyes from synthetic textile effluent by electrocoagulation process using Al-Al and Fe-Fe electrodes: Parametric optimization by response surface methodology. Desalination Water Treat. 2021;223:363-379. doi:10.5004/dwt.2021.27111

[3] Sümer G. Production technology in the ceramic industry. J Min Sci Mining J. 1976;59(1):37-43. doi:10.30797/madencilik.705498

[4] Akarsu C, Taner F, Ayol A. Treatment of leachate using the electrooxidation process. In: ISEM2014, Adıyaman; 2014.

[5] Özyonar F, Karagözoğlu B. Treatment of textile wastewater by electrocoagulation process. Erciyes Univ J Inst Sci Technol. 2012;28(1):29-37.

[6] Emir G. Treatment of ceramic industry wastewater by electrocoagulation method. Master's thesis, Anadolu University, Turkey; 2015.

[7] Carvalho HP, Huang J, Zhao M, et al. Improvement of methylene blue removal by electrocoagulation/banana peel adsorption coupling in a batch system. Alexandria Eng J. 2015;54(3):777-786.

[8] Camcıoğlu Ş. Treatment of paper industry wastewater by electrochemical method. Doctoral dissertation, Ankara University, Turkey; 2016.

[9] Öztürk D. Treatment of marble industry wastewater by electrocoagulation method. Master's thesis, Anadolu University, Turkey; 2018.

[10] Özden M, Tekbaş M, Çalışkan Y, Bektas N. Decolourisation of disperse brown dye solution by electrocoagulation process with Al and Fe electrodes. Gazi Univ J Sci. 2019;32(1):104-114.

[11] Kasaplar M. Application of electrocoagulation process in the treatment of automotive industry wastewater. Master's thesis, Bursa Uludağ University, Turkey; 2019.

[12] Öztürk H. Removal of phenol by electrooxidation−electrocoagulation hybrid process: Reaction kinetics and determination of metabolites. Master's thesis, Kocaeli University, Institute of Science; 2019.

[13] Salah A, Bensmaili A. Decolourization of disperse blue 3 dye by electrocoagulation process using Al and Fe electrodes – Application of the artificial neural network model. Iran J Chem Chem Eng. 2022;41(4):1-11.

[14] Kurtoglu Akkaya G, Üçgül İ. Treatment of textile wastewater by electrocoagulation using direct solar energy. Black Sea J Sci. 2023;13(2):504-516. doi:10.31466/kfbd.1227078