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RESEARCH PAPER

Comparison of Different Anodes and Investigation of Energy Consumption in the Treatment of Real Wastewater by Electrooxidation

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Abstract
The present study aims to compare the efficiencies and energy consumption of different anodes in the treatment of slaughterhouse wastewater (SWW) by electro-oxidation method with using two different anodes (Ti/Pt and Ti/IrO_2/RuO_2). It aims to remove many parameters from wastewater at the same time and to examine the efficiency of the electro-oxidation method for food industry wastewater. The electrooxidation mechanism was prepared and the parameters to be removed from the wastewater were determined using two different anodes and using different supporting electrolytes (SE). The efficiency of removal of COD, turbidity, suspended solids (SS), and color from wastewater was studied. The highest removal was obtained at approximately 7.0 of pH, which is the natural value of the wastewater. Color, turbidity, and SS removals provided over 95% removal for both anodes. In optimum electrolyte concentration (0.2 M NaCl), the COD removal efficiency and the energy consumption are obtained as 80.05% and 210.7 kWh/m^3 for the Ti/Pt anode and 66.46% and 183.6 kWh/m^3 for Ti/IrO_2/RuO_2 anode. It has been observed that as the current density increases, the efficiency also increases, but the energy consumption increases depending on the voltage increase. Cost is also important here. Priority should be determined for the option to be preferred. Both anodes were found to be quite efficient at removing dirt. Additional processes can be considered to increase treatment efficiency. It is an ideal method for small-scale areas. However, sizing is recommended so that it can be applied to larger areas.

Article Highlights

- **The aim of the study is to demonstrate the application of electrochemical treatment methods for slaughterhouse wastewater and to evaluate them in terms of efficiency.**
- **Electrooxidation, which is one of the electrochemical treatment methods that has become widespread recently, is to determine the most suitable conditions by examining the removal of slaughterhouse wastewater and electricity consumption.**
- **As a result of the study, it was emphasized that electrooxidation is a very efficient method for water containing such high organic pollution and its use is recommended.**
- **In the results obtained, it was found that high color, suspended solids, turbidity, and COD removal were achieved with this method in the treatment of slaughterhouse wastewater. Electrochemical methods have advantageous applications.**

Keywords Ti/Pt anode · Ti/IrO_2/RuO_2 anode · Slaughterhouse wastewater treatment · Electrochemical process · Energy consumption

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Abbreviations

SE	Supporting electrolyte
SEC	Supporting electrolyte concentration
SWW	Slaughterhouse wastewater
EO	Electrooxidation process
COD	Chemical oxygen demand
$K_2Cr_2O_7$	Potassium dichromate

$C_8H_5KO_4$ Potassium Hydrogen Phthalate
HgSO4 Mercury sulfate

Introduction

Rapid technological advancements and a growing population place heavy demands on the ecology, endanger freshwater supplies, and drive people to use all available water sources up till discharge (Waziri and Akinniyi 2012; Ebraheim and Karbassi 2021). Water, which is an indispensable basic need for all living things in the world, has limited resources and is the basic substance that should be given importance to its consumption. The treatment and reuse of wastewater are very important, because the water that makes up most of the earth is limited. Slaughterhouse industry wastewater is also colored wastewater containing high amounts of oil and organic matter, which must be purified and discharged up to certain limits. The slaughterhouse industry has been recognized by agriculture as one of the sectors that consume the most water with 29% (Gerbens-Leenes et al. 2013). In addition, slaughterhouses produce a large amount of wastewater and solid waste during the meat production phase and the cleaning processes after it (Cuetos et al. 2008). SWW contains large amounts of carbohydrates, proteins, and fats. It is considered a source of antibiotic-resistant microbes and pathogens. Thus, potentially contributing to the release of these pollutants into aquatic environments (Savin et al. 2020). Therefore, SWW is considered the most polluting wastewater for ground and surface waters due to insufficient treatment in many countries (Bustillo-Lecompte et al. 2016). Municipal wastewater often consists of both household and industrial wastewater. As a result of the complexity of municipal wastewater, both home and industrial chemicals have the potential to be significant pollutants in wastewater and cause hazardous effects (Rogowska et al. 2020; Pereao et al. 2021). The eventual discharge of treated wastewater to the environment or use as process water while minimizing the costs of building, operation, and maintenance of wastewater treatment facilities is a significant problem (Druskovic et al. 2021). Different treatment processes can be used for the treatment of slaughterhouse wastewater. One of them is electrochemical treatment. Electrochemical treatment can be used for wastewater with different characteristics due to its various advantages. Some of its advantages are it is easy to operate and control, the space requirement is less, sludge formation after treatment is less, chemical use is less. In the literature, electrochemical processes have been used in the treatment of SWW and very efficient results have been obtained. In some studies, conducted in the literature, 93% of COD removal using aluminum electrodes (Asselin et al. 2008). In another study, 90.4% efficiency was obtained using iron electrode and 95.6% efficiency was obtained with aluminum electrodes by electrochemical methods (Godini et al. 2012).

The electro-oxidation process is an advanced oxidation process that scientists take into consideration. Because it is a promising technique for the mineralization and degradation of many organic pollutants (Kaur et al. 2019). In general, EO processes have advantages due to their durability and simplicity in the process (Muddemann et al. 2019). The electro-oxidation process is an important process in terms of its wide area of use and removal of organic–inorganic compounds (Matayeva and Biller 2021).

Electrochemical oxidation is produced through indirect and/or direct anodic reactions in which oxygen is transferred to the product to be oxidized. The main feature of this process is that it uses electrical energy to remove pollution from the water. In this type of oxidation, compounds degrade by reacting to electrochemically produced oxidants (Poyatos et al. 2009).In this study, different conditions (such as SE type and concentration, current density, initial pH value) were investigated to examine the effect of different anode materials on the electrooxidation process. The wastewater used in this study was taken from a slaughterhouse owned by a local business. An average of 300 cattle and 100 ovine animals are slaughtered daily at the facility. The study also aims to present innovation in terms of comparing the simultaneous removal of unwanted color turbidity and suspended solids in wastewater with different anodes.

Materials and Methods

Electrochemical Reactor Setup

A jacketed glass reactor with a diameter of 15 cm and a capacity of 2000 mL was employed in the reactor configuration. The anode material was Ti/Pt and $Ti/IrO_2/RuO_2$, while the cathode material was sieve type uncoated titanium electrodes. A cooling circulator was utilized, since the reaction's procedure raised the water's temperature. A 3-h reaction time was used in all trials, which were conducted at room temperature. 8 electrodes altogether (4 anodes and 4 cathodes) were employed. Electrode dimensions 70 × 100x2 mm distance between electrodes 5 mm and wet surface area of all plates were calculated as approximately 2464 cm^2. To increase the surface area, the electrodes were connected parallel to each other, and the power supply required for the system was provided with a KXN-3050D branded direct current power supply. Color measurements (Organoleptic Method) were made at 430 nm wavelengths, turbidity measurements (SM 2130 B) were made at 530 nm and SS measurements at 660 nm wavelengths with a Lovibond Multi Direct brand photometer (SM 2540 D). The wastewater was mixed at 400 rpm throughout the reaction with a magnetic stirrer at the bottom of the reactor. All experiments were carried out at 25 ± 2°C room temperature and using 1200 mL wastewater volume. In the studies, the effects of SE type and SE concentration, initial pH value of wastewater, and current density were investigated. The experimental setup is shown in Fig. 1.

Analysis Methods

Chemical Oxygen Demand (COD) Analysis

COD analysis was performed using standard methods (5220-B). For COD measurements, first solutions were prepared, and a calibration curve was created. The chemicals used in the preparation and analysis of the solutions are listed below.

Potassium Hydrogen Phthalate: ($C_8H_5KO_4$, M_A = 204.23 g/mol) 850 mg of $C_8H_5KO_4$ was made up to 1 L with distilled water. It was used in the preparation of the standard calibration curve for the COD analysis.

Shredding solution: 10,216 g of Potassium Dichromate ($K_2Cr_2O_7$) and 33 g of mercury sulfate ($HgSO_4$) were dissolved in 167 mL of concentrated sulfuric acid and the solution was prepared by making up to 1 L with distilled water.

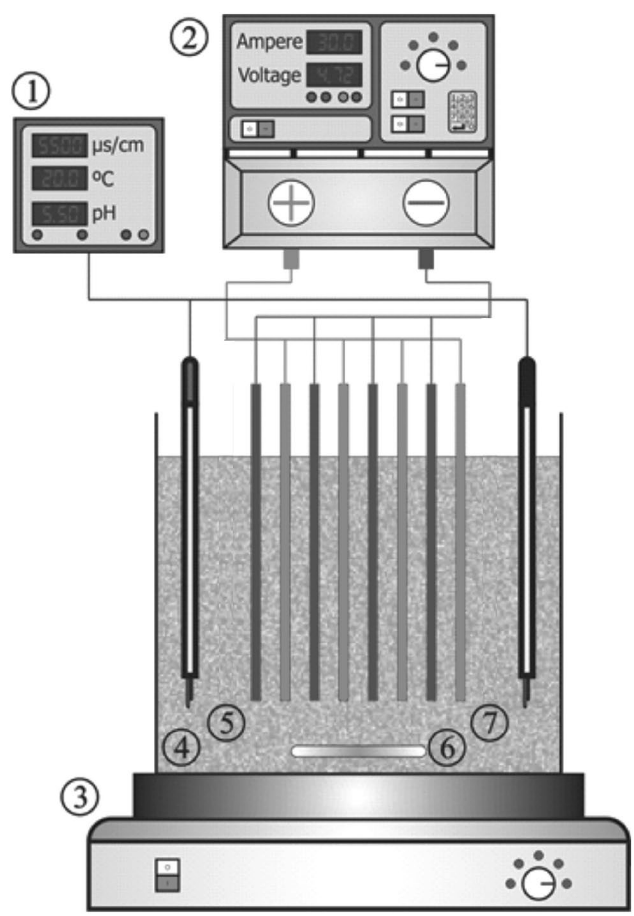

Fig. 1 Electrochemical reactor setup (1—multi-parameter meter, 2—direct current power supply, 3—magnetic stirrer, 4—wastewater, 5—steel cathode, 6—magnet, 7—Ti/IrO_2/RuO_2 anode)

Acid solution: It was prepared by dissolving 11 g of Ag_2SO_4 in 1 L of concentrated sulfuric acid. The solution was made ready by waiting for 1 day.

COD measurements were made according to standard methods. The solutions to be used were prepared as above, the calibration curve was drawn, and the measurements were made after the necessary procedures. COD, color, turbidity and SS removals from wastewater were investigated. Energy consumption and COD removal efficiencies are calculated using the formulas below:

$$\text{Energy consumption}: \left(\text{kW}-\text{h/m}^3\right) = \frac{V \times I \times t}{v} \quad (1)$$

where V (Volt) is the potential difference, I (ampere) is the current intensity, t; (hour) is the time, and v (m^3) is the SWW volume.

Removal efficiency:

$$\eta(\%) = \left(\frac{C_0 - C_e}{C_0}\right) \times 100 \quad (2)$$

where C_0 and C_e refer to "initial and final pollutant concentrations.

The reactions during indirect electro-oxidation are shown in the equations below. Hypochlorite (ClO^-) is a strong oxidizer that can oxidize organic matter in wastewater (Fil 2014).

Anodic reactions:

$$2Cl^- \rightarrow Cl_2 + 2e^- \quad (3)$$

$$6HOCl + 3H_2O \rightarrow 2ClO_3^- + 4Cl^- + 12H^+ + 1.5O_2 + 6e^- \quad (4)$$

$$2H_2O \rightarrow O_2 + 4H^+ + 6e^- \quad (5)$$

Solution reactions:

$$Cl_2 + H_2O \rightarrow HOCl + H^+ + Cl^- \quad (6)$$

$$HOCl \rightarrow H^+ + OCl^- \quad (7)$$

Cathodic reactions:

$$2H_2O + 2e^- \rightarrow 2OH^- + H_2 \quad (8)$$

$$OCl^- + H_2O + 2e^- \rightarrow Cl^- + 2OH^- \quad (9)$$

The realization of anodic and cathodic events depends on the solution–anode interface, the adsorbing of ions or molecules on the electrode surface and their electrochemical reaction, the properties of the electrode material, ambient conditions, temperature, etc. dependent on factors (Fil 2014). The oxidation and reduction happen on the surface of the two different electrodes and compete favorably with electron/hole recombination (Leng et al. 2006; Zarei and Ojani 2017; Ebraheim et al. 2022). The characteristics of the wastewater used in the studies are shown in Table 1.

Results and Discussion

Effect of SE Type

The effect of SE type on removal efficiency was investigated for $Ti/IrO_2/RuO_2$ anodes. At the same concentrations (0.2 M), different SE were tested at 400 rpm stirring speed, 4.06 mA/cm^2 current intensity, and natural pH (≈7) conditions. In the experiments carried out at the end of the 3-h reaction time to examine the SE effect, the COD efficiency obtained in the studies without NaCl, KCl, NaNO3, Na2SO4, and SE was found to be 66.46%, 54.50%, 30.88%, 25.52%, and 20.88%, respectively. Color removal efficiencies were 98.67%, 98.26%, 94.95%, 91.35% and 81.96%, respectively. The turbidity removal efficiencies were 98.47%, 94.81%, 87.89%, 83.25%, and 73.95%, and the SS removal efficiencies were 98.91%, 98.30%, 95.65%, 91.35% and 85.61%, respectively. For Ti/Pt anode the COD removal efficiencies were 80.05%, 73.67%, 57.42%, 37.63% and 25.03% for NaCl, KCl, $NaNO_3$, Na_2SO_4 and without SE, respectively. Color removal efficiencies were 98.64%, 97.68%, 93.94%, 91.57% and 86.50%, respectively. The turbidity removal efficiencies were 99.18%, 97.55%, 94.47%, 89.34% and 80.96%, respectively. SS removal efficiencies were found to be 98.47%, 98.01%, 95.72%, 92.28% and 85.15%, respectively. It was shown that the removal efficiency was significantly increased by all SE used in the studies. NaCl and KCl salts were found to be more efficient at both anodes. The effect of NaCl on purification is also seen in other studies in the literature (Yıldız et al. 2008; Carneiro et al. 2018; Belal et al. 2021). The reason for the higher efficiency in NaCl and KCl electrolytes is the chlorine ions in their structures. Chlorine facilitates the breakdown of impurities by increasing the conductivity more. $NaNO_3$ and Na_2SO_4, the other SE types, were less effective in breaking down pollutants. In this case, it can be attributed to the reduction of the activity of the electrode surface by covering the anode surface like a film. These electrolytes do not contain chlorine ions in their structure and can be converted into more stable media types that cannot be oxidized directly by electrolysis. These observations are confirmed by other studies (Awad and Galwa 2005). The results are shown in Fig. 2A, B.

Table 1 Parameters measured in wastewater

Parameters	Concentration (mg/L)			
	Highest	Lowest	Average	Standard deviation
Total COD	6691.20	626.45	3099.82	1208.05
Dissolved COD	6565.80	605.34	2726.96	1036.59
DCOD/TCOD	1.00	0.57	0.87	0.10
BOD	5145.00	325.00	2173.00	627.12
Suspended Solid	520.00	35.00	158.91	94.55
Total Solids	13,635.00	310.90	2688.30	2156.27
Total Nitrogen	632.00	48.00	213.67	163.82
Ammonium Nitrogen	144.00	2.30	50.96	44.15
Nitrate Nitrogen	44.00	5.00	13.36	9.62
Total Phosphorus	80	7	33	18
Oil–grease	387.50	21.4	124.7	99.84
pH	7.8	5.9	6.3	1.24

Effect of SE Concentration

In the studies using $Ti/IrO_2/RuO_2$ anode, wastewater was examined at natural pH, mixing speed of 400 rpm and current density of 4.06 mA/cm^2 at concentration values of 0 M, 0.1, 0.2, 0.3, and 0.4 M. COD removal efficiencies were found to be 20.88%, 52.25%, 66.46%, 70.14%, and 74.48%, respectively. The optimal concentration was determined to be 0.2 M, because, as shown in Fig. 2, the removal efficiency likewise rose as the SE concentration increased. However, the efficiency did not change much after 0.2 M. The COD removal efficiencies at 0 M (without SE), 0.1 M, 0.2 M, 0.3 M, and 0.4 M are, respectively, 25.03%, 67.25%, 80.05%, 83.36%, and 85.78% in experiments using Ti/Pt as the anode material. The results are shown in Fig. 2C, D.

Effect of Wastewater Initial pH Value on Removal

The effect of the pH value of the wastewater in the electrochemical process is effective both in the use of electricity and in the dissolution of metal hydroxides. It has been shown that the greatest effect of removing contaminants from wastewater occurs at pH values of about 7 (Druskovic et al. 2021). pH is an important factor for the oxidation of many contaminants by EO, thus directly affecting process performance. Ti/Pt electrodes are categorized as active material (Martinez-Huitle and Ferro 2006; Martínez-Huitle and Panizza 2018). In the EO process, hydrogen ions are produced when an oxygen formation reaction takes place, which can cause a reduction in wastewater pH (Iskurt et al. 2020). In the experiments using $Ti/IrO_2/RuO_2$ as the anode material, 0.2 M NaCl, pH 3.0, pH 7 (natural pH), 9.0, and 11.0 at 25 °C constant temperature, 400 rpm stirring speed, and 4.06 mA/cm^2 current density were studied. Based on the results, it was determined that the wastewater's natural pH value provided the best treatment efficiency. As the

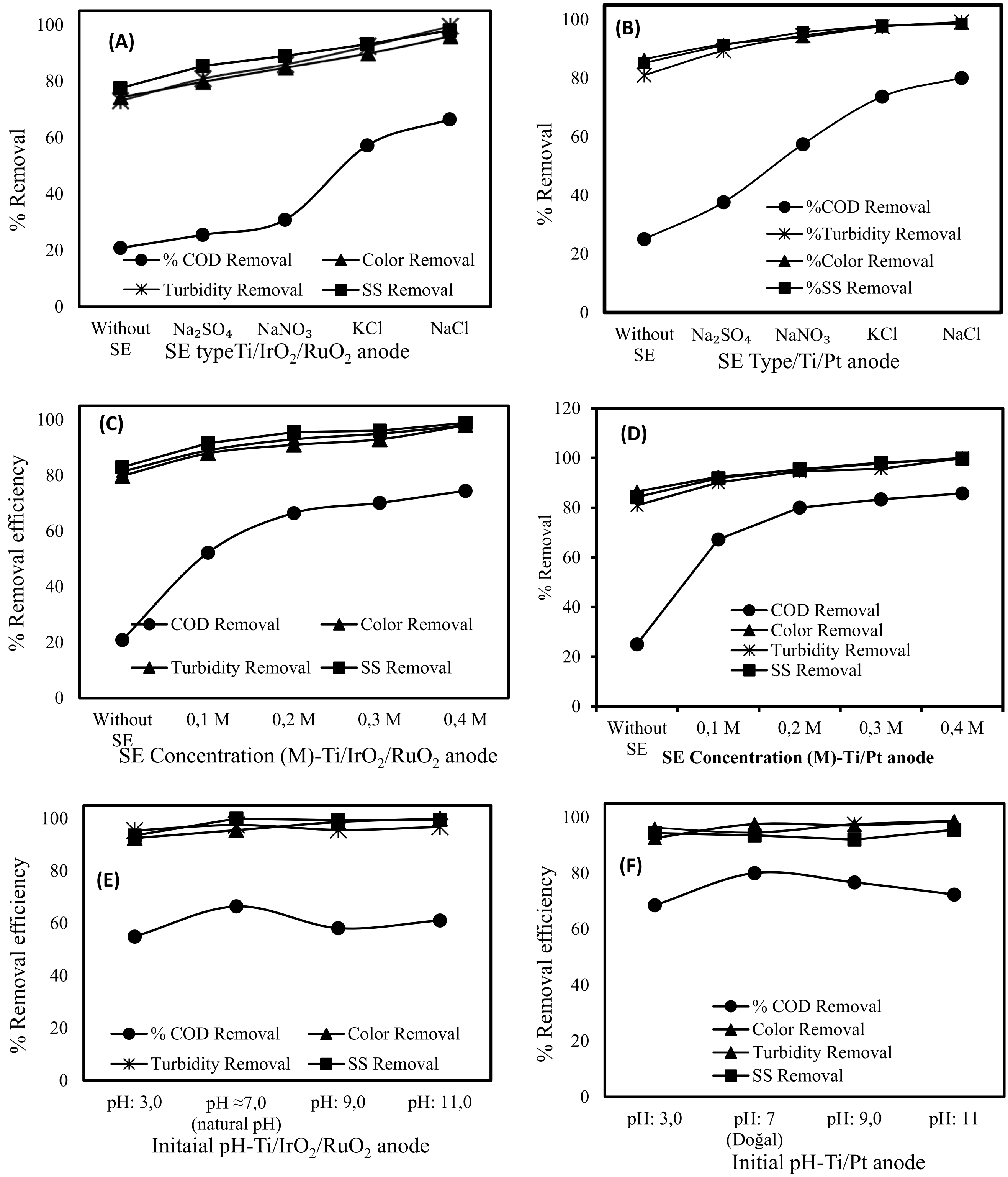

Fig. 2 Effect of SE type (**A**, **B**), SE concentration (**C**, **D**), initial pH (**E**, **F**) on color turbidity and SS removal for both anodes

OH ion release increases with the reactions taking place at the cathode and anode, the pH rises. Where EO predominates, pH tends to remain constant or rise slightly (Ozturk and Yilmaz 2019). The pH of the medium is more acidic or basic, depending on whether it is $HOCl^-$ or OCl^-. Decomposition of organic compounds can occur at different pHs.

Maximum removal efficiency at initial pH (7.03) can be explained by this approach. Therefore, it can be said that the removal efficiency of the EO process is not only related to the initial wastewater pH, but also to the change in pH during the process (Ozturk 2019). The Ti/Pt used in the trials as the anode material was assessed under the same conditions and pH values, and it was found that the natural pH value generated the anodes' highest efficiency. The effectiveness of both anodes was shown to be diminished under severely acidic conditions. Figure 2E, F displays the outcomes.

Effect of Current Density on Removal Efficiency

The applied current density, defined as the ratio of the applied current to the active surface area of the electrodes, is one of the key design parameters in electrochemical treatment (Mohtashami and Shang 2019). In the experiments using $Ti/IrO_2/RuO_2$ and Ti/Pt anode as anode material, current densities of 4.06 mA/cm^2, 6.09 mA/cm^2, 8.12 mA/cm^2, 10.15 mAcm^2, 12.18 mA/cm^2 were studied. The COD removal efficiencies for the $Ti/IrO_2/RuO_2$ anode were 66.46%, 74.47%, 82.36%, 94.57% and 98.87%, respectively. For Ti/Pt anode, 80.05%, 87.29%, 95.76%, 97.86% and 99.70% were found, respectively. In the obtained results, it was observed that the removal efficiency increased as the current density increased. The highest purification efficiency was achieved at the current density of 12.18 mA/cm^2. In addition, the removal time is decreased as the current density rises. Low current prevents the electrodes from oxidizing and coagulating, because they lack the necessary power. These findings demonstrate that running at low current density is more advantageous for anode performance and energy efficiency (Can et al. 2019). The results are shown in Fig. 3G, H.

Energy Consumption

Effect of SE Type on Energy Consumption

The effect of SE type is natural pH for both anodes, current density of 4.06 mA/cm^2, concentration of 0.2 M and 400 rpm mixing speed and energy consumption values were found in the data obtained from these results. The effect of SE type on energy consumption for $Ti/IrO_2/RuO_2$ anode is as follows: Without SE: 295.0 kWh/m^3, $NaNO_3$:223.6 kWh/m^3, Na_2SO_4:210.5 kWh/m^3, KCl:193.5 kWh/m^3 NaCl:183.6 kWh /m^3. The energy consumptions for Ti/Pt anode without SE, $NaNO_3$, Na_2SO_4, KCl, NaCl are as follows: 275 kWh/m^3, 245.5 kWh/m^3, 227.3 kWh/m^3, 187.3 kWh/m^3, 210.7 kWh/m^3. When the results were examined, it was seen that the SE significantly affected energy consumption. In the results, the minimum energy consumption was obtained in NaCl for the $Ti/IrO_2/RuO_2$ anode and in the KCl electrode for the Ti/Pt anode. Because salts containing chlorine reduce energy consumption by increasing conductivity more. Similar results are also available in the literature (Yıldız et al. 2008; Sivri et al. 2020). Experiments without SE had the highest energy consumption for both anodes. All tests utilizing SE used less energy. This is because the utilized electrolytes have extremely high levels of solubility and ionization in water, which improves the solutions' electrical conductivity. With an increase in the solution's electrical conductivity, the applied potential difference decreases. Less energy will be consumed as a result. The results are shown in Fig. 4A.

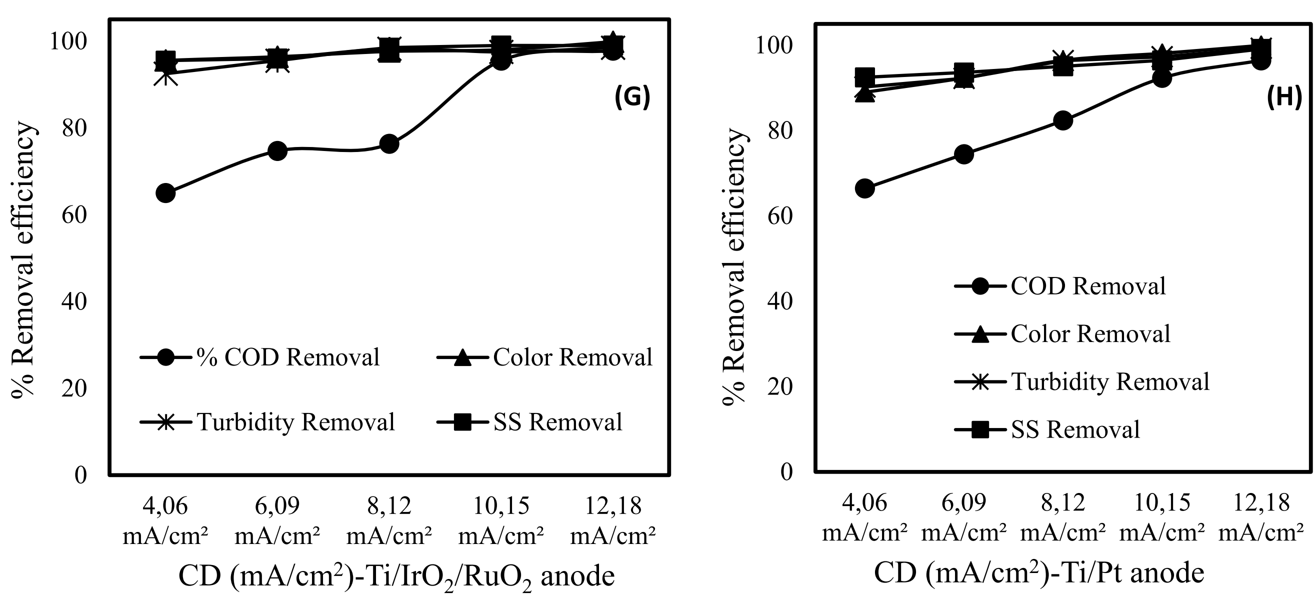

Fig.3 Effect of current density on COD, color turbidity and SS removal efficiencies.(Ti/IrO2/RuO2–Ti/Pt anode)

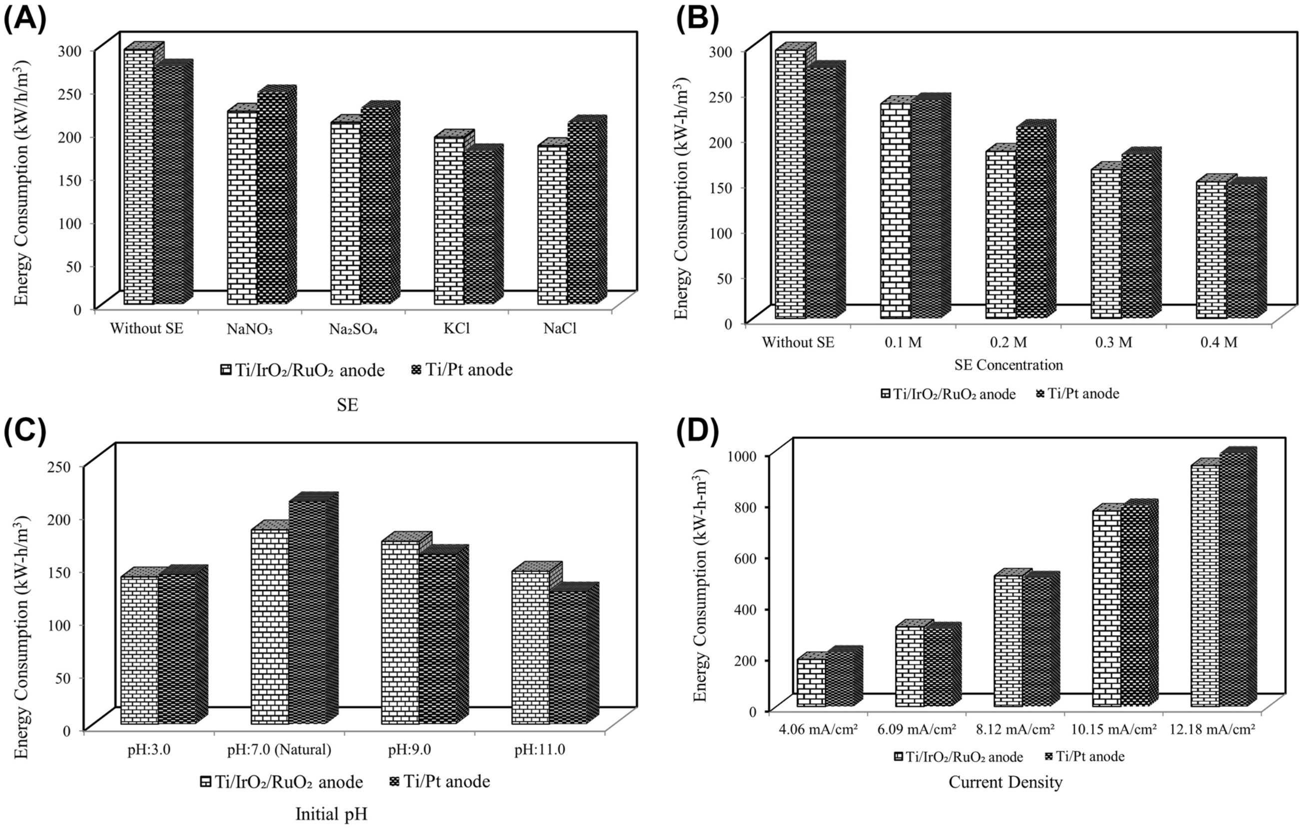

Fig. 4 Energy consumptions (**A** SE type, **B** SE concentration, **C** initial pH, **D** CD)

Effect of SE Concentration on Energy Consumption

The effect of SE concentration on energy consumption was investigated and consumption values for $Ti/IrO_2/RuO_2$ and Ti/Pt anodes were calculated with the help of formula (1). The studies were carried out at a current density of 4.06 mA/cm^2, natural pH(~ 7) and a stirring speed of 400 rpm. The energy consumption values for the SE concentration are as follows for the $Ti/IrO_2/RuO_2$ anode: Without SE: 295.0 kWh/m^3,0.1 M: 245.0 kWh/m^3, 0.2 M: 183.6 kWh/m^3, 0.3 M: 163.6 kWh/m^3, 0.4 M: 150.2 kWh/m^3. The energy consumption for the Ti/Pt anode without SE is, respectively: without SE: 275.5 kWh/m^3, 0.1 M:240.0 kWh/m^3, 0.2 M:210.7 kWh/m^3 0.3 M:180.5 kWh/m^3, 0.4 M:147.3 kWh/m^3. As the SE concentration increases, energy consumption is seen to decrease. The reason for the drop in energy consumption at high concentrations is because of the increase in conductivity of the wastewater and the potential difference needed to generate the same amount of current in the system is reduced. This results in a reduction in energy consumption. As shown in the figures, the increased concentration of SE significantly reduces energy consumption. The results are shown in Fig. 4B.

The Effect of Wastewater Initial pH Value on Energy Consumption

With a $Ti/IrO_2/RuO_2$ and Ti/Pt anode, energy consumption levels were determined for pH values of 3.0, 7.0, 9.0, and 11.0 with 0.2 M NaCl, 4.06 mA/cm^2 current density, and 400 rpm stirring speed. The $Ti/IrO_2/RuO_2$ anode was found to have an energy consumption of $7 > 9 > 3 > 11$, respectively. It was determined to be $7 > 9 > 11 > 3$ for the Ti/Pt anode. As can be seen from the results, the highest energy consumption is at pH 7. Because in order for energy consumption to be low, the conductivity of the medium must be high. To adjust the initial pH of the wastewater to the desired initial pH values, In the experiments conducted with constant current density, the supporting electrolyte (NaOH) added to the wastewater increased the conductivity of the wastewater, and the increase in the conductivity caused the voltage applied to the system to decrease. The decreasing potential difference also resulted in lower energy consumption values. The results are shown in Fig. 4C.

Effect of Current Density on Energy Consumption

The effect of current density applied on energy consumption in electro-oxidation experiments carried out at different current densities was investigated. An increase in current density increases the voltage applied to the system, and with an increase in voltage, energy consumption increases. In addition, according to Faraday's Law rules, the increase in current density causes a decrease in electrode life (Ratna Kumar et al. 2004). For both anode 4.06 mA/cm^2,6.09 mA/cm^2, 8.12 mA/cm^2,10.15 mA/cm^2, and 12.18 mA/cm^2 current densities were studied. The energy consumption for the Ti/IrO_2/RuO_2 anode was found to be 183.6 kWh/m^3, 310.9 kWh/m^3, 529.1 kWh/m^3, 763.6 kWh/m^3, 940.9 kWh/m^3, respectively; for Ti/Pt anode, it was found as 210.7 kWh/m^3, 302.7 kWh/m^3, 501.8 kWh/m^3, 784.1 kWh/m^3, 988.2 kWh/m^3. As expected, as the current density increases, the electricity consumption also increases. As a result, the increase in current density significantly increases energy consumption. Which of the operating parameters should be considered from the results obtained is the priority? Because at low current density values, it takes a longer time for the system to reach equilibrium, and oxidation of organic matter in the environment takes longer. Energy consumption also decreases accordingly. As the current density increases, the reaction time shortens, and the energy consumption increases. While choosing the ideal current density, the current density with the lowest energy consumption should be taken into account, as well as the value with the fastest treatment time (Yildiz et al. 2007). The results are given in Fig. 4D. In addition, the COD color, turbidity and SS study results under the optimum conditions of the experiments are shown together in Fig. 5.

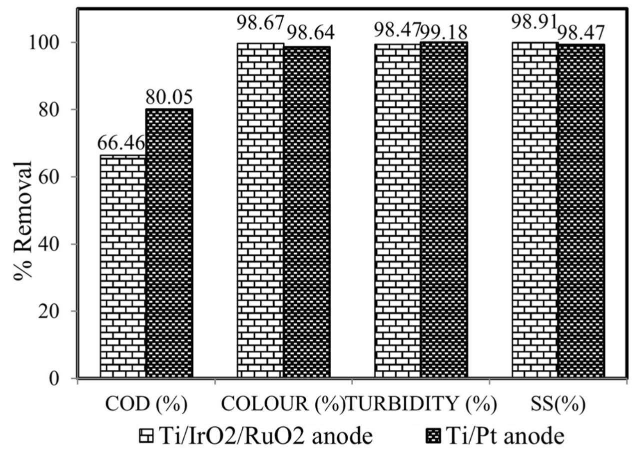

Fig. 5 Removal efficiencies calculated under optimum experimental conditions

Conclusions

In the present study, the authors aimed to simultaneously remove many pollution parameters from wastewater. Removal of COD, color, turbidity, SS of parameters from SWW by electro-oxidation was considered a suitable method. This study was carried out to compare the effect of different anodes on the removal efficiency in the treatment of SWW. From the results obtained for both anodes, it was seen that electro-oxidation provides an effective treatment for SWW. The study includes innovation in terms of testing and comparing different anodes in this wastewater. It allows to see different effects of the same results for all parameters. The wastewater treatment that was most effective, based on the data, was done at its natural pH level. NaCl was discovered to be the SE type that is most effective. Based on efficiency and cost, the SE concentration was set at 0.2 M. The COD removal efficiency was found to be 66.46% for the 80.05 Ti/IrO_2/RuO_2 anode under optimum conditions for Ti/Pt. The electricity consumption was 210.7 kWh/m^3 for 0.2 M NaCI at Ti/Pt anode and 183.6 kWh/m^3 at 0.2 M NaCl electrolyte for Ti/IrO_2/RuO_2 anode. In the selection of anode material, electricity consumption and chemical material cost can be compared and can be selected according to priority. As the current density increases, the voltage increases, so the energy consumption also increases. At high current density, the treatment time is shortened, but the energy consumption is increased. Besides, high voltage is corrosive to anode materials. According to the data obtained as a result of 3-h studies, it has been seen that the removal of color, turbidity and suspended solids from SWW provides a high removal rate of over 90% for all studies. However, for the use of these systems in larger areas, process sizing and the establishment of a system that will provide the necessary conditions are required. As a result, the use of both anodes in the treatment of SWW was deemed appropriate. Material selection can be made by considering the priority according to the cost expense preference. Both anodes can be preferred depending on the wastewater characteristics. These findings allow for the recommendation of Ti/IrO_2/RuO_2 anodes for decreased electricity usage. However, Ti/Pt should be chosen if efficiency is the top goal. Before starting therapy, a cost-efficiency evaluation should be conducted for this.

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Author Contributions Sermin Günaslan (MSc student) conducted all the experiments. Visualization and editing done by Baybars Ali Fil.

Declarations

Conflict of Interest The authors have no conflicts of interest to declare that are relevant to the content of this article.

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