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Reduction of Organic Pollutant Levels in Slaughterhouse Wastewater Using the Electrocoagulation Method

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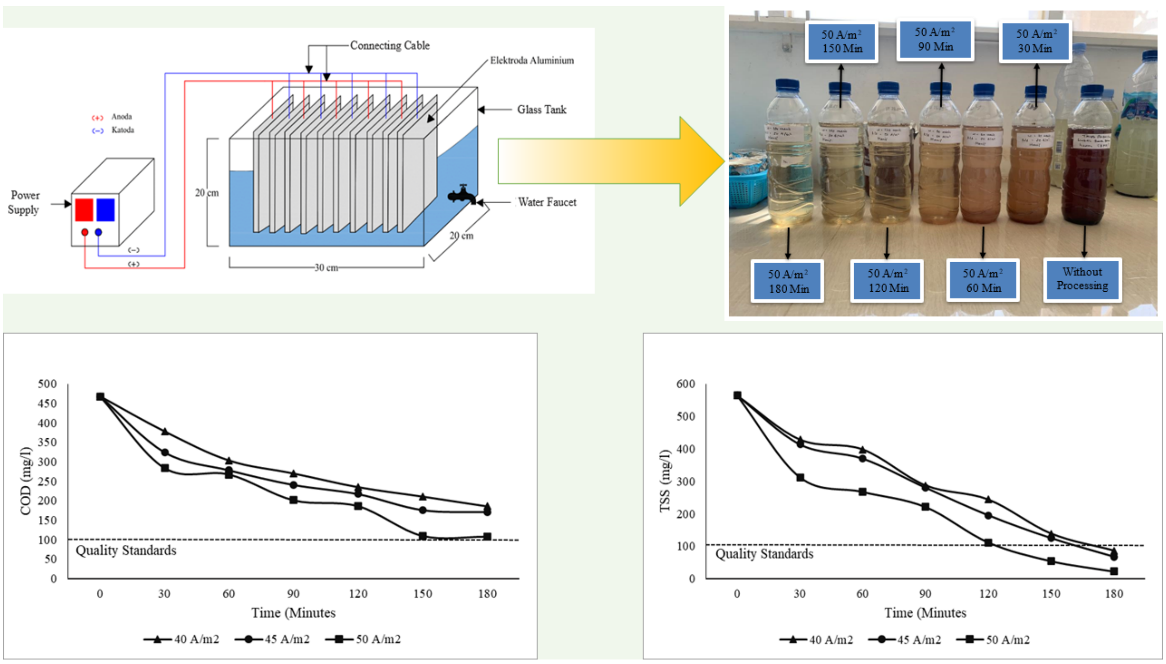
GRAPHICAL ABSTRACT



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ABSTRACT

The increasing demand for meat has increased the number of livestock slaughtered. An increase in cuts means an increase in the waste generated. One of the wastewater treatment techniques is the aluminium (Al) plate electrocoagulation method. Electrocoagulation is a coagulation process or coagulation and deposition of fine particles in wastewater by utilizing electrical energy through an electrolysis process so that it can degrade pollutants or contaminants in RPH liquid waste. This research was conducted to determine the effect of variations in current density and contact time and their effectiveness in reducing levels of COD and TSS, as well as increasing DO and optimum pH changes in abattoir waste. The current density variations used are 40, 45 and 50 A/m^2 with 30, 60, 90, 120, 150 and 180 minutes of contact times. The effectiveness of electrocoagulation on the decrease in the highest TSS value was 96.04%, and COD was 76.81%, with a contact time of 180 minutes and a current density of 50 A/m2. The pH value increased at 50 A/m^2 current density with a contact time of 180 minutes, an increase from 5.9 to 8.1, and the DO value increased at a current density of 50 A/m^2 with a contact time of 180 minutes, an increase from 1.2 to 4,3 mg/L.

1. INTRODUCTION

Slaughterhouses produce two types of waste: solid waste and liquid waste. Solid waste includes feathers, rumen contents, and animal feces, while liquid waste is blood and fat from animal washing [1]. Animal blood, organic particles, suspended solids, and colloidal components such as lipids, proteins, and cellulose are commonly found in slaughterhouse wastewater. These are present in significant quantities in slaughterhouse liquid waste [2]. Due to its high concentration of organic pollutants, slaughterhouse wastewater has the potential to harm the environment and emit a very pungent odor. Its decomposition process can cause respiratory problems in humans, leading to physiological reactions such as nausea and loss of appetite [3].

In principle, the electrocoagulation method can reduce pollutants due to the release of natural coagulants from the electrodes during the electrolysis process. This principle is similar to adding coagulants using chemical materials [4]. Electrocoagulation is one type of coagulation that offers many advantages, including simple equipment, short reaction times, and relatively low maintenance costs [5]. The electrocoagulation method produces fewer dissolved ions than other coagulants, as the addition comes solely from aluminium metal, which dissolves into Al^{3+}. The higher the applied current, the greater the release of Al^{3+} ions from the electrode, forming $Al(OH)_3$ flocs. At the cathode, hydrogen gas bubbles are generated, which help lift suspended flocs that cannot settle within the cell [6].

Several previous studies on the electrocoagulation method have shown that contact time, current density, and the number of electrodes influences pollutant removal's effectiveness. For instance, research by Hernaningsih [7] demonstrated that using aluminium and iron plates in the electrocoagulation procedure could achieve optimal pollutant removal efficiency. The recovery time for four electrodes was shorter, requiring only 70 minutes, compared to 90 minutes with two electrodes. Four electrodes proved more effective than two, as evidenced by a more significant reduction in TSS and TDS levels and higher recovery rates. Additionally, the reaction time was relatively shorter with four electrodes. Based on the study by Ananda et al. [8], it was found that electrocoagulation using aluminium plates provided the best results after 10 hours, achieving a COD reduction of 97.25% and leaving a final wastewater COD concentration of 122.88 ppm in tofu wastewater.

Meanwhile, Nur and Jatnika [9] applied electrocoagulation with aluminium electrode pairs to recycle hotel greywater using batch and continuous reactor variations. The research showed that the optimum results in the batch process were achieved with a current density of 104 A/m^2, requiring a detention time of 15 minutes, with removal efficiencies of 87.73% for turbidity, 87.48% for COD, and 77.50% for oil and grease. In the continuous electrocoagulation system with variations in contact time, the best results were obtained at a detention time of 16 minutes, with removal efficiencies of 89.32% for turbidity, 89.09% for COD, and 89.79% for oil and grease.

This study aims to determine the effectiveness of slaughterhouse wastewater treatment using the electrocoagulation method with aluminium electrodes, focusing on the impact on pH, COD, TSS, and DO values. Additionally, it evaluated the effect of variations in current density and contact time on changes in pH, COD, TSS, and DO values in slaughterhouse wastewater. This study investigates the effectiveness of electrocoagulation using aluminium electrodes for slaughterhouse wastewater treatment, focusing on the simultaneous impact on pH, COD, TSS, and DO levels, which has not been comprehensively explored in previous research. Unlike prior studies that primarily examined single pollutant removal, this research evaluates the combined effect of varying current densities and contact times to determine optimal conditions for enhanced treatment efficiency. The findings contribute to advancing electrocoagulation technology by demonstrating its potential for improving wastewater quality while minimizing operational complexity and chemical usage.

2. EXPERIMENTAL METHODS

The wastewater used in this study was from a slaughterhouse wastewater treatment unit (UPTD RPH) in Lambaro Village, Ingin Jaya Subdistrict, Aceh Besar District. Sampling of wastewater was conducted using the grab sampling method, which involves instantaneous sample collection. The wastewater sample from the slaughterhouse (RPH) was collected following the procedures outlined in SNI 6989.59:2008. A long-handled dipper was used to collect the sample, which was then transferred into a 10 L plastic container following the standards specified in SNI 6989.59:2008. The container used for sampling was required to meet specific criteria, including being made of a material that does not alter the sample's properties, being easy to clean from previous residues, being convenient for transport, allowing easy transfer into storage bottles without leaving suspended residues, and having a capacity that aligns with the research objectives.

A total of 8 L of wastewater was used. The research reactor was made of glass with a thickness of 5 mm, measuring 30 cm in length, 20 cm in width, and 20 cm in height. The electrodes consisted of aluminium plates serving as both the anode and cathode. The electrode plates measured 20 cm in length, 16 cm in width, and 1 mm in thickness. The electrodes were supplied with an electric current from a power supply at current densities of 40, 45, and 50 A/m^2, connected through cables, with contact times varying between 30, 60, 90, 120, 150, and 180 minutes. The electrocoagulation reactor is shown in Figure 1.

The pH measurement was conducted following SNI 6989.11-2019. The wastewater sample was first shaken until homogeneous, and then 100 mL of the sample was placed in a Pyrex beaker glass. A pH meter was activated, and its electrode was immersed into the sample. The reading was observed until it stabilized, and the measured pH value was recorded.

The Chemical Oxygen Demand (COD) measurement was performed according to SNI 6989.2:2019. A 2.5 mL wastewater sample was placed in a COD tube, adding 1.5 mL of a potassium dichromate ($K_2Cr_2O_7$) solution and 3.5 mL of sulfuric acid (H_2SO_4). The tube was then sealed. A COD reactor was set to heat up to 150°C, and once the temperature was reached, the COD tube was inserted into the reactor and left for 2 hours. After cooling, the sample was measured using a COD meter, and the final COD value was recorded.

The Total Suspended Solids (TSS) measurement was based on SNI 06-6989.3:2019. A filtering process was performed using filtration equipment, where the filter paper was first moistened with deionized water. The wastewater sample was mixed until homogeneous, and a specific volume was then quantitatively transferred onto the filtration medium while activating the vacuum system. The filter was rinsed three times using 10 mL of deionized water each time, ensuring all residues were collected. The glass fiber filter was carefully removed and placed into a weighing dish. The sample was then dried in an oven at 103–105°C for at least 1 hour, cooled in a desiccator, and weighed. The TSS value was calculated based on the final weight.

The Dissolved Oxygen (DO) measurement followed SNI 06-6989.14-2004. The wastewater sample was first shaken until homogeneous, and 100 mL was placed in a Pyrex beaker glass. A DO meter was activated, and its electrode was immersed into the sample. The reading was monitored until it stabilized, and the recorded DO value was noted. The study was conducted in the Multifunction Laboratory at Universitas Islam Negeri Ar-Raniry Banda Aceh.

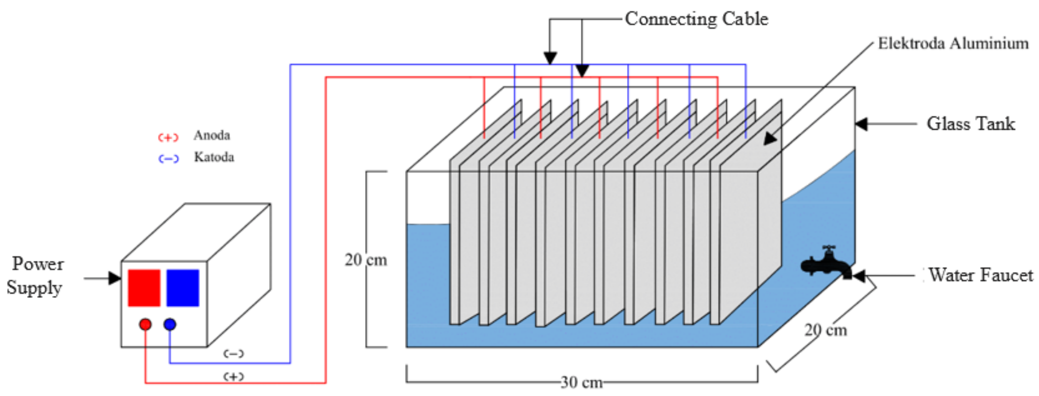

Figure 1. The model of reactor.

3. RESULTS AND DISCUSSIONS

3.1. Characteristics of Wastewater from Vehicle Washing Businesses

Table 1 presents the quality of slaughterhouse wastewater before treatment. Based on the initial measurement results, the parameters TSS, COD, pH, and DO exceeded the permissible limits for slaughterhouse wastewater quality or did not meet the standards established in the Indonesian Ministry of Environment Regulation No. 5 of 2014 on Wastewater Quality Standards. Therefore, slaughterhouse wastewater must undergo treatment before being discharged into water bodies.

TABLE 1. Initial Analysis Results of COD, TSS, pH and DO Parameters

Parameters	Units	Pre-experiment	Quality Standart
COD	mg/L	467	200
TSS	mg/L	564	100
pH	-	5.9	6-9
DO	mg/L	1.2	-

(Source: Ministry of Environment and Forestry Regulation No. 5 of 2014)

Table 2 below presents the COD, TSS, pH, and DO analysis results after the electrocoagulation process.

TABLE II. Analysis results of COD and TSS parameters for wastewater from the Lambaro slaughterhouse, Ingin Jaya Subdistrict, Aceh Besar District.

Current Density (A/m^2)	Time (minutes)	COD (mg/l)				TSS (mg/l)			
		QS	IMR	PEMR	DE (%)	QS	IMR	PEMR	DE (%)
40	30	200	467 ± 3.33	377.7 ± 18.2	19.12	100	563.7 ± 4.6	428.3 ± 17.8	24.02
	60			303.3 ± 5.6	35.05			398 ± 15.5	29.40
	90			270.3 ± 11.7	42.12			287.3 ± 9.5	49.03
	120			235.3 ± 10.7	49.61			243.7 ± 18.9	56.77
	150			211.3 ± 5.7	54.75			139 ± 6.7	75.34
	180			186.3 ± 4.5	60.18			86.3 ± 6.0	86.41

45	30	324 ± 9.2	30.62	413.3 ± 13.1	26.68
	60	278 ± 3.9	40.41	369.7 ± 8.0	34.42
	90	240.7 ± 9.9	48.46	280.3 ± 4.2	50.27
	120	217.3 ± 5.4	53.47	195.3 ± 6.0	65.35
	150	176.3 ± 5.7	62.31	125 ± 4.5	77.83
	180	171.3 ± 2.6	63.32	67.7 ± 4.8	87.99
50	30	283.7 ± 6.5	38.18	312.3 ± 8.7	44.60
	60	267.3 ± 5.4	42.76	267.3 ± 14.1	52.58
	90	201.3 ± 5.7	59.9	221 ± 14.4	60.79
	120	186.3 ± 5.4	60.17	111.7 ± 1.7	80.18
	150	110.3 ± 6.2	76.38	54.3 ± 5.6	90.37
	180	108.3 ± 2.1	76.81	22.3 ± 1.2	96.04

*Description: Quality Standard (QS), Initial Measurement Results (IMR), Post-Experiment Measurement Results (PEMR), Degradation Effectiveness (DE).

TABLE III. Analysis results of pH and DO parameters for wastewater from the Lambaro slaughterhouse, Ingin Jaya Subdistrict, Aceh Besar District.

Current Density (A/m^2)	Time (minutes)	pH			DO (mg/l)	
		QS	IMR	PEMR	IMR	PEMR
40	30			6.1		1.4
	60			6.6		1.6
	90			7		2.1
	120			7.2		2.5
	150			7.4		3.2
	180			7.8		3.9
45	30			6.2		1.4
	60			6.7		1.7
	90	6-9	5.9	6.9	1.2	2
	120			7.4		2.7
	150			7.6		3.5
	180			7.9		4
50	30			6.4		1.7
	60			6.9		1.9
	90			7.3		2.5
	120			7.6		3
	150			7.9		3.9
	180			8.1		4.3

*Description: Quality Standard (QS), Initial Measurement Results (IMR), Post-Experiment Measurement Results (PEMR), Degradation Effectiveness (DE).

Figure 2 below shows the physical appearance of vehicle-washing wastewater before and after the electrocoagulation process.

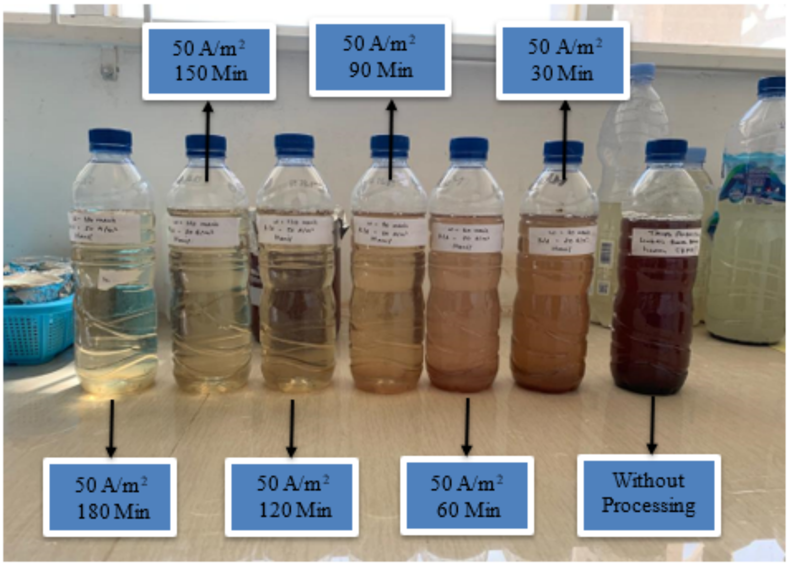

Figure 2. Wastewater Before and After Treatment

3.2. Effectiveness of Pollutant Reduction in Wastewater

1) The Effect of Current Density and Time on the Effectiveness of COD Reduction

Based on the experimental results, the electrocoagulation process effectively reduced the COD levels of slaughterhouse wastewater to below the quality standards set by the Indonesian Ministry of Environment Regulation No. 5 of 2014. COD (Chemical Oxygen Demand) refers to the oxygen required to decompose organic compounds in water chemically. The high organic content from animal slaughter activities causes the high COD levels in slaughterhouse wastewater to exceed the quality standards. This organic content comprises carbon (C^{4-}), hydrogen (H^{+}), oxygen (O_2^{-}), nitrogen (N^{3-}), phosphorus (P^{3-}), and sulfur (S^{2-}) [10].

The organic content in slaughterhouse wastewater can be degraded through the electrocoagulation process. Theoretically, the principle of electrocoagulation involves the use of two types of electrodes (anode and cathode) that operate based on reduction and oxidation (redox) reactions [11]. Figure 3 illustrates the reduction in COD levels of slaughterhouse wastewater based on variations in contact time and current densities of 40 and 45 A/m². At a current density of 50 A/m², a significant reduction in COD was observed after 180 minutes of contact time, reaching a level of 108.3 mg/L. The degradation effectiveness of COD using electrocoagulation at a current density of 50 A/m² with 180 minutes of contact time reached 76.81%.

Using a higher current density accelerates the electrocoagulation process, as current density is directly proportional to the flowing electric current, by Faraday's law, as shown in Equation 1. A higher current increases the release of Al^{3+} ions from the electrode, forming $Al(OH)_3$ flocs. At the cathode, hydrogen gas bubbles are generated, which lift suspended flocs that cannot settle within the cell [6]. COD removal occurs as dissolved organic substances bind with the flocs, which trap pollutants in the slaughterhouse wastewater [9]. Additionally, contact time is a critical factor in the electrocoagulation process; the longer the contact time, the greater the removal of pollutants from slaughterhouse wastewater.

$$m = \frac{M \,.\, I \,.\, t}{n \,.\, F} \qquad (1)$$

Where m is the mass of dissolved metal (g), M is the molar mass of the electrode material (g/mol), I is the current applied (A), t is the electrolysis time (s), n is the number of electrons involved in the reaction, and F is Faraday's constant (96,485 C/mol).

The DO (Dissolved Oxygen) levels in untreated slaughterhouse wastewater were initially low, indicating excessively polluted water. Dissolved oxygen refers to the oxygen content dissolved in water and is essential for the survival of aquatic organisms such as plants and animals. Lower COD values correspond to higher DO levels, which indicate improved water quality [12]. High dissolved oxygen levels significantly impact the survival of aquatic organisms. Moreover, higher DO levels improve the ability of water bodies to oxidize and degrade organic pollutants.

Initial testing showed that the DO level was 1.2 mg/L. After electrocoagulation treatment, DO levels increased progressively over time. At a current density of 50 A/m² with 180 minutes of contact time, the DO level significantly increased, reaching 4.3 mg/L.

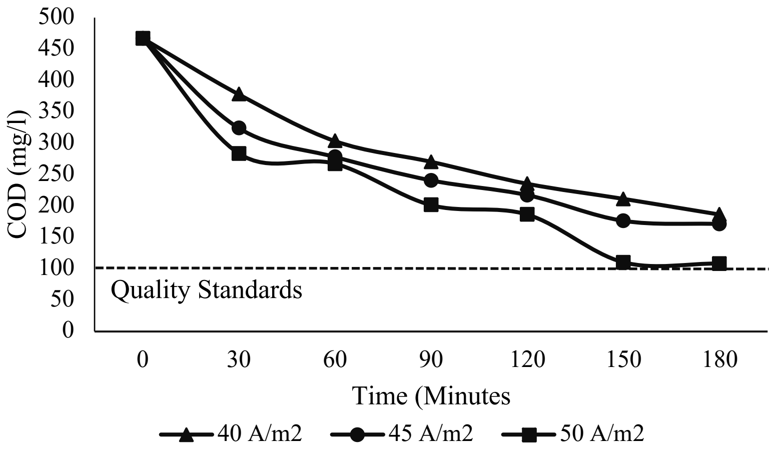

Figure 3. Graph of COD reduction for current density variations of 40, 45, 50 A/m² and contact times of 30, 60, 90, 120, 150, and 180 minutes.

2) The Effect of Current Density and Contact Time on the Effectiveness of TSS Reduction

The initial TSS value of slaughterhouse wastewater exceeded the quality standards of the Indonesian Ministry of Environment Regulation No. 5 of 2014. TSS (Total Suspended Solids) refers to insoluble solids that cause turbidity in water. The high TSS levels in slaughterhouse wastewater are due to animal blood, organic particles, suspended solids, and colloidal components such as lipids, proteins, and cellulose commonly found in slaughterhouse wastewater [2].

The initial TSS value of 563.7 mg/L was reduced to 22.3 mg/L at a current density of 50 A/m² with a contact time of 180 minutes. Theoretically, during the electrocoagulation experiment, the anode releases active coagulants in the form of Al^{3+} ions into the solution, while the cathode releases hydrogen gas (H_2) and hydroxide ions (OH^-) [13]. The release of Al^{3+} from the electrodes during the electrochemical process forms $Al(OH)_3$ flocs that bind contaminants in the wastewater [14]. The electrochemical reactions occurring at the electrodes are as follows.

Anode (Oxidation):
$$Al(s) \rightarrow Al^{3+}(aq) + 3e^-$$

Cathode (Reduction):
$$2H_2O(l) + 2e^- \rightarrow H_2(g) + 2OH^-(aq)$$

Formation of Aluminum Hydroxide Flocs:
$$Al^{3+}(aq) + 3H_2O(l) \rightarrow Al(OH)_3(s) + 3H^+(aq)$$

These $Al(OH)_3$ flocs bind the suspended solids in the slaughterhouse wastewater. Based on Figure 4, the electrocoagulation method achieved a maximum TSS reduction of 96.04% at a current density of 50 A/m² with a contact time of 180 minutes.

Contact time is one of the factors influencing the electrocoagulation process; the longer the contact time, the more significant the reduction in TSS [15]. This is also attributed to the fact that the amount of aluminium ions formed is directly proportional to the current flowing from the power supply to the electrodes. The current density of 50 A/m² uses a higher current than other current densities, and the higher the current density, the faster and more significant the reduction in TSS in slaughterhouse wastewater.

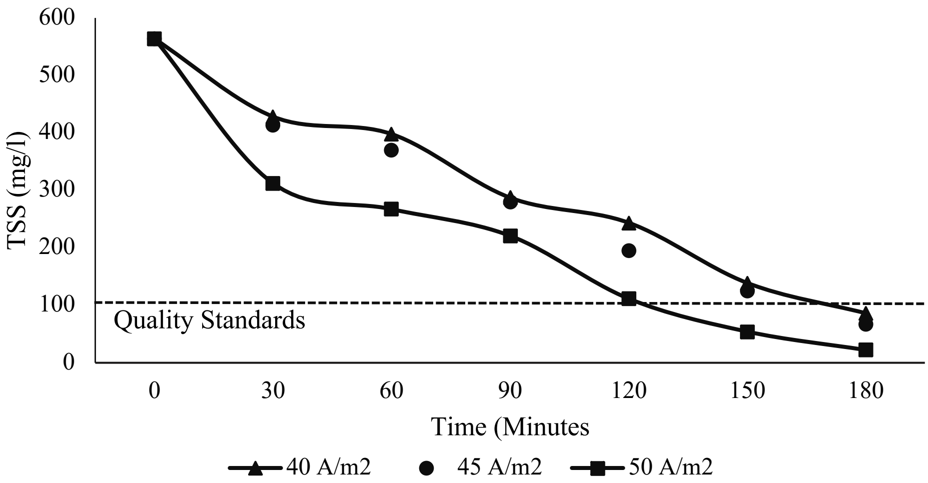

Figure 4. Graph of TSS reduction for current density variations of 40, 45, 50 A/m² and contact times of 30, 60, 90, 120, 150, and 180 minutes.

3) The Effect of Current Density and Contact Time on Changes in pH Parameter

The initial pH test result showed a pH value of 5.9. According to the Indonesian Ministry of Environment Regulation No. 5 of 2014, the permissible pH range for slaughterhouse wastewater discharged into the environment is 6-9. Therefore, the pH of the slaughterhouse wastewater did not meet the quality standards. The low pH value indicated that the wastewater was acidic. Juliasih and Amha [16] stated that low pH values suggest the presence of microorganism activity in the waste, which degrades easily decomposed organic matter into acids. Organic pollutants also cause acidity in slaughterhouse wastewater from slaughtering activities.

Figure 5 shows that the electrocoagulation method could increase the pH value over time. At a current density of 50 A/m² with a contact time of 180 minutes, the pH increased dramatically from 5.9 to 8.1.

The solution's pH changed and tended to increase over time. This is due to the acidic conditions at the cathode, where aluminium undergoes acid reduction, producing H_2 gas, while the aluminium anode undergoes oxidation, releasing Al^{3+} ions. The electrochemical reactions occurring at the electrodes are as follows.

Anode (Oxidation):

$Al(s) \rightarrow Al^{3+}(aq) + 3e^-$

Cathode (Reduction):

$2H_2O(l) + 2e^- \rightarrow H_2(g) + 2OH^-(aq)$

The H_2 gas generated facilitates the formation of hydroxide ions that bind pollutants in the wastewater, forming insoluble compounds that float to the surface of the reactor [17]. Each treatment showed increased in pH at contact times of 30, 60, 90, 120, 150, and 180 minutes.

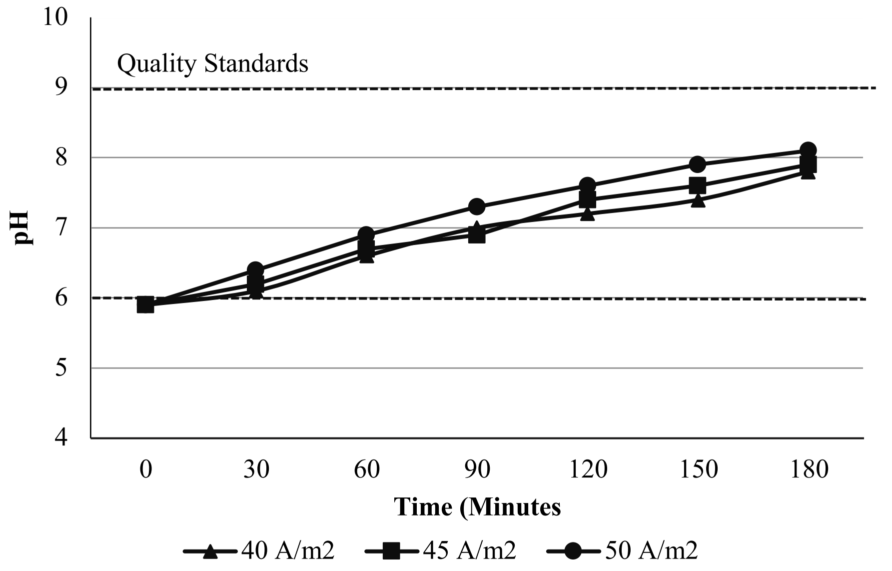

Figure 5. Graph of pH changes for current density variations of 40, 45, 50 A/m² and contact times of 30, 60, 90, 120, 150, and 180 minutes.

4. CONCLUSIONS

Treating slaughterhouse wastewater using electrocoagulation effectively reduced COD and TSS levels, increased DO, and altered pH values. The electrocoagulation method reduced the COD parameter across current density variations of 40, 45, and 50 A/m², with the most optimal results achieved at a current density of 50 A/m² and a contact time of 180 minutes, reaching 108.3 mg/L with an effectiveness of 76.81%. The method also reduced TSS levels across the same current density variations, with the optimal result obtained at a current density of 50 A/m² and a contact time of 180 minutes, reaching 22.3 mg/L with an effectiveness of 96.04%. Additionally, the electrocoagulation method adjusted the pH of slaughterhouse wastewater from 5.9 to 8.1 at a current density of 50 A/m² and a contact time of 180 minutes.

The high removal efficiency of COD and TSS suggests that this method can be implemented in slaughterhouses to improve wastewater quality before discharge, helping to meet environmental regulations and reduce pollution. The pH adjustment indicates that electrocoagulation removes contaminants and improves water quality for potential reuse in non-potable applications. Future research should explore the long-term performance of electrocoagulation under continuous operation, investigate the influence of different electrode materials on treatment efficiency, and assess the feasibility of integrating this method with other advanced wastewater treatment techniques to enhance overall effectiveness.

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