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Effect of Electrocoagulation on Improving the Quality of Palm Oil Liquid Waste

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Abstract

Palm oil liquid waste is difficult to handle due to the large amount and ineffective processing system. To overcome this problem, electrocoagulation process has been proven effective in treating various liquid waste. Therefore, this study aimed to identify a decrease in pollution load on palm oil mill secondary effluent (POMSE) in electrocoagulation process through a batch system. The process was carried out using a reactor from a power supply circuit, a voltmeter, a trophy cup, an aluminum electrode rod, and a magnetic stirrer. The electrodes used comprised aluminum measuring 12 x 2 cm, which were arranged bipolarly with a distance of 1 cm. The voltage variations used were 15, 20, and 25 volts with contact times of 30, 60, and 90 minutes. The objective of this study was to determine the performance of electrocoagulation to reduce the pollution load on POMSE under various operating conditions such as voltage and contact time. The results showed that the best treatment was obtained at a voltage of 25 volts for 30 minutes with the removal efficiency of chemical oxygen demand (COD), total suspended solids (TSS), turbidity, and color of 50.6%, 98.69%, 97.83%, and 88.71%, respectively. Cost calculation using the Activity-Based Costing (ABC) method. The operational costs required to process POMSE were found to be $ 0.98/m3.

Keywords: Aluminum electrode; Electrocoagulation; Palm Oil Mill Secondary Effluent; Wastewater Management

1. Introduction

Palm oil mill is a significant source of liquid waste capable of polluting the environment (Tamrin and Zahrim 2017). This waste is difficult to handle biologically, requiring a long time, and large land for effective processing (Lee *et al.,* 2019). The method of handling palm oil mill effluent (POME) by biological treatment or anaerobic process produces effluent in the form of palm oil mill secondary effluent (POMSE) (Zainuri *et al.,* 2018). Compared to POME and POMSE has distinctive characteristics, including brownish color, unpleasant odor, high pH (7 to 9) as well as lower biochemical oxygen demand (BOD) and chemical oxygen demand (COD) (Darajeh *et al.,* 2016; Shahrifun *et al.,* 2015). Additionally, it has COD 3234 - 3624 mg/L, (Shahrifun *et al.,* 2015),

BOD 1565 mg/L (Puasa *et al.,* 2021), pH 7.48 - 7.78, color 4191 - 4193 PtCo, and turbidity 650.35 - 655.56 NTU (Sidik *et al.,* 2019). POMSE also contains pollutants and is difficult to degrade biologically (recalcitrant) (Aziz *et al.,* 2020).

Electrocoagulation is a new environmentally friendly and cost-effective method that has been proven effective in eliminating contaminants in liquid waste using electric current (Padmaja *et al.,* 2020). According to previous studies, electrocoagulation is a simple and effective process where coagulant production is managed in situ through electrochemical oxidation of the anode (Khaled *et al.,* 2019). The working principle of electrocoagulation depends on using electrochemical cells to treat waste. Electrochemical cells consist of two electrodes, namely an anode and a cathode, which are inserted into the liquid waste and connected to an electrical circuit that includes a current source and a control device (Abbas and Ali 2018).

The method of electrocoagulation has been widely used to treat various liquid wastes. According to a previous study (Mahmad *et al.,* 2016), aluminum electrodes are the best electrodes for removing turbidity and color. A bipolar configuration with two electrodes (Al-Al) can reduce COD by up to 80% (Bote, 2021), using a voltage of 20 V with a residence time of 60 minutes. Another investigation (Sailah *et al.,* 2020) reported that electrocoagulation using a voltage of 20 V with a residence time of 60 minutes reduced TSS levels by 98.66%. The method has also been used (Safari *et al.,* 2016) to eliminate COD values in oil liquid waste using batch reactors to set aside COD values reaching 99.1%.

Therefore, this study aimed to determine the performance of electrocoagulation to reduce the pollution load on POMSE under various operating conditions such as voltage and contact time.

2. Methodology

2.1 Reactor design and setup

Palm oil liquid waste used in this study was the remaining result of biological handling in the form of POMSE from anaerobic pond effluent. According to Mollah *et al.,* (2001), a bipolar configuration with two electrodes is a configuration that is simple and easy to maintain. Sailah *et al.,* (2020) also reported that electrocoagulation using a voltage of 20 V with a residence time of 60 minutes could reduce TSS levels by up to 98.66%.

In this study, electrocoagulation process was carried out with a batch system using a reactor equipped with a power supply, voltmeter, goblet cup, aluminum electrode rod, and magnetic stirrer. A total of 500 mL of waste was put into a 1000 mL glass chamber, followed by the administration of electric current to the reactor containing 4 electrode rods measuring 12 x 2 cm. An illustration of the electrocoagulation device circuit is presented in Figure 1.

2.2 Experimental design

The electrodes were arranged bipolarly with a distance of 1 cm between the electrodes, with a combination of time and voltage presented in Table 1.
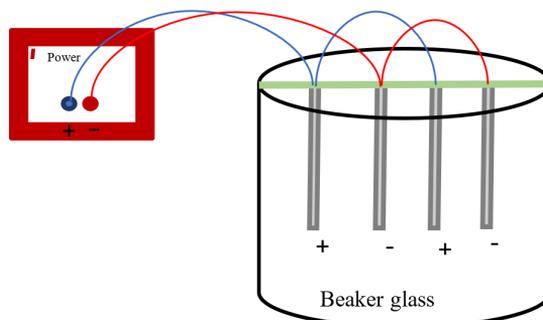

Figure 1. Schematic diagram of a batch electrocoagulation reactor

Table 1. Combination of electrocoagulation time and voltage

Voltage (Volt)	Time (minutes)		
	30	60	90
15	V1/T1	V1/T2	V1/T3
20	V2/T1	V2/T2	V2/T3
25	V3/T1	V3/T2	V3/T3

2.3 Chemical analysis

The data processing procedure was carried out to compare data on the initial characteristics of palm oil anaerobic waste with the results obtained after electrocoagulation treatment. The parameters compared were pH, TSS, COD, BOD, color, and turbidity. The analysis method uses the Indonesian National Standard (SNI) regarding waste water quality standards. Comparison was also made with the quality standards of palm oil liquid waste, namely the Minister of Environment Regulation of the Republic of Indonesia No. 5 of 2014.

2.4 Economic analysis

Generally, each technology has advantages and disadvantages, showing the need to consider economic, technical, and environmental aspects. Cost and energy requirements analysis is an important process in waste management to determine the financial and energy resources required. Cost is specifically a crucial factor during the selection of waste treatment. In this study, the energy requirement for electrocoagulation process and cost are determined through the voltage and contact time (Sailah *et al.*, 2020). Economic analysis using Activity-Based Costing (ABC) Analysis. This method allocates overhead and indirect costs to products or services based on the activities that consume resources. This provides a more accurate picture of production costs.

The estimation of the cost of liquid waste treatment using electrocoagulation can be carried out by adding up the cost of electricity and electrodes (Ashari *et al.,* 2015). In this study, the cost of electricity is determined using Equation (1).

$$W = \frac{V \text{ x } I \text{ x } t}{v}$$

Where:
W = Electrical energy used (w)
V = Voltage (volt)
I = Current (ampere)
t = Time (hours)
v = volume of liquid waste (m³)

The electrode charge is estimated by multiplying the mass of dissolved by the metal price/kg. Meanwhile, electrode consumption is determined in this study using Equation (2).

$$C = \frac{I \text{ x } t \text{ x } M}{F \text{ x } z \text{ x } v}$$

Where:
C = electrode consumption (g/m³),
I = electric current (A)
t = contact time (hours)
M = mass molecule (g/mol)
F = constant Faraday (96,485 C/mol)
z = number of electrons
V = Volume of Liquid Waste (m³)

The operational cost of electrocoagulation process is the sum of both costs

$$Co=(a.W)+(b.C)$$

Co = operating costs (USD/m3),
a = electricity price (USD/kWh),
W = electricity consumption (kWh/m³),
b = aluminum price (USD/kg),
C = electrode consumption (kg/m³).

3. Results and Discussion

The influence of parameters such as voltage and contact time was identified and evaluated under certain conditions at constant temperatures.

3.1 Characteristics of POMSE

Liquid waste subjected to an anaerobic treatment process did not meet the established quality standards. After the electrocoagulation process, the characteristics of waste samples appeared visually brighter than before treatment, as shown in Figure 7. Visually, POME is brownish and contains highly suspended solids indicated by elevated color intensity (3136.5 PtCo), and TSS (1787 mg/L). After electrocoagulation, a precipitate formed at the bottom and bubbles on the surface. This process included oxidation and reduction at the electrodes, which could reduce the stability of suspended and dissolved contaminants as well as emulsion breakdown (Mallesh 2018).

3.1.1 Effect of Electrocoagulation on COD Reduction

A decrease in COD concentration shows a reduction in organic compounds in liquid waste. This is because the measurement of COD is carried out to determine the amount of oxygen needed to oxidize organic compounds in water (Hanum *et al.,* 2015). According to the double layer theory, the inner ring is filled with positively charged coagulants that absorb negative ions from the outer ring (Schmickler 2020). During the process, the positive and negative charges collide, creating van der Waals forces between the two ions, resulting in very strong bonds and the formation of coagulants, which form floc settling organic substances.

In this study, COD levels before electrocoagulation were 1163.1 mg/L but reduced to 28 – 50.6% after treatment. The electrocoagulation process with a voltage of 25 volts for 30 minutes was able to reduce COD levels by 50.6% with a value of 590.8 mg/L. Figure 2 shows the effect of this process on decreasing the COD value of POMSE. A previous study stated that electrocoagulation process reduced COD levels in ice cream liquid waste and palm sago waste by 49% and 58.28%, respectively (Qasim and Mane 2013; Sutanto *et al.,* 2018).

3.1.2 Effect of electrocoagulation on TSS reduction and turbidity

TSS (Total Suspended Solids) are solids containing undissolved organic and inorganic matter, which are water held in a filter of a maximum of 2 μm. The decrease in TSS value in electrocoagulation is caused by changes in the floc period that are bonded to each other. This process causes a significant increase in specific gravity, leading to the occurrence of precipitation and colloids. The formation of colloids is caused by $Al(OH)_3$ ions binding to pollutants that are pushed to the surface by H_2 gas.

The effect of voltage and time on the decrease in TSS value is shown in Figure 3. In this study, the TSS value of palm oil liquid waste was 1787 mg/L before electrocoagulation. This high value was influenced by the content of organic compounds found in liquid waste and the amount of suspended solids, leading to turbidity (Wicke *et al.,* 2008).
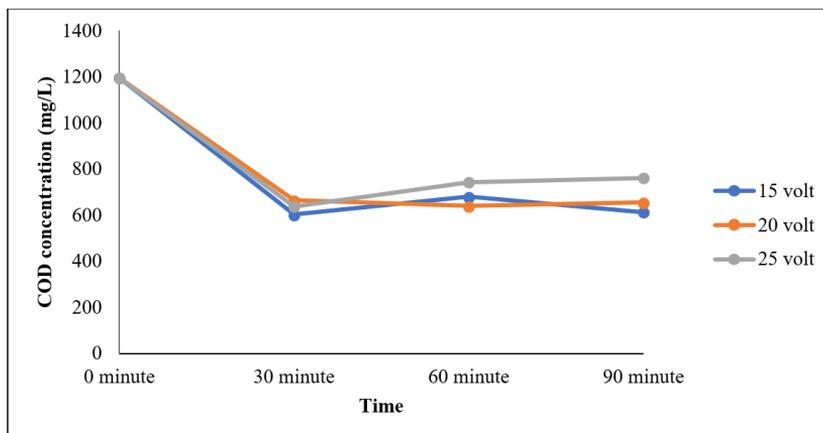

Figure 2. Effect of electrocoagulation on COD concentration

TSS removal values obtained from the electrocoagulation process ranged from 23.38 to 56.01 mg/L. This result fulfilled liquid waste quality standards, which specified TSS parameter of 300 mg/L. The largest removal in TSS value was 98.46% at a voltage of 25 volts for 90 minutes with a value of 23.38 mg/L. A previous study (Naje *et al.,* 2019) reported that electrocoagulation in landfill leachate could reduce TSS by approximately 84%. However, these results are inefficient when compared to a voltage of 25 volts for 60 minutes with a reduction efficiency of 98.46%. According to another report (Zaied *et al.,* 2020), treatment of more than 50 minutes passed through electrode passivation, causing the displacement rate to slow down and insignificant pollutant removal efficiency.

Previous studies (Putri and Purnama 2022) have shown that electrode contact time has an effect on decreasing TSS value. This is attributed to the oxidation reaction in the anion as well as high floc mass and specific gravity that will precipitate. The increase in floc period occurs due to the high number of interactions between particles in liquid waste, resulting in a larger floc size, which binds the particles in the waste to make better water quality.

Turbidity is a measure that uses the effect of light as a basis for determining the state of raw water with the Nephelometric Turbidity Unit (NTU) scale expressed in turbidity units. It is generally caused by the presence of mixed or colloidal objects in water, making a real difference in terms of aesthetics as well as water quality. Water turbidity is attributed to the presence of inorganic and organic materials due to industrial and household waste. Figure 4 shows the efficiency of reducing the turbidity value of palm oil liquid waste from 390.33 NTU before electrocoagulation to 83.7 - 97.83% or 8.44 - 63.57 NTU. A previous study (Valente and Mendonça 2015) reported that waste from the dairy industry reduced turbidity by approximately 99%.
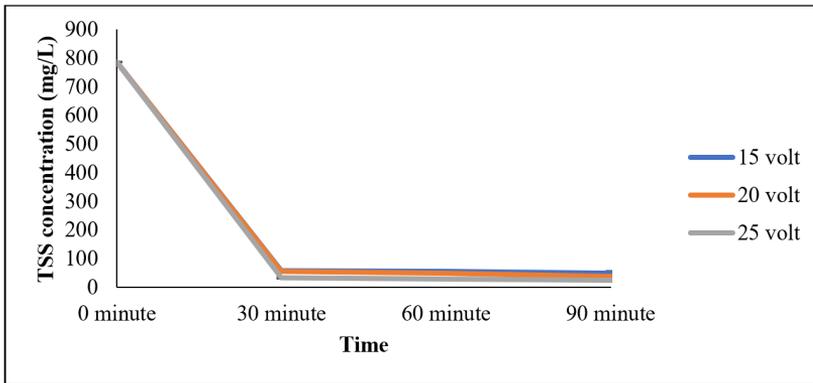

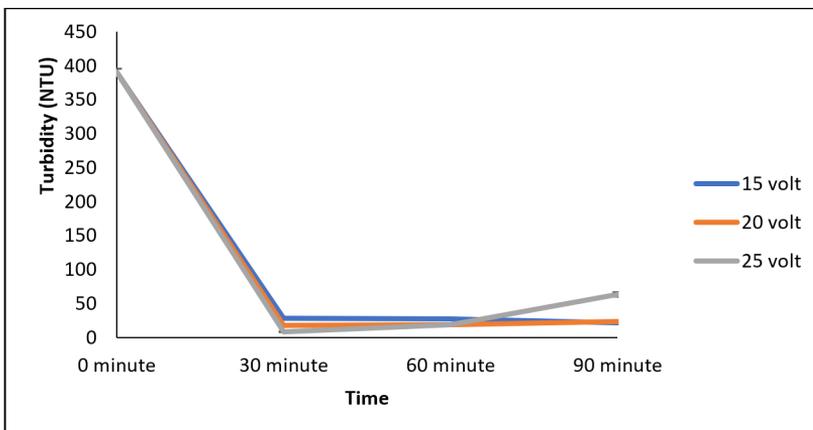**Figure 3.** Effect of electrocoagulation on TSS concentration

Figure 4. Effect of electrocoagulation on turbidity

TSS values do not always follow linear fluctuations of turbidity value, due to the presence of suspended as well as dissolved organic and inorganic substances, such as sludge, fine sand, and other microorganisms in liquid waste. Different types of materials have various properties and weights, which do not reflect comparable residual weight. This is also related to differences in TSS measurement principles and turbidity, thereby the level of significance of the decrease is not precisely determined. High turbidity value causes the oxygen content in water to decrease because sunlight that can penetrate water is limited.

3.1.3 Effect of electrocoagulation on pH

The results of the analysis showed a significant change in pH during electrocoagulation process. The change was observed to increase with the addition of electrocoagulation time, resulting in pH values ranging from 10.2 to 12.8, which exceeded the palm oil liquid waste quality standard of 6.0 - 9.0.

During electrocoagulation process, there was an increase in pH caused by the formation of hydrogen gas, which binds to Al^{3+} ions and forms $Al(OH)_3$ in an alkaline state (Hermida *et al.,* 2020; Lestari and Agung, 2014). The concentration of COD in liquid waste can be affected by pH, which plays a role in the degradation process of organic compounds. Moreover, high pH in liquid waste will lead to an improper oxidation of organic compounds. Low oxygen levels can be caused by reduced pH, which is capable of decelerating the breakdown of organic compounds in liquid waste. Therefore, wastewater should have a neutral pH to facilitate optimal oxidation.

3.1.4 Effect of electrocoagulation on color

Electrocoagulation process provides electricity to POME, leading to a chemical reaction between the electrode and the contaminant. Additionally, it removes solutes, disperses particles, and other pollutants. The initial color value in the sample was 3136.5 PtCo, but reduced to approximately 90% or 313.5 PtCo after electrocoagulation at a voltage of 25 volts for 90 minutes, as shown in Figure 6. Ibrahim *et al.* (2018) and Saad *et al.* (2020) reported a significant color reduction in POME using electrocoagulation of 75% and 90.2%. The visual color differences obtained in this study are presented in Figure 7.

Electrocoagulation is capable of improving color quality of liquid waste. According to a previous study, electrodes used will release metal ions produced from the positive and negative electrodes to form floc (Villalobos-Lara *et al.,* 2021). During this process, aluminum cations produced in solution at higher voltages promote more formation of $Al(OH)_3$ coagulation species, which are important for floc hydroxide formation, contributing to high rate of color removal (Bazrafshan *et al.,* 2013; Ibrahim *et al.,* 2018).
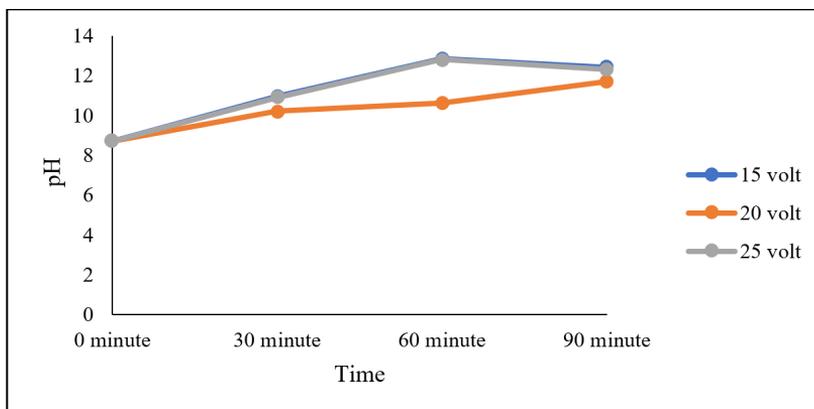

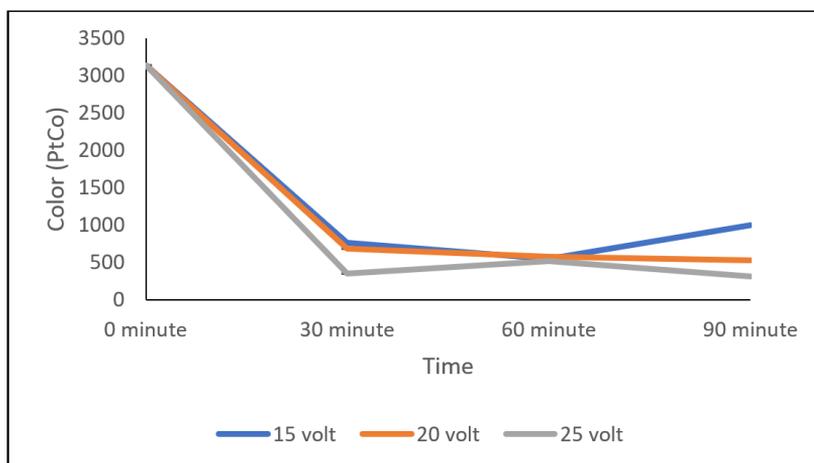**Figure 5.** Effect of electrocoagulation on pH

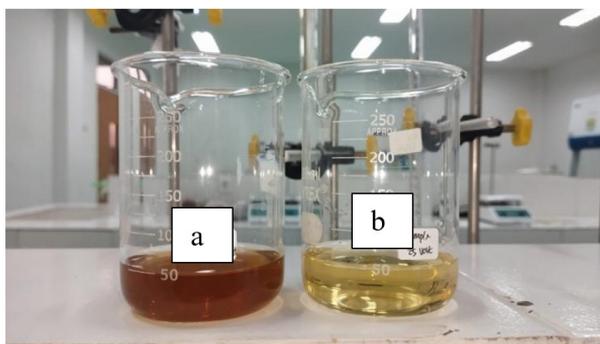**Figure 6.** Effect of Electrocoagulation on color values

Figure 7. Discoloration of palm oil liquid waste (a) before electrocoagulation,
(b) after electrocoagulation

Color change is caused by the molecular substance leaving the waste solution and joining on the surface of solid or coagulant during electrocoagulation. Particles that contribute to color in POME can be trapped in floc and settle, thereby reducing color intensity. A study (Saad *et al.,* 2020) has established that electrocoagulation process is more effective than nanofiber membranes in removing color from POME.

3.2 Foam and Precipitate Characteristics

The electric current in electrocoagulation process causes organic material molecules to become unstable. Physical bonds between organic molecules are broken, allowing adsorption by coagulant floc, followed by precipitation after achieving sufficient weight. During this process, the presence of hydrogen and oxygen gas causes some dissolved organics to floc including floc hydroxide which captures some organic waste that is not deposited on the cathode stem (Villalobos-Lara *et al.,* 2021). Subsequently, floating floc will settle when it has reached sufficient weight (Hanum *et al.,* 2015).

The formation of hydrogen and oxygen gas from the electrolysis of water occurs during the electrocoagulation process. This phenomenon is attributed to the flow of electric current passing through the electrodes submerged in the solution, resulting in a chemical reaction between the electrodes, solution, and solute. The reaction produces gases trapped in solution, forming gas bubbles (foam) on the surface. Additionally, the formation of foam can be caused by the presence of certain compounds in the solution that react with the gases formed during the electrocoagulation process. Table 2 shows the results of proximate analysis of flocculants and deposits from electrocoagulation process.

The foam and precipitate from the electrocoagulation process contain nutrients derived from liquid waste-soluble organic matter. This organic matter can accumulate in deposits in small quantities and provide little nutritional value after being reused as organic fertilizers.

3.3 Energy requirements and costs

Based on Equation 1, an energy requirement of 0.031 kWh/m³ was obtained in the electrocoagulation process with a voltage of 25 volts for 30 minutes. The electrode requirement estimated using Equation 2 was found to be 335.7 g/m³, with an operational cost of $ 0.98/m³. The calculation of operational costs in this study was relatively cheaper compared to previous results of $ 1.01/m³ by Eulmi *et al.* (2019) which was $ 3/m³ liquid waste. A study (Geraldino *et al.,* 2015) performed electrocoagulation on dairy industry liquid waste showed an operational cost of US $ 1.04 /m³ liquid waste.

The cost is often calculated using unit costs applicable in Lampung Province. Since the price of electricity and electrodes can vary significantly in different countries or regions, there is a need to make adjustments according to local conditions. The difference in electricity and electrode prices is capable of affecting the overall cost estimation in the electrocoagulation process (Bashir *et al.,* 2016). Therefore, it is important to conduct a more specific and in-depth study to consider the actual local conditions. This can include surveying prices in the local market, calculating transportation costs, and other factors that can affect overall costs (Sailah *et al.,* 2020).

Waste processing using electrocoagulation is 52% cheaper compared to chemical methods (Riadi and Ferydhiwati 2014). According to a previous study (Sahu *et al.,* 2014), electrocoagulation is a low-cost technology due to simple equipment, operation, and environmental sustainability that does not require chemicals for sedimentation and floc

Table 2. Proximate analysis of foam and electrocoagulation precipitate

Composition	Foam (%)	Sludge (%)
Moister content	96.44 ± 0.022	98.34 ± 0.02
Ash content	1.78 ± 0.034	0,25 ± 0.001
Oil content	0.05 ± 0.001	0.05 ± 0.008
Proteins	0.56 ± 0.040	1.12 ± 0.012
Crude fiber	0.57 ± 0.058	0.26 ± 0.007
Carbohydrate	1.18 ± 0.014	0.24 ± 0.004

Table 3. Electrocoagulation effluent characteristics of different types of liquid waste

Types of Waste	COD (%)	TSS (%)	Turbidity (%)	Color (%)	Reference
POMSE	50.6	98.46	97.83	90	This study
Ice cream waste	49	35.8	81.78	-	(Qasim and Mane 2013)
Palm sago waste	58.28	89.17	-	-	(Sutanto *et al.,* 2018)
Leachate	85	84	-	-	(Naje *et al.,* 2019)
Dairy industry	57	92.5	99	-	(Valente and Mendonça 2015)
Batik industry	83.33	90	-	88.51	(Lestari and Agung 2014)
POME	-	-	-	75	(Ibrahim *et al.,* 2018)
POME	-	-	-	90.2	(Saad *et al.,* 2020)

formation (Sahu *et al.,* 2014; Tahreen *et al.,* 2020). It also allows liquid waste to oxidize electrochemically or reduce organic pollutants to harmless inorganic substances.

In conclusion, the effluent characteristics of electrocoagulation produced in this study were compared with the results of other studies, including parameters of COD, TSS, turbidity, color. As shown in Table 3, these characteristics are influenced by the factors of raw material, electrode type, voltage, current, and contact time.

4. Conclusion

In conclusion, this study successfully carried out electrocoagulation process of palm oil liquid waste using aluminum electrodes. Based on the results, optimum performance was obtained at a voltage of 25 volts for 30 minutes. The maximum reduction efficiency of COD, TSS, turbidity, and color concentrations were 50.6%, 98.69%, 97.83%, and 88.71%, respectively. The process was considered to be a relatively cheap technology, requiring energy of 50 kWh/m³, electrode of 11.33 g/m³, and operational cost of $ 1.01/m³. However, the efficiency of electrocoagulation was affected by the type of electrode, electrode area, pH, and current.

Acknowledgment

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