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POME Processing with Bioremediation Using Indigenous Bacteria (*Bacillus toyonensis* and *Stenotrophomonas rhizophila*), and Bioremediation Assisted with Electrocoagulation Methods

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Abstract

The POME treatments were studied; bioremediation method using enriched indigent lypholitics bacteria (*Bacillus toyonensis* and *Stenotrophomonas rhizophila*.), electrocoagulation method, and combination of those methods. The parameters were oil and fat contents, Chemical oxygen demand (COD), pH, Total Suspended Solid (TSS), Total Dissolved Solid (TDS), Fe, and Cu metals. In the electrocoagulation method, the electrodes were used 25 x 25 cm^2 iron electrodes with a variety of electrical voltage 1.5, 3, 4.5, and 6 V. The bioremediation method results in the removal; oil and fat -74.62%, COD -52.44%, TSS -43.11% and pH 6.38, TDS 21.42%, Fe -5.3% and Cu -64.70% at the incubation time for 6 days. The electrocoagulation method results in the removal; oil and fat -93.27%, COD was -85.71%, TDS -39%, TSS -84%, Cu -46%, Fe +92.35%, and pH 11.39 at a voltage of 6 V for 6 h. The combination of the two methods can reduce: oil and fat -87.39%, COD -56.70%, TDS -0.42%, TSS +15.88%, Cu -23.33%, Fe +93.74% and pH 8.82. The three methods were studied can improve the POME treatments processing significantly, however the electrocoagulation method could reduce oil and fat content at the highest level.

Keywords; POME, bioremediation, electrocoagulation, combination methods

Abstrak (Indonesian)

Pengolahan POME dipelajari; bioremediasi menggunakan bakteri lipolitik (*Bacillus toyonensis* dan *Stenotrophomonas rhizophila*.) yang diperkaya, sistim elektrokuagulasi, dan metode kombinasinya. Parameternya adalah kandungan minyak dan lemak, COD, pH, TSS, TDS, logam Fe dan Cu. Dalam metode elektrokoagulasi, electrode yang digunakan adalah electrode besi 25 x 25 cm^2 dengan variasi tegangan listrik1.5, 3, 4.5, dan 6 V. Metode bioremediasi menghasilkan pengurangan; minyak dan lemak -74.62%, COD -52.44%, TSS -43.11% and pH 6.38, TDS 21.42%, Fe -5.3% dan Cu -64.70% pada waktu inkubasi 6 hari. Metode elektro koagulasi mengasilkan penurunan; minyak dan lemak fat -93.27%, COD was -85.71%, TDS -39%, TSS -84%, Cu -46%, Fe +92.35%, and pH 11.39 pada tegangan 6 V selama 6 jam. Metode kombinasi dari 2 metode tersebut dapat mereduksi; minyak dan lemak -87.39%, COD -56.70%, TDS -0.42%, TSS +15.88%, Cu -23.33%, Fe +93.74% dan pH 8.82. Ketiga metode yang dipelajari dapat meningkatkan proses pengolahan POME secara signifikan, namun metode elektrokoagulasi dapat mengurangi minyak dan lemak pada tingkat paling tinggi.

Kata Kunci: POME, bioremediasi, elektrokoagulasi, metode kombinasi

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INTRODUCTION

In the last decade, the palm oil industry has been growing significantly in Indonesia. Currently, the crude palm oil (crude Palm Oil/CPO) commodity is the mainstay of the Indonesian main industry [1] In 2016, the area of oil palm plantations reached 11 million hectares and increased to 12 million hectares in 2017, and reach 14 million hectares in 2020 [2]

The amount of production has a positive impact on the Indonesian economy, both in terms of its contribution to state income and the amount of labor absorbed around the factory area. The palm oil industry will produce a large amount of liquid waste. For each production of 1 ton of CPO results 2.5 tons of liquid waste [3]

Since most substances in this class have low biodegradability, their release to the environment through wastewaters may impact the biosphere. Even the thinnest layer of oil will affect aquatic life by decreasing both the penetration of light and the oxygen transfer between air and water [4] For this reason, discharge limits for oil and grease are regulated by environmental law in most countries.

POME processing in Indonesia has so far been conducted with an open pond system. POME treatment techniques with an open pond system are less efficient because it requires a large area of land in addition to the palm oil mill effluent causing greenhouse gas effects due to carbon dioxide (CO_2) and methane (CH_4) produced during degradation in aerobic and anaerobic processes [5].

Palm oil mill effluent (POME) is wastewater that contains dissolved substances such as CH_4, SO_2, NH_3, halogen, or dissolved liquids with concentrations above the threshold value. POME in its untreated form is a very high strength waste depending on the operation of the process, that is; informal, semi-formal and formal processes, the biological oxygen demand (BOD) of these wastes' ranges from 25000 to 35000 mg/L. It contains about 94% water. POME is the sum of liquid waste which cannot be easily or immediately reprocessed for extraction of useful products and is run down the mill internal drain system to the so-called effluent (or sludge) pit. Therefore, to manage palm oil waste, an inexpensive and effective waste treatment technology is needed, bioremediation technology that uses bacterial activity and electrocoagulation technology [6].

Electrocoagulation is an alternative wastewater treatment that combines electrochemical processes with conventional chemical coagulation or bioremediation process. Many studies have evaluated the performance of this technique in waste water treatments [7]. One of them is electrocoagulation. In the electrocoagulation direct electrical current is used to add metal ions into wastewater, which are subsequently hydrolyzed to generate coagulating species. The entire process is conducted in an electrolytic reactor (batch or continuous) in which a clarified liquid and a separation of coagulant.

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Based on this background, this study compares the processing of POME with electrocoagulation and bacterial anaerobes. Bacteria that will be used are *Bacillus toyonensis* strain BCT-7112 and *Stenotrophomonas rhizophila* strain e-p10 which were previously isolated by Said [8] then electrodes to be used in this study are 8 couples Fe-Fe electrodes, by varying the voltage on the adapter in reducing oil content and fats, COD, pH, TSS, TDS, Fe and Cu metals.

MATERIALS AND METHODS

Material

Materials used samples of palm oil mill effluents, filter paper, $HgSO_4$, $K_2Cr_2O_7$, Ferro ammonium sulfate 0.1 N, $MgSO_4.7H_2O$, $CaCl_2$, KH_2PO_4. NH_4NO_3, $FeCl_3$, NB medium, NA medium, HCl, H2SO4, n-hexane, Na_2SO_4, HCl, H_2SO_4, n-hexane, Na_2SO_4, HNO_3 and ferroin indicator were purchased from Merck, *Bacillus toyonensis strain* BCT-7112, *Stenotrophomonas rhizophila strain* e-p10 strain, strain BCT-7112 *Stenotrophomonas rhizophila strain* e-p10 strains, were isolated from POME ponds, and distilled water.

Bacterial isolation

Oil and fat degrading bacteria, each as much as 1 ose inoculated aseptically into NA slant agar by placing the culture-containing loop on the slope of agar and pulled by zigzag motion, then incubated at room temperature for 48 h so that it will be obtained isolate stock and work cultures that are ready to use [9].

Mineral medium preparation

Mineral Medium is prepared by dissolving $MgSO_4$ 0.2 g, $CaCl_2$ 0.1 g, 4,5 g K_2HPO_4, 0.2 g $(NH_4)_2SO_4$, 0.1 g NaCl, 0.02 g $FeCl_3$, 3 g beef extract, 5 g of yeast extract and 20 mL of vegetable oil in distilled water with a volume of 1000 mL solution. The solution is boiled on a hot plate and homogenized with a magnetic stirrer. After boiling is covered with cotton and aluminum foil then the solution is sterilized by autoclaving at 121 °C and a pressure of 15 lbs or approximately 15 min. In this research, 5 liters of mineral medium were made [10].

Bacterial inoculum preparation

Each bacterium was inoculated 1 ose into 500 mL of Nutrient Broth medium then incubated on a shaker on 30 rpm at room temperature for 24 h. The number of bacteria was calculated using a hemocytometer [11].

Bacterial starter preparation

Bacterial starter is made from 550 mL mineral medium, 200-mL wastewater from POME is added, then in Erlenmeyer 25% inoculum isolates are inoculated with mixed bacterial *Bacillus toyonensis* strain BCT-711 and *Stenotrophomonas rhizophila* strain e-p10 with a minimum density of 106 cells/mL, so a total volume of 1000 mL. The culture was incubated in a rotatory shaker incubator at a speed of 30 rpm at 28 °C for 3 h.

Bacterial population calculations

The bacterial population in the substrate was calculated using a hemocytometer in units of cells per ml. The bacterial population in units of cells per mL is calculated using the following equation [13]:

Bacterial Population (cell/ml) = A x 250.000

Where A is Number of bacterial cells in the small cell

Liquid waste treatment by the electrocoagulation method

A sample of 12000 mL of palm oil waste was put into a 15000 mL bioreactor, the process was conducted in the Batch-type electrocoagulation reactor that previously contained an electrode plate and was anaerobically conditioned. Furthermore, the electrodes are connected to a voltage source (DC power supply) then an electrocoagulation reaction is conducted with 4 voltage variations (1.5 V, 3 V, 4.5 V, and 6 V). Electrocoagulation processing samples were taken according to a predetermined time, i.e. (0, 1, 2, 3, 4, 5, and 6 h) to be analyzed for changes in levels of COD, pH, TSS, TDS, Oils and Fats, Fe metals, and Cu metals The voltage and the results of the optimum changes in POME levels obtained are used for the degradation process of liquid waste using a consortium of indigenous bacteria by the electrocoagulation method [14].

POME treatment by using aerobic bacteria

A sample of 5000 mL of palm oil waste is put into a bioreactor and can be conditioned anaerobically, then a periodic sampling is conducted according to a predetermined time, i.e. (0, 1, 2, 3, 4, 5, and 6 days) then the content changes are analyzed COD, pH, TSS, TDS, Oils and Fats, Fe metals, and Cu metals. The procedure is intended as a control for the degradation of liquid waste using a consortium of indigenic bacteria [15].

POME treatment by using indigenous consortium bacteria

The process of degradation of liquid waste using a consortium of indigenic bacteria was conducted for 6 days. Three bioreactors were prepared and then in each bioreactor 3,000 mL of palm oil waste samples were added then 1 liter of mineral medium and 1 liter of inoculum mixed with *Bacillus toyonensis* strain BCT-7112 and *Stenotrophomonas rhizophila* strain e-p10 were added so that the total volume of the substrate and inoculum on each 5-liter bioreactor. Furthermore, sampling is done periodically in accordance with a predetermined time, namely (0, 1, 2, 3, 4, 5, and 6 days), then analyzed changes in levels of COD, pH, TSS, TDS, Oils and Fats, Fe metals, and Cu metals [16].

POME treatment by using a combination of bioremediation and electrocoagulation process

Samples from 3 bioreactors from bacterial incubation for 6 days were put into the electrocoagulation reactor so that the total volume was 12000 mL. Then, the electrocoagulation reaction was conducted with a voltage of 6 V for 6 h. Electrocoagulation processing samples were taken and analyzed for changes levels of COD, pH, TSS, TDS, Oils and Fats, Fe metals, and Cu metals [17].

Sample analysis stages

The liquid waste used in this test was taken from PT Agro Indralaya Mandiri's anaerobic ponds.

Test of COD (chemical oxygen demand) level

Palm oil liquid waste samples taken as much as 2.5 mL were put into COD tubes, added 1.5 mL $K_2Cr_2O_7$ 0.1 N and sulfuric acid reagents as much as 3.5 mL. Then closed the COD tube and shaken until homogeneous. The tube was placed on a heater, heated at a temperature of 150, digested for 2 h. After digestion conducted for 2 h, the solution was cooled to room temperature, then the sample was transferred to Erlenmeyer and added 2 drops of ferroin indicator were added [18].
Calculation of COD Level:

$$\mathrm{COD}\ (mg/L\ O_2) = \frac{(A-B)(N)(1000)}{mL\ sample}$$

Information:
A: volume of blank solution, mL;
B: volume of sample solution, mL;
N: normality of $K_2Cr_2O_7$ solution

TSS (Total Suspended Solid) content test

Palm oil wastewater is stirred with a magnetic stirrer to obtain a homogeneous palm oil wastewater. The sample as of palm oil waste was filtered using filter paper with previously dried in an oven and in a desiccator. Filter paper containing suspended solids is transferred to the weighing bottle and put into the oven for 2 h at 103°C - 105°C. After completion of drying, cooled filter paper into desiccator for 1 h to balance the temperature and weighed [19].
Calculation of TSS levels:

$$mg\ TSS = \frac{(A-B)x\ 1000}{mL\ sample}$$

Information:
A: filter paper weight + dry residue, mg;
B: filter paper weight, mg.

pH Test

The pH meter was calibrated using a buffer solution of pH 4, pH 7, and pH 10. After the calibrated instrument the electrodes are dried with a tissue paper then rinsed with distilled water. Then, the electrode is rinsed again with the sample, then dipped into the sample until the pH meter shows a constant reading. Then, reading on the pH meter is recorded [20].

Tests for oil and fat content

Palm oil mill effluent samples are put into a separating funnel set the pH by adding HCl or H_2SO_4 until the pH is smaller than 2 then 30 ml of n-hexane is added to the separating funnel, shaken vigorously for 2 min then left to the water layer and n-hexane separates. The aqueous phase is separated into an Erlenmeyer, while the n-hexane phase layer is passed through a filter paper containing 10 grams of anhydrous Na_2SO_4 and stored in a distillation flask with known weight (W_0). The water phase was put back into the separating funnel to be extracted again and extract 2 times with 30 ml of n-hexane. The n-hexane phase and extract layers were combined in a distillation flask and then distilled in water bath at 70°C. When the solvent condensation was stopped, the distillation is stopped. Distilled flask was cooled and dried in an oven at 70°C ± 2°C for 30–45 min. The distillation flask was put into a desiccator for 30 min and the distillation flask was weighed until a fixed weight (W1) was obtained [21].
Calculation of oil-fat content in samples:

$$Oil-fat\ content\ \left(\frac{mg}{L}\right) = \frac{((W1-W0)}{(V\ sample\ (mL))}\ x\ 1000$$

Information:
W_0: Weight of empty distillation flask expressed in milligrams (mg)
W_1: weight of distilled oil and fat flask (amount of vegetable oil and mineral oil) expressed in milligrams (mg)

Test the level of TDS (Total Dissolve Solid)

The calibrated EC (electrical conductivity) meter is rinsed with distilled water and then dried with a tissue. Then, the electrode is rinsed again with the sample, then dipped into the sample until the EC meter shows a constant reading. Then, reading on the EC meter is recorded [22].

Test the levels of Fe metal and Cu metal using SSA

A 100 mL sample in Erlenmeyer was added with 5 mL of concentrated HNO_3. The mixture is heated slowly until it boils. Destruction is stopped after a clear solution is obtained, then cooled. After chilling filtered using Whatman paper no.42. After that the sample was put into a 50 mL measuring flask and distilled water was added to the mark limit [23].

Calibration curve

The calibration curves of Fe and Cu elements were obtained by measuring the uptake of standard solutions of each element at the optimum conditions of the standard Fe and standard Cu solutions with a series of levels of each solution namely Cu levels 0.5; 1; 1,5; 2; and 2.5 mg/L, and Fe solution of 0.05; 0.1; 0.5; 1; 1,5; 2; and 2.5 mg/L were injected on the AAS device at a wavelength of 248.3 nm for Fe and Cu measured at a wavelength of 324.7 nm. The absorbance results are used to make the calibration curves and linear regression equations, slope values and intersections [24].

RESULTS AND DISCUSSION

Palm Oil Mill Effluent (POME) Samples

The characteristics of POME are conducted to see the initial conditions of palm oil liquid waste before the electrocoagulation-testing process. The liquid waste used in this test was taken from PT Agro Indralaya Mandiri's anaerobic ponds. The results of the initial characteristic test of the anaerobe pond sample can be seen in Table 1, these values are compared to the trace hold value/trace hold limits from the Regulation of Environment Minister of the Republic of Indonesia number 5; 2014, and It can be seen as the red dash-line in every graphs in the following results discussion.

Table 1. Results of the initial characterization tests for Palm Oil Liquid waste

Parameters	Unit	Value	Trace Hold Value
pH	-	7.75	6–9
TSS	mg/L	290.95	250
TDS	mg/L	1726.28	2000
COD	mg/L	800	350
Fat and oil	mg/L	10161.33	25
Iron metal (Fe)	mg/L	0.835	5
Cuprum metal (Cu)	mg/L	0.03	2

Based on the results of the initial characteristics of sample test, which were taken from anaerobic pond treatment, it can be seen that the parameters of COD, Oil and Fat, and TSS have not met the quality standard in accordance with Regulation of the Minister of Environment of the Republic of Indonesia number 5 of 2014 concerning the quality standard of wastewater (Trace hold values/trace hold limits). Then the samples were treated using many methods, electrocoagulation, bioremediation, and combination of bioremediation and electrocoagulation.

The effect of electrocoagulation techniques on pH POME treatment with electrocoagulation 4 pairs iron electrodes with a variation of electrical voltages and times.

The results of the influence of electrocoagulation on the pH value of Palm Oil Liquid waste can be seen in **Figure** 1. Based on Figure 1, it can be seen that the variation in the electrical voltage and time variation of the electrocoagulation process is influential on the pH value. The pH value increased from the pH value at the time of characterization, which is 7.75 to 11.39 at a voltage of 6 volts with a contact time of 6 h. In the electrocoagulation process, the longer the contact time and the greater the voltage applied, the pH value will increase this increasing due to the increase of the hydroxide ions where OH-ions are produced from the water reduction (H_2O) process at the cathode. An increase in pH value occurs due to the accumulation of OH ions in wastewater, where the more OH ions that accumulate, the pH value or alkalinity of the treated wastewater will increase [25]. This value shows that the electrocoagulation process used for palm oil liquid waste impacts increasing pH so that it does not meet the Minister of Environment Regulation of the Republic of Indonesia number 5 of 2014 concerning wastewater quality standards, which range from 6–9.

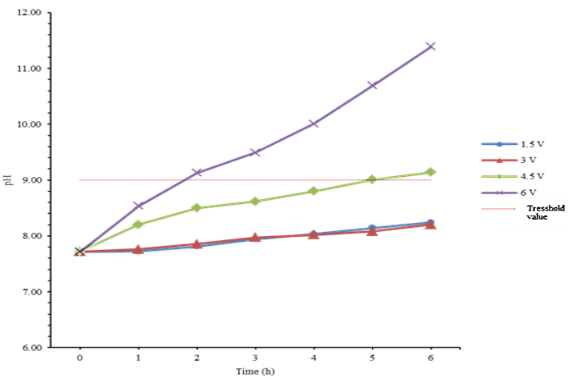

Figure 1. Graph of the effect of variations in voltage and contact time on the pH of Palm Oil Liquid waste

The influence of electrocoagulation techniques on TDS concentrations

TDS value affects water quality, where the smaller the TDS value, the better the water quality, whereas if the greater the TDS value, it will have a negative impact on water quality. The results of the influence of electrocoagulation on the TDS concentration value of Palm Oil Liquid waste can be seen in **Figure** 2.

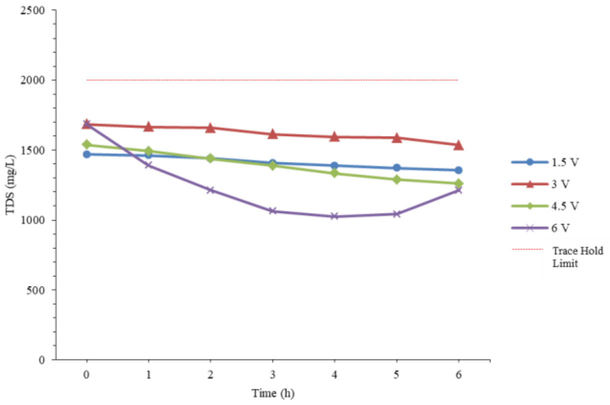

Figure 2. Graph of the effect of variations in voltage and contact time on the TDS concentration of Palm Oil liquid waste

Based on the graph in **Figure** 2. The effect of voltage variations and contact time on the TDS concentration decreases with increasing time and applied voltage. This change is because the voltage is directly proportional to the current and time. If the greater voltage was applied, the greater the current flowing to the electrodes, which results in greater a deposition. The greater the mass of the sediment produced by the electrodes, the decrease in the value of TDS will be even greater [26]. Based on the research data obtained, it can be seen that the concentration of TDS produced both before and after the electrocoagulation process still meets the quality standards set by the Minister of Environment Regulation of the Republic of Indonesia number 5 of 2014, which is 2000 mg / L.

The effect of electrocoagulation techniques on TSS concentrations

The results of the influence of electrocoagulation on the TSS concentration of palm oil liquid waste can be seen in **Figure** 3.

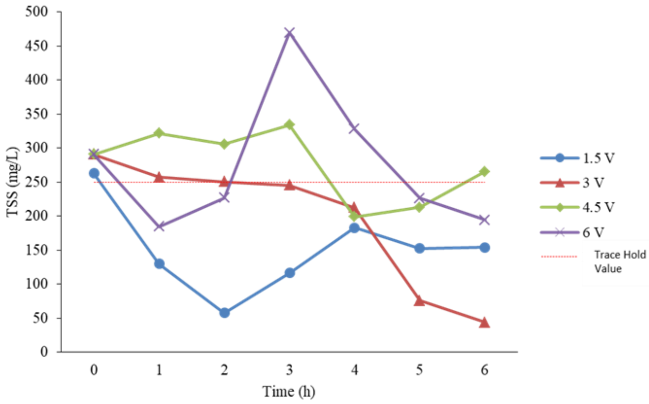

Figure 3. Graph of the effect of variations in voltage and contact time on the TSS concentration of Palm Oil liquid waste

Based on the graph in **Figure** 3, it appears that the data generated are fluctuating. This is because flocks produced in the electrocoagulation process can partially settle and some are exposed to the bioreactor surface. The voltage of 6 V is an increase in the value of high suspended solids at the 3rd hour; this is due to the large number of flocks that settle beneath the bioreactor surface. The flock is conducted when taking samples for measurement.

In the electrocoagulation process at the anode an oxidation reaction occurs to the anion (negative ion), an anode made of metal such as iron will undergo an oxidation reaction to form $Fe\ (OH)_2$[27], while at the cathode hydrogen gas will form which functions to lift the flock $Fe\ (OH)_2$ onto the surface. Flocks that form over time will increase in size and eventually settle to the bottom of the electrocoagulation bioreactor. The hydroxide or poly hydroxide produced has a strong attraction toward dispersed particles and opposing ions to cause coagulation. The hydrogen gases formed in the electrodes also cause suspended solids to rise to the surface, causing the TSS to decrease [28]. Based on the research data, it can be seen that the TSS value of palm oil liquid waste after the electrocoagulation process has met the quality standard set by the Minister of Environment Regulation of the Republic of Indonesia number 5 of 2014, which is 250 mg/L. The highest efficiency decrease in TSS is obtained at 3 V with a contact time of 6 h, which is equal to 84.94%.

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The influence of electrocoagulation techniques on the COD concentration

High COD in a waste indicates organic pollutants in large quantities. The results of testing samples with variations in voltage and contact time to the COD concentration can be seen in **Figure** 4.

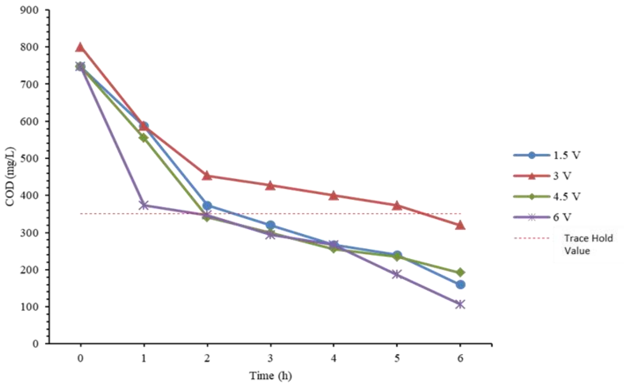

Figure 4. Graph of the effect of variations in voltage and contact time on the COD concentration of Palm Oil liquid waste

The effect of electrocoagulation treatment on palm oil liquid waste can be seen in **Figure** 4. The test results obtained show that the greater the voltage and time of the box given, the lower the COD concentration will be even greater. The highest decrease in COD concentration occurred at the 6th hour and 6V voltage, from 746.67 mg/L to 106.67 mg/L with a removal efficiency of 85.71%. The lowest concentration decrease occurred at the first hour and the voltage was 1.5 V, from 746.67 mg/L to 587 mg/L with a provision efficiency of 21.43%. Based on the results of research obtained from the value of COD concentration after the electrocoagulation process has met the quality standard set by Regulating the Minister of Environment of the Republic of Indonesia number 5 of 2014, which is 350 mg / L.

The decrease in COD is due to the flock formed by the ions of organic compounds that bind to positive coagulant ions [29]. The molecules in palm oil liquid waste are formed into a flock. Colloidal particles in waste are binding to particles or other compounds present in waste such as positively charged $Fe(OH)_2$ colloids because their surface binds to H^+ ions. The working principle that occurs in electrocoagulation is the same as the double layer theory, namely the formation of adsorption particle flocculation, positively charged coagulants will absorb negative ions of waste such as nitrites, phosphates, and other organic compounds and form flocks that help the COD reduction process.

The influence of electrocoagulation techniques on the concentration of oils and fats

Oil and fat are a compound whose concentration should be limited because it can cause pollution in water. The results of samples with variations in voltage and contact time for electrocoagulation of oil and fat concentrations can be seen in **Figure** 5.

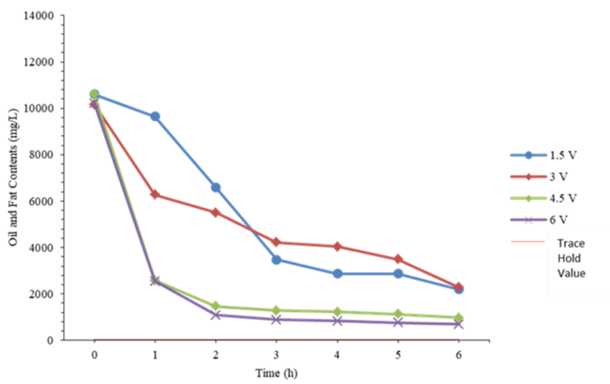

Figure 5. Effect of variations in voltage and contact time for electrocoagulation on the oil and fat contents in Palm Oil liquid waste

Based on the graph in **Figure** 5, the effect of voltage and contact time variations on the concentration of oil and palm oil liquid waste decreases with increasing time and voltage applied. The decreases in oil and fat concentrations due to electrophoretic destabilization by electric fields [30]. The highest decrease in oil and fat concentrations occurred at the 6th hour and voltage 6 V, from 10223 mg/L to 688 mg/L with a removal efficiency of 93.27% but the decrease that occurred after electrocoagulation still did not meet the established quality standards by the Minister of Environment Regulation of the Republic of Indonesia number 5 of 2014, which is 25 mg / L.

The influence of electrocoagulation techniques on the concentration of Fe metals

Ferrous metal (Fe) is included in the type of heavy metal because it has a specific gravity greater than 5 g/cm^3[31]. Based on **Figure** 6. The effect of voltage variations on the concentration of ferrous metals has increased. The results obtained state that the greater the voltage and time given the concentration of ferrous metals in palm oil liquid waste will also increase, this is because in the electrocoagulation process using Fe-Fe electrodes the iron metal-dissolving reaction results in Fe^{2+} or Fe^{3+} ions at the anode [32]. **Figure** 6 shows a graph of the effect of voltage variations on the iron metal concentration and time on the palm oil liquid waste.

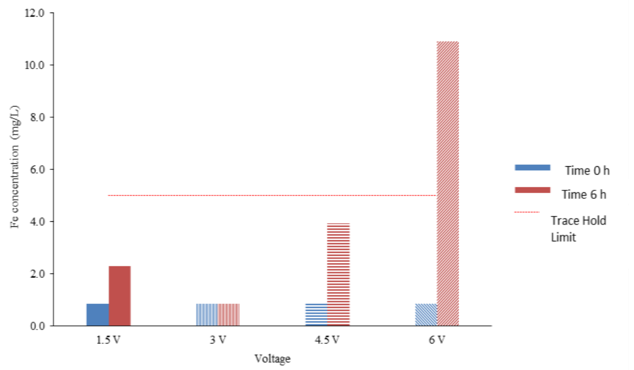

Figure 6. Graph of the influence of electrocoagulation voltage variations on Fe metal concentration and time on the palm oil liquid waste.

In this study, in addition to an increase in the concentration of ferrous metals, there was also a change in color where the waste before electrocoagulation turned brown then after electrocoagulation turned into a greenish-yellow turbid the green and yellow colors produced during the electrocoagulation process came from ions Fe^{2+} and Fe^{3+}[33]. Based on **Figure** 6. The highest increase in the concentration of ferrous metal occurred at the 6th hour and 6V voltage, from 0.835 mg/L to 10.922 mg/L, therefore the results at the 6th hour and 6V voltage did not meet the quality standards set. Determined by the government number 5 in 2014, while the results of voltage variations of 1.5 V, 3 V, and 4.5 V at the 6th hour are still below the quality standard set by the government number 5 in 2014 that is equal to 5 mg /L.

The effect of electrocoagulation techniques on the concentration of Cu metal

Cu metal is also included as a type of heavy metal because it has a specific gravity greater than 5 g/cm3 [34]. The effect of electrocoagulation voltage and time variations on the Cu metal concentration of palm oil liquid waste can be seen in **Figure** 7.

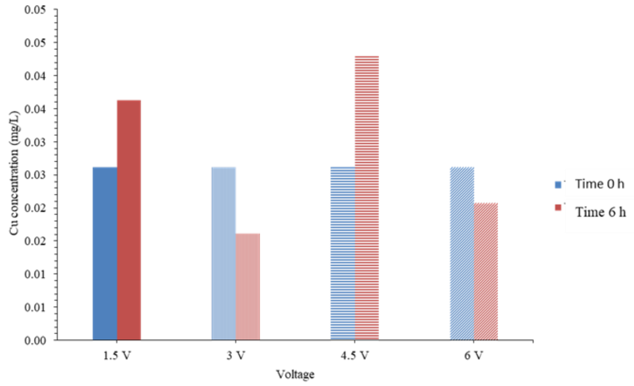

Figure 7. Graph of the influence of electrocoagulation voltage variations on Cu metal concentration and time on the palm oil liquid waste.

Based on the graph in **Figure** 7. The data obtained are fluctuating. At a voltage of 1.5 V and 4.5 V the concentration of Cu metal shows an increase, whereas at a voltage of 3 V and 6 V the concentration of Cu metal obtained shows a decrease. At a voltage of 1.5 V and 4.5 V, the increase occurs because no reaction occurs between $Fe(OH)_3$ and existing contaminants [35]. The contact time between wastewater and electrodes in the electrocoagulation device affects the decrease in Cu levels. The longer the contact time, the longer the wastewater reacts with the electrodes, affecting the removal efficiency. However, because the ability of electrodes to reduce wastewater is limited, even though the contact time is prolonged, when the reaction between the electrodes is saturated the electrodes' ability decreases. In addition, the formation of OH^- at the cathode decreases due to the deposition of deposits at the cathode. The greater the deposition attached, the greater the closed cathode surface, and the inhibition of OH- formation. If the resulting OH^- decreases, it means that the binding of Fe^{3+} to form a coagulant will be reduced, so that the allowance that occurs in the reactor will decrease, which increases the concentration [36].

The effect of Sample Treatment with Addition of bacterial Consortium

The effect of incubation time on pH

The effect of incubation time on pH on palm oil liquid waste by adding anaerobic bacterial consortium can be seen in **Figure** 8. According to the figure the longer the incubation time, the pH decreases due to the degradation of organic compounds by bacteria into acid long chain fat.

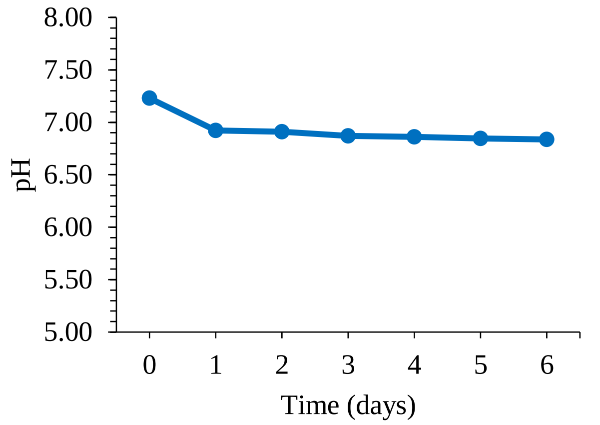

Figure 8. Graph of the effect of incubation time on pH

A decrease in pH indicates the occurrence of the hydrolysis process; there are four stages of anaerobic decomposition in which the hydrolysis process occurs, proteins become amino acids, carbohydrates are converted into sugars, and lipids are converted into long chain fatty acids and glycerol [37].

The effect of incubation time on TDS concentration

In the non-methanogen phase the TDS value will increase because large organic matter is converted into a smaller size (degradation process). In addition, the increase in the value of TDS is directly proportional to the bacterial population that is in the bioreactor, where the longer incubation time, the bacterial population in the bioreactor increased.

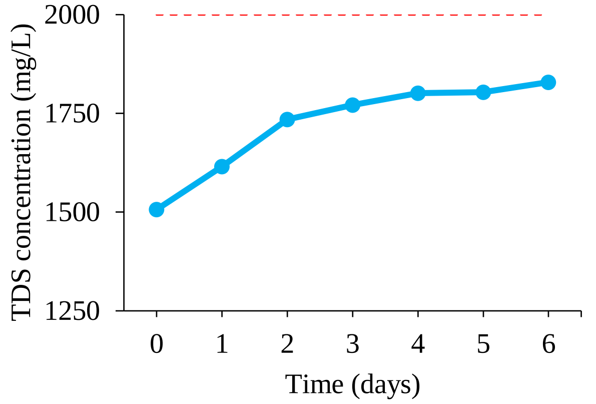

Figure 9. Graph of the effect of incubation time on TDS concentration

In this study, the value of TDS increased on day 0, which is 1506.41 mg/L to 1829.06 mg/L on day 6 with an increase efficiency of 21.42%. The increase in TDS values can be seen in **Figure** 9.

The increase in TDS values indicates that organic matter that is small ≤ 1 µm has not been completely degraded into gas and there is an increase in microorganism biomass that is smaller than filter paper size of 1 µm [38].

As the days go by, TSS levels will decrease, then become stable, rise again, and eventually will fall. This agrees with the theory, where the rise in TSS values is due to bacterial performance. Bacteria will break down the solids contained in POME and convert it into food, so the TSS value in the tank will decrease with increasing days, and eventually it will become stable and rise slightly, caused by the death of decomposing bacteria, which will increase the value of TSS [25].

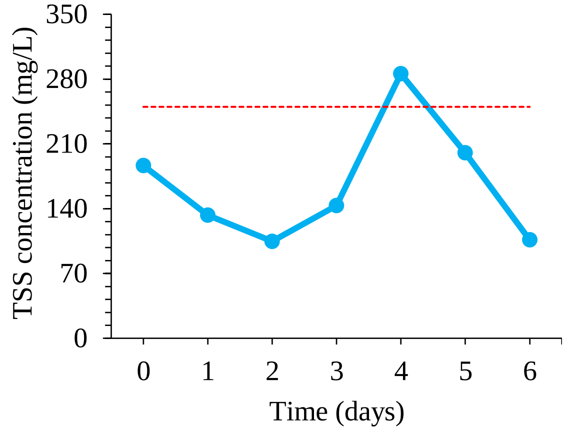

Figure 10. Graph of the effect of incubation time on TSS concentration

The effect of incubation time on COD concentration

The change in pH in the reactor indicates that the degrading bacteria are active, so it is ensured that the COD content in the waste can be degraded by the anaerobic bacteria. Based on the results of the study obtained the value of COD at the beginning and end of the degradation process that is equal to 4023.47 mg/L and 1913.60 mg/L. The highest efficiency of COD reduction occurred at the time of the 6th day, which was 52.44%. However, the COD reduction results obtained in this study did not meet the quality standards set by the government number 5 of 2014, which was 350 mg/L. The graph of the effect of processing time on the COD concentration can be seen in **Figure** 11.

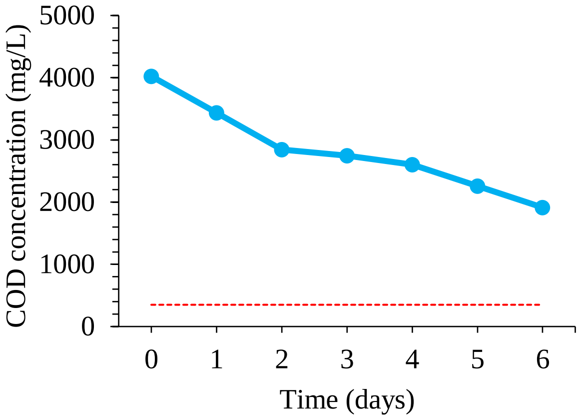

Figure 11. Graph of the effect of incubation time on COD concentration

Based on the graph in **Figure** 11, COD concentrations decrease with increasing days, this is because bacteria multiply to form biomass that functions to break down organic matter, so the amount of organic matter contained in waste will be less. The reduction in COD was due to COD being a food ingredient of microorganisms for the process of anaerobic hydrolysis and acid formation, then the acid formed would be utilized by microorganisms to produce biogas [39].

The effect of incubation time on Oil and Fat Concentration

The effect of incubation time on the concentration of oil and fat on palm oil liquid waste with the addition of a bacterial consortium can be seen in **Figure** 12. Based on the graph in Figure 12 the longer the incubation time the greater the decrease in oil and fat content. This is caused by the activity of bacteria that produce lipase enzymes, where the lipase enzyme degrades the levels of oil and fat contained in the bioreactor to glycerol and fatty acids. In addition, the longer the incubation time, the bacterial population will increase, which decreases oil and fat levels, so that the oil and fat levels in the bioreactor will be exhausted.

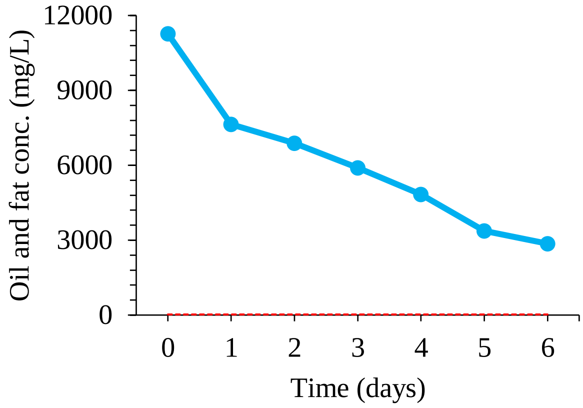

Figure 12. Graph of the effect of incubation time on oil and fat concentrations

Oil degradation by bacteria occurs due to the hydrolysis of oil with the secretion of lipase enzymes (oil-decomposing enzymes) that degrade oil into organic acids and volatile fatty acids (VFA) and finally, oil is processed into CO_2 and H_2O [40]. The highest decrease in oil and fat concentrations occurred during the 6th day process from 11267 mg/L to 2859.6 mg/L with a removal efficiency of 74.62%. The results of the reduction in oil and fat levels obtained in this study did not meet the quality standards set by the government number 5 of 2014, which is 25 mg/L.

The effect of incubation time on the concentration of Fe metal and Cu metal

The effect of incubation time on the concentration of Fe metal and Cu metal on the palm oil liquid waste by the addition of a bacterial consortium increased during the 6th day-processing time. Based on the research results obtained by concentrating Fe and Cu metals at the end of the degradation process increased by 2,261 mg/L for Fe metals while for Cu metals amounted to 0.051 mg/L. The concentration value of Fe metal and Cu metal is influenced by changes in pH, where the Fe and Cu metals will increase if there is a decrease in pH in the bioreactor. The graph effect of processing time on the concentration of Fe metal and Cu metal on the palm oil liquid waste by adding a bacterial consortium can be seen in **Figure** 13.

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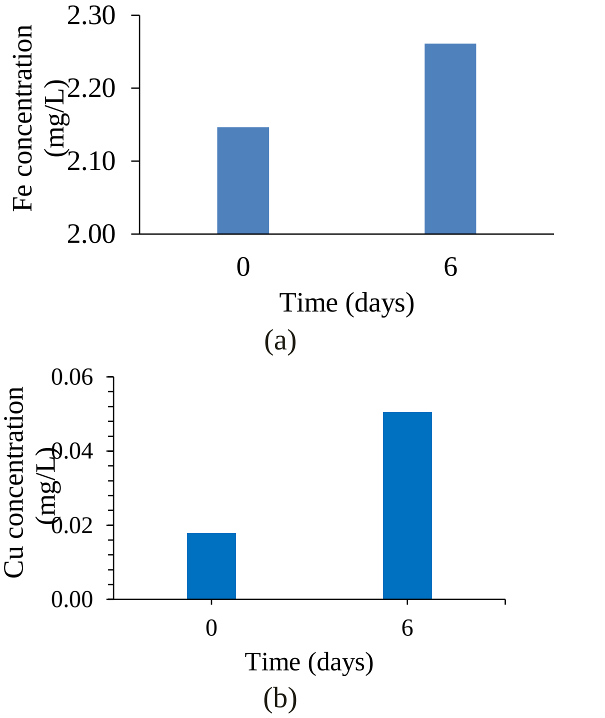

Figure 13. Effect of incubation time on the concentration of Fe (a) and Cu (b) metals

Based on **Figure** 13, the concentrations of Fe and Cu metals have increased on the 6th day. Increased metal content occurs due to a decrease in pH in the bioreactor. The decrease in pH indicates that the process of hydrolysis in the process of hydrolysis bacteria degrades waste into long chain fatty acids and glycerol. The presence of fatty acids causes the metal content to dissolve in waste.

Table 2. Comparation of POME Treatments Using Electrocoagulation, Bioremediation, and Combination Bioremediation-Electrocoagulation

Parameter	Unit	Ec.	Bio.	Ec. & Bio.
pH	-	11.39	6.84	8.82
TDS	mg/L	1211.54	1829.06	1500
TSS	mg/L	195.00	106.19	221.90
COD	mg/L	106.67	1913.60	1741.87
Oil & Fat	mg/L	688.00	2859.67	1420.33
Fe	mg/L	10.83	2.261	34.34
Cu	mg/L	0.02	0.051	0.01
Bact. Pop.	Cfu/mL	ND	9.16×10^{11}	7.05×10^{5}

The amount of Fe and Cu metal concentration is proportional to the large TDS concentration. In addition to the increasing population of metal bacteria, it is also a large contributor to the TDS concentration. The amount of TDS solubility is influenced by a decreased pH value. The increase in Fe and Cu metals obtained in this study still meets the quality standards set by the government number 5 of 2014, which is 5 mg/L for Fe metals and 2 mg/L for Cu metals.

The effect of sample treatment with addition of the bacteria and electrocoagulation consortium

After the sample is treated biologically by adding a bacterial consortium for 6 days then on the 6th day the sample is in electrocoagulation for 6 h using a voltage of 6 V. Based on the results of the research results of the electrocoagulation test after the addition of a bacterial consortium to the palm oil liquid waste sample day-to-day 6 can reduce levels of TDS, COD, oils and fats, Cu metals, and bacterial populations in the bioreactor while pH, TSS, and Fe metals have increased. The results of the palm oil liquid waste test with the addition of a bacterial consortium and electrocoagulation can be seen in Table 2.

Based on **Table** 2, it can be concluded that the results of the electrocoagulation process have better performance in reducing the levels of palm oil liquid waste compared with the addition of bacteria and the merging between the bioremediation process using bacteria and electrocoagulation besides the electrocoagulation process does not require a long time in reducing the levels of palm oil liquid waste compared to the process of using bacteria.

CONCLUSIONS

Based on the results, it can be concluded as follows:

1. The effect of the applied voltage on palm oil liquid waste using the electrocoagulation method with iron electrodes affects the increase in the value of some pollution parameters including pH, TDS and TSS concentrations.
2. The effect of incubation process time on palm oil wastewater treatment with the addition of consortium bacteria influences the decrease in the value of some of the exhibition parameters including pH, TSS, COD, Oil and Fat with the highest reduction efficiency values as follows TSS 43.88, COD 52.44% Oil and fat 74.62%, respectively, and pH reached 6.84 at the end of the incubation process. As for the value of TDS, Fe Metals and Cu metals increased with the highest efficiency increases as follows TDS 21.42, Fe metals 5.3, and Cu metals 64.70%, respectively.

3. The effect of electrocoagulation treatment with the addition of a bacterial consortium to the palm oil waste sample affects the decrease in parameter values including TDS, COD, Oil and Fat, and Cu metal. As for pH, TSS, and Fe metals have increased.

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