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Processing of Tofu industrial liquid waste by electrocoagulation method using aluminum (Al) electrode at the electrical current and contact time variations

Addy Rachmat ✉, Fatma, Nisa Manora Pratama dan Eva Musifa

Chemistry Department, Faculty of Mathematics and Natural Sciences, Universitas Sriwijaya, Inderalaya Campus Telp. (0711) 580572 Ogan Ilir South Sumatra 30662

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Abstract

This research aims to determine the effect of varying current and contact time on reducing levels on Chemical Oxygen Demand (COD), Total Suspended Solids (TSS), Total Dissolved Solids (TDS) and ammonia as well as increasing pH values in tofu industrial liquid waste by electrocoagulation using Aluminum electrodes. There were 4 variations of current (10,20,30,4 0A) and 5 variations of contact time (30,60,90,120,150 minutes). Analysis of COD levels and ammonia levels was carried out using a UV-Vis spectrophotometer, analysis of TSS levels gravimetrically using Whatman filter paper No. 42, analysis of TDS levels with gravimetrically, and analysis of pH values by a pH meter. The best results were obtained from treatment at current of 40 A and a contact time of 150 minutes with the highest efficiency of reducing COD, TSS, TDS, ammonia levels respectively at 90.35; 92; 66; 85% and the highest increase in pH value from 4 to 8,3. The results of the diversity analysis or Tukey's advanced test showed that at the 5% level each treatment had a significant effect on reducing COD, TSS, TDS and ammonia levels as well as increasing the pH value. Chemical kinetics analysis of the reduction in COD and TSS levels showed results that were close to first orde linear and obtained R^2 and k values respectively of (0.9904; 0.0164); (0.9952; 0.0182) at current variation of 40 A.

✉ Correspondence address:
Building Chemistry Department, Ideralaya Campus, Organ Ilir, Sumatera Selatan 30662
E-mail: fiyan.maulana48@gmail.com (choose Correspondence Style)

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Introduction

Tofu is a type of protein-rich food made from soybeans that is much consumed by Indonesian people (Sayow *et al.*, 2020). Based on data from the Agency for the Study and Application of Technology (BPPT) (2013), for every 80 kg of tofu produced, 2,610 liters of tofu whey or liquid waste will be produced. Whey or tofu liquid waste contains protein, water, peptides, oligosaccharides, simple sugars, amino acids, and various minerals such as phosphate, calcium and potassium. The large number of organic and inorganic substances shows that tofu or whey liquid waste in Indonesia has the potential to pollute the environment if it is thrown into rivers or ditches. The discarded tofu liquid waste will pollute the air. Therefore if the liquid waste is thrown into water that does not flow and emits an unpleasant odor (Hikmah *et al.*, 2019).

Tofu liquid waste that is disposed into the environment has to comply with the provisions of State Minister for the Environment Regulation Number 15 of 2008 with parameters including COD, suspended residue, TDS and pH as well as Government Regulation No. 82 of 2001 concerning quality standards for ammonia in liquid waste. Various methods for processing liquid tofu waste have been carried out, such as aeration and filtration systems (Pradana *et al.*, 2018), aerobic batch system methods (Utami *et al.*, 2019, using water hyacinth and coconut shells (Alimsyah and Damayanti, 2013) , aerobic-anaerobic method (Nursanti, 2017)), and so on. These methods were still not optimal for processing liquid waste from the tofu industry because they are less effective and require expensive costs (Amri *et al.*, 2020). Electrocoagulation as an alternative technology can be used as a liquid waste processing technology because it is easy to apply, it also uses everyday materials that are easily obtained (Muliyadi and Sowohy, 2020). The electrocoagulation method utilizes an electrical current that is applied directly to the electrode to neutralize the negative charge of waste particles through the formation of hydroxide complexes in water which causes the coagulation of dissolved solids. Electricity also helps to bridge the formation and stabilization of flocks which encourage sedimentation due to gravity without using chemical coagulants (Amri *et al.*, 2020).

Based on research results from Amri *et al* (2020), liquid waste of the tofu industry was processed by electrocoagulation using aluminum electrodes with current variations (8; 10; 12 volts) and flew rate variations (0.439; 0.243; 0.087 m3/minute). Aluminum (Al) electrodes are used in the electrocoagulation process because they have high conductivity, easy to make and inexpensive (Amelia *et al.*, 2019). Chemical Oxygen Demand (COD) and Total Suspended Solid (TSS) levels can decrease in the electrocoagulation process due to the redox process (oxidation and reduction reactions) in the electrocoagulation reactor (Amri *et al.*, 2020). An oxidation reaction occurs at the anode when the aluminum (Al) electrode dissolves into Al^{3+} and then reacts with water (H_2O) to form $Al(OH)_3$ as a coagulant. The reduction reaction occurs at the cathode with the formation of hydrogen gas so that the flock formed is lifted above the surface. This decrease in concentration can be studied further with the reaction kinetics of reducing levels of Chemical Oxygen Demand (COD) and Total Suspended Solid (TSS). Reaction kinetics can determine good variations in the rate of decrease of a concentration of reactants. The kinetics of reducing COD (Chemical Oxygen Demand) and Total Suspended Solid (TSS) levels can use zero-orde, first-orde and second-orde equation models (Sutanto *et al.*, 2018). Therefore, it is necessary to conduct research on the use of electrocoagulation methods with aluminum electrodes and variations in electrical current and contact time for processing liquid waste from the tofu industry.

Method

This research began to be carried out from January to April 2023 at the Chemical Analysis Laboratory, Department of Chemistry, Faculty of Mathematics and Natural Sciences, Sriwijaya University as a sample testing site and at one of the tofu small industry in the Plaju Ilir area as a sampling site. The equipment used in this research consisted of a set of electrocoagulation tools, a set of glassware, a set of vacuum tools, a desiccator, a pH meter, a hot plate, a porcelain cup, a spray bottle, tweezers, clamps, an oven, a digestion vessel, a heating block, a UV-Vis spectrophotometer. Aquamate 8000, and analytical balance. The materials used include samples of tofu industry liquid waste was taken from one of the tofu in the industry in the Plaju Ilir area, aquademin, Whatman No. filter paper. 42, Concentrated Sulfuric Acid p.a Merck (H_2SO_4), Potassium Dichromate p.a Merck ($K_2Cr_2O_7$), Potassium Hydrogen Phthalate p.a Merck ($C_8H_5KO_4$), Ammonium Chloride p.a Merck (NH_4Cl), Nessler Reagent p.a Merck, and Potassium Sodium Tartrate p.a Merck ($KNaC_4H_4O_6$. $4H_2O$).

Processing of Tofu Industrial Liquid Waste using the Electrocoagulation Method

Samples before electrocoagulation were characterized using the Chemical Oxygen Demand (COD) level test, Total Suspended Solid (TSS) level test, Total Dissolved Solid (TDS) level test, ammonia level test and pH test. The sample was pumped and put into an electrocoagulation reactor bath which contained aluminum electrodes. Next, the machine which had been connected to a strong 220 v DC (direct current) power supply was turned on, then the electrocoagulation process was carried out with 4 variations of current strength (10, 20, 30 and 40 A). Samples resulting from processing that had been electro coagulated were taken according to the predetermined variations in the contact time of the electrocoagulation process, namely 30, 60, 90, 120 and 150 minutes to analyze the levels of Chemical Oxygen Demand (COD), Total Suspended Solid (TSS), Total Dissolved Solid (TDS), ammonia, and pH value.

COD Content Test (SNI 6989.2:2019)

Liquid of tofu industry waste was added to a tube of digestion solution and sulfuric acid reagent solution. Then, the tube was closed and homogenized, and then the tube was placed in a heating block at a temperature of 150°C for 2 hours. The high concentration working solution series was made from potassium hydrogen phthalate (KHP) stock solution with 1 blank and a minimum of 5 levels in the measurement range. The UV-Vis spectrophotometer was optimized and the wavelength was set to 600 nm. The absorption of each working solution was measured then recorded and the COD content was determined. Next, a calibration curve was created and the straight line equation was determined. It was repeated again and the condition of the tool was checked if the linear regression correlation coefficient (r) < 0.995 until an r coefficient value ≥ 0.995 was obtained. To measure the test samples, a blank solution was used to obtain an absorbance value of zero. The test samples were measured for absorption at a wavelength of 600 nm. The COD value is calculated based on the linear equation of the calibration curve. The results of the test sample absorption readings are entered into a linear regression calibration curve. The COD value is also obtained from the results of reading the levels of the test sample from the calibration curve with the following calculation:

$$\textbf{COD content (mg O2/l)} = \mathbf{C \times f} \quad \text{(1)}$$

Information:
C = COD value of test sample (mg/l)
F = dilution factor

TSS Level Test (SNI 6989.3:2019)

The filter paper was vacuum filtered by wetting 20 mL of aqua mine on the filter paper, then dried in the oven for 1 hour (during drying, the oven must not be opened and closed) at a temperature of 103ºC – 105ºC. Next step, the filter paper was cooled in a desiccator, and then weighed. After that, the filter paper was slightly moistened in a vacuum using aqua mine, then the tofu liquid waste was pipetted with a certain volume and filtered using vacuum. If the filtering process took more than 10 minutes, the volume of liquid tofu waste was reduced or the diameter of the filter paper was increased. The filter paper was rinsed with 10 mL of distilled water 3 times and vacuum filtration was continued. The filter paper containing the tofu liquid waste was placed in the oven (during drying, the oven must not be opened and closed) for 1 hour at a temperature of 103ºC – 105ºC to dry. Then, it was cooled in a desiccator to balance the temperature, and then weighed. The following is the calculation of Total Suspended Solid (TSS) levels:

$$\textbf{TSS (mg/l)} = \frac{(W_1 - W_0) \times 1000}{V} \quad \text{(2)}$$

Information:
W_0 = weight of the weighing media containing the initial filter media (mg)
W_1 = weight of weighing media containing filter media and dry residue (mg)
V = volume of tofu (mL)
1000 = convert mL to L

TDS Level Test (SNI 6898.27:2019)

The clean porcelain cup was heated in the oven at 180ºC for 1 hour. Following the next step, the porcelain cup was cooled in a desiccator, and then weighed. The stages of heating, cooling in a desiccator, and weighing were repeated until a constant weight (W_0) was obtained. The test sample obtained from the TDS test filtrate was transferred into a porcelain cup that had a constant weight. The filtrate in the porcelain cup was evaporated until dry using a hotplate at a temperature <100ºC. After that, the porcelain cup containing the dried filtrate was placed in the oven at 180ºC for 1 hour. Afterwards, the porcelain cup containing the filtrate was cooled in a desiccator, and then weighed. The stages of heating, cooling in a desiccator, and weighing were repeated until a constant weight (W_1) was obtained. The following is the calculation of TDS levels

$$\textbf{TDS (mg/l)} = \frac{(W_1 - W_0) \times 1000}{V} \quad \text{(3)}$$

Information:
W_0 = weight of the weighing media containing the initial filter media (mg)
W_1 = weight of weighing media containing filter media and dry residue (mg)

V = volume of tofu (mL)
1001 = convert mL to L

Test of Ammonia Levels

A certain volume of tofu industry liquid waste was added to the tube and successively added a certain volume of sodium potassium tartrate solution (Signet's salt) and Nessler's reagent. Then, the tube was closed and homogenized, then left for 10 minutes. The working solution series is made from ammonium mother liquor with 1 blank and a minimum of 5 levels in the measurement range. The spectrophotometer was optimized and the wavelength was set at 410 nm. The absorption of each working solution was measured then the ammonia content was recorded and plotted. Next, a calibration curve was created and the straight line equation was determined. It was repeated again and the condition of the tool was checked if the linear regression correlation coefficient (r) < 0.995 until an r coefficient value ≥ 0.995 was obtained. To measure the test samples, a blank solution was used to obtain an absorbance value of zero. The ammonia value was calculated based on the linear equation of the calibration curve. The results of the test sample absorption readings are entered into a linear regression calibration curve. The ammonia value was also obtained from the results of reading the levels of the test sample from the standard Ammonium Chloride (NH4Cl) solution curve with the following calculation:

$$\textbf{Ammonia Level (mg N/l)} = C \times f_p \quad (4)$$

Information:
C = ammonia value of test sample (N/l)
fp = dilution factor

Test of pH

The internal pH meter was calibrated using a buffer solution or pH 4, pH 7 and pH 10 buffer solution, and then the pH meter electrode was rinsed with water and rinsed with tissue. The pH electrode was dipped into liquid tofu waste until it reached a stable reading on the pH meter. After that, the results of the scale reading on the pH meter were recorded.

Parametric Statistical Data Analysis

The data in this study was processed using ANOVA (diversity analysis). The BNJ test (Honest Significant Difference) level of 5% is used to test treatments that have a real effect. The parametric statistical analysis of this research refers to the general model, Factorial Completely Randomized Design (CRD) with two treatment factors (current strength and contact time) as follows:

$$Y_{ijk} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \varepsilon_{ijk} \quad (5)$$

Information:
Y_{ijk} = Observation value
μ = General average value
α_i = Effect of current treatment
β_j = Effect of contact time treatment
$(\alpha\beta)_{ij}$ = Interaction effect of current and contact time
ε_{ijk} = experimental error (error)
I = factor A of the ith level
J = jth level B factor
k = kth repetition

Parametric statistical analysis was used to process the measurement results in the study. Analysis of diversity (ANOVA) in statistics can be seen in Table 1.

Table1. List of factorial Completely Randomized Design Analysis

Source of Diversity (SD)	Degrees of freedom (df)	Sum of Squares (SS)	Sum of Middle Square	$F_{\text{-Count}}$	$F_{\text{-Table}}$ 5%
Treatment (T)	$V_1 = (m.n) - 1$	JKP	$\frac{JKP}{V_1}$	$\frac{KTP}{KTG}$	$(V_1 . V_5)$
Factor A	$V_2 = m - 1$	JKA	$\frac{JKA}{V_2}$	$\frac{KTA}{KTG}$	(V_2, V_5)
Facrtor B	$V_3 = n - 1$	JKB	$\frac{JKB}{V_3}$	$\frac{KTB}{KTG}$	(V_3, V_5)
AB Interaction	$V_4 = (m - 1)(n - 1)$	JKAB	$\frac{JKAB}{V_4}$	$\frac{KTAB}{KTG}$	(V_4, V_5)
Error	$V_5 = V_6 - V_1$	JKG	$\frac{JKG}{V_5}$		

Source of Diversity (SD)	Degrees of freedom (df)	Sum of Squares (SS)	Sum of Middle Square	F_{-Count}	F_{-Table} 5%
Total	$V_6 = (m.n.r) - 1$	JK_{Total}	$\frac{JKTotal}{V_6}$		

Source: *Gomez and Gomez, 2010*

F_{table} in the 5% test is compared with F_{count} to see the significance of diversity on the basis of the following comparison :

- If F_{table} 5% $\geq F_{count}$, then it can be stated that the effect is not real and is given the symbol ns
- If F_{table} 5% $\leq F_{count}$, then it can be declared as having a real effect and given the symbol*

If the diversity analysis is found to have a real effect, it will be followed by the Honestly Significant Difference (BNJ) Test. The BNJ test was carried out to determine the mean difference for each treatment. The formula used for the BNJ test is as follows:

$$BNJ = q\ (p,\ v) \times S\bar{y} \qquad (6)$$

$$S\bar{y}\alpha = \frac{\sqrt{KTG}}{4 \times r} \qquad (7)$$

$$S\bar{y}\beta = \frac{\sqrt{KTG}}{5 \times r} \qquad (8)$$

$$S\bar{y}\alpha\beta = \frac{\sqrt{KTG}}{r} \qquad (9)$$

Information:

q	= value in table q 5% test level	r	= number of repetitions
p	= number if treatments tested	α	= electrical current treatment
v	= degree of error freedom	β	= contact time treatment
$S\bar{y}$	= standard error of the generalized mean	αβ	= interaction effect of electrical current and operating time
KTG	= mean square error		

Based on (Gomez, *et al.*) To determine the level of accuracy, the diversity of coefficient (KK) is used. If the coefficient of diversity (KK) is < 15% then this research has good accuracy. The formula for the diversity coefficient (KK) value is as follows:

$$\mathbf{KK\ (\%)} = \frac{\sqrt{KTG}}{\bar{x}} \times 100\% \qquad (10)$$

Information:

KK = Coefficient of Diversity
KTG = Mean squared
$\bar{x}$ = Average value of all research data

Kinetic Data Analysis

The data in this study can be analyzed using fisrt-orde and second orde kinetic models with the following equation:

$$\ln C_t = -k_1 t + \ln C_0 \text{ (First Orde)} \qquad (11)$$

$$\frac{1}{C_t} = \frac{1}{C_0} + kt \text{ (Second Orde)} \qquad (12)$$

Information:

C_0 = Concentration of Initial Substance before the Process
C_t = Substance Concentration after the Process
k = constant
t = Reaction Time (minutes)

Results and Discussion

Characteristics of Tofu Liquid Waste before Electrocoagulation

The initial characteristics of the sample need to be known first so that a comparison of levels/values can be seen before the electrocoagulation process and after the electrocoagulation process. The results of the analysis of the initial characteristics of tofu liquid waste can be seen in Table 2.

Table 2. Initial Characteristics of Tofu Industrial Liquid Waste

Parameter	Quality	Standard Unit (Maximum)	Grade/Value	Description
COD	mg/L	300	1444	Not eligible
TSS	mg/L	200	972	Not eligible
TDS	mg/L	2000	5768	Not eligible
Ammonia	mg/L	0,5	2,653	Not eligible
pH	-	6-9	4	Not eligible

Based on the initial characteristics of tofu liquid waste in Table 2, it shows that all parameters do not meet the quality standards for tofu liquid waste in accordance with the Regulation of the Minister of Environment of the Republic of Indonesia number 5 of 2014 concerning waste water quality standards and Government Regulation No. 82 of 2001 concerning quality standards for ammonia levels of liquid waste. Parameters that do not meet quality standards are because during the tofu production process, tofu liquid waste is produced whey, which contains organic and inorganic compounds such as protein (nitrogen, amino acids, ammonia, peptides), oligosaccharides, simple sugars, hydrogen sulfide, and various minerals such as phosphate, calcium and potassium (Widayat *et al*., 2019). These organic and inorganic compounds cause tofu liquid waste to contain a low pH and high levels of COD, TSS, TDS and ammonia. The tofu liquid waste has not been processed perfectly, which causes the initial levels of each parameter to not meet the quality standards (Afifah and Suryawan, 2018).

Effect of Electrocoagulation on Tofu Industry Liquid Waste Samples

Tofu liquid waste that does not meet quality standards is processed using a set of electrocoagulation equipment consisting of an electrocoagulation reactor, electrodes and a DC Power Supply. The variables in this research consist of variations in current strength and variations in contact time. Variations in current strength consist of 10, 20, 30, and 40 A and variations in contact time consist of 30, 60, 90, 120, and 150 minutes.

Figure1. Physical Condition of Sample before and after the Electrocoagulation Process

The image above shows the physical changes in the tofu liquid waste sample. The sample before electrocoagulation had a white, turbid yellow color, while the sample after electrocoagulation had a clearer color. This is due to the process of electrolysis (redox reaction) and coagulation by the coagulant $Al(OH)_3$ as follows:

$$Al \leftrightarrow Al^{3+} + 3e^- \text{ (anode)} \quad (13)$$

$$2H_2O + 2e^- \rightarrow 2OH^- + H_2 \text{ (cathode)} \quad (14)$$

$$3Al^{3+} + 3OH^- \rightarrow Al(OH)_3 \text{ (coagulant)} \quad (15)$$

$$Al(OH)_3 + 3CH_3COOH \rightarrow Al(CH_3COO)_3 + 3H_2O \quad (16)$$

$$2Al(OH)_3 + 3H_2S \rightarrow Al_2S_3 + 6H_2O \quad (17)$$

$$Al(OH)_3 + NH_3 \rightarrow AlN + 3H_2O \quad (18)$$

$$Al(OH)_3 + PO_4^{3-} \rightarrow Al(PO_4)_3 + 3OH^- \quad (19)$$

$Al(OH)_3$ coagulant binds organic and inorganic contaminants that cause cloudy color in liquid waste from the tofu industry, such as amino acids, carboxylic acids, ammonia, phosphate and others. The formation of hydrogen gas at the cathode causes the flock that has formed to rise to the surface. Over time, the flocks in the form of contaminants increase in number on the surface and are accompanied by small amounts of sediment in the water (Takwanto *et al*., 2018). This proves that the electrocoagulation process has an effect on the clarity or physical changes of liquid tofu waste.

Chemical Oxygen Demand (COD) Levels of Tofu Industrial Wastewater after Electrocoagulation Process

Chemical Oxygen Demand (COD) is a wastewater parameter that is measured to determine the oxygen levels required for chemically oxidized organic and inorganic substances or the amount of organic and inorganic content in the wastewater. COD levels can decrease in the electrocoagulation process due to the redox process (oxidation and reduction reactions) in the electrocoagulation reactor. The electrodes in the electrocoagulation reactor form hydrogen which affects COD reduction. The redox process that occurs in the electrocoagulation reactor causes flocks to form during the electrocoagulation process. Flocks are formed due to organic compound ions binding to positive coagulant ions from $Al(OH)_3$. The working principle of electrocoagulation is the same as the electric double layer theory, namely particle flocculation is adsorption so that positive coagulants absorb negative ions in tofu wastewater such as organic compounds and form flocks that can reduce COD (Amri *et al.*, 2020). Organic contaminants are partially flocculated and oxidized, causing them to separate from the water, resulting in a decrease in COD. The higher the current strength given, the more COD can be reduced, so the quality standards can be met (Sutanto and Artanti, 2019).

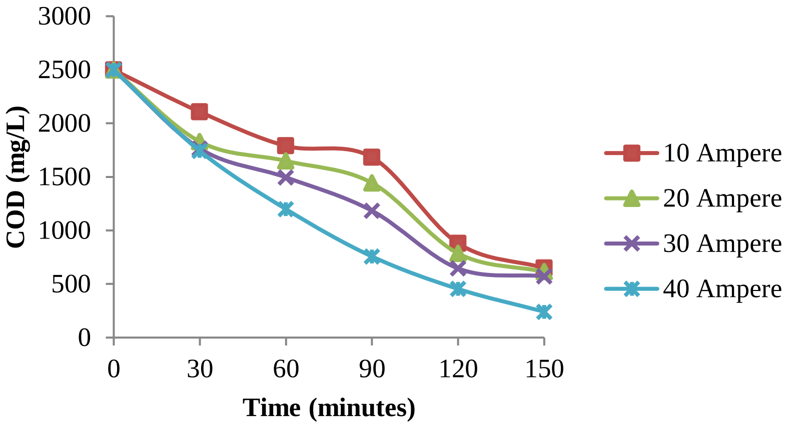

Figure 2. Graph of the Effect of Contact Time on Variation of Current on COD Levels of Tofu Industry Liquid Waste

Based on the graph above, it shows that variations in current strength and contact time have an effect on reducing COD levels. The best treatment obtained COD levels that decreased from the initial characteristics of 2498 mg/L to 241.17 mg/L at a current strength of 40 A with a contact time of 150 minutes. The best COD reduction efficiency was obtained at a current of 40 A and a time of 150 minutes of 90.35%. Based on the results of the diversity analysis or Tukey's further test, it shows that at the 5% level in each treatment, variations in electrical current and contact time have a significant effect on the COD levels of tofu industry liquid waste.

Total Suspended Solid (TSS) Levels of Tofu Industry Liquid Waste

After Electrocoagulation Process, the Total Suspended Solid (TSS) parameter is measured to determine the insoluble solids in wastewater. TSS levels in tofu industry liquid waste are organic substances such as amino acids, carboxylic acids, oligosaccharides and others that are not dissolved in water. TSS levels use the gravimetric method using filter paper with a maximum pore size of 2 µm (Ni'am *et al.*, 2018). TSS levels can decrease due to the relationship between current strength and electrical current. The greater the current and current strength are, the faster Al^{3+} and OH^- ions as coagulants release.

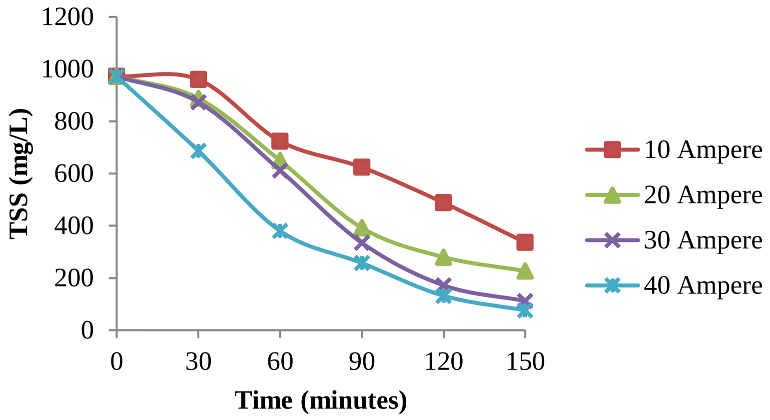

Figure 3. Graph of the Effect of Contact Time on Electrical Current Variation on TSS Levels of Tofu Industry Liquid Waste

The graph in Figure 3 shows that variations in current and contact time have an effect on the decrease in TSS levels. The best treatment obtained TSS levels that decreased from the initial characteristics of 972 mg/L to 76 mg/L at a current strength of 40 A with a contact time of 150 minutes. The best efficiency of increasing suspended residue levels was obtained at a current of 40 A and a time of 150 minutes of 92%. Based on the results of the diversity analysis or Tukey's further test, it shows that at the 5% level in each treatment, variations in current strength and contact time have a significant effect on the value of suspended residue levels in tofu industry liquid waste.

Total Dissolved Solids (TDS) Levels of Tofu Industrial Liquid Waste after the Electrocoagulation Process

Total Dissolved Solids (TDS) is one of the pollutants contained in tofu waste which consists of solids that decompose and dissolve in water. The TDS content of tofu industry liquid waste can be solid objects from minerals, salts, metals, and anion cations dissolved in water which are measured in parts per million (ppm). The level of ionized TDS in a liquid affects the electrical conductivity of the liquid. The higher the level of ionized TDS in a liquid, the greater the electrical conductivity of the solution (Zamora *et al.*, 2016). The high TDS levels in tofu liquid waste are caused by minerals, salts and metals contained in tofu liquid waste such as PO_4^{3-}, NO^{3-}, CH_3COO^-, S^{2-}, Ca^{2+}, Na^{2+}.

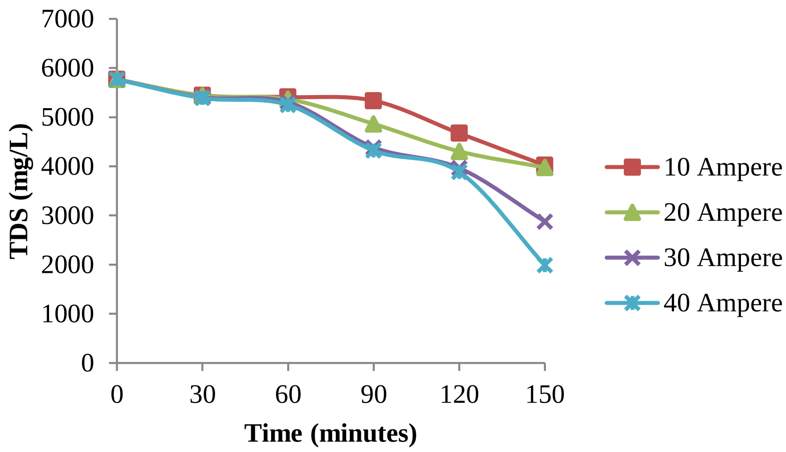

Figure 4. Graph of the Effect of Contact Time on Variation of Current on TDS Levels of Tofu Industry Liquid Waste

Based on the graph, it shows that variations in current and contact time affect the decrease in TDS levels. The decreased TDS levels in the electrocoagulation process are due to the presence of an electric current that causes Al metal to oxidize into Al^{3+} ions at the anode and produces OH^- ions at the cathode. $Al(OH)_3$ formed from Al^{3+} ions and OH- ions is a coagulant. The coagulant binds organic matter and dissolved solids in tofu industry liquid waste and then produces flocks that settle so that the TDS levels decrease. The best treatment obtained TDS (Total Dissolved Solid) levels which decreased from the initial characteristics of 5768 mg/L to 1988 mg/L at a current strength of 40 A with a contact time of 150 minutes. The best efficiency of increasing ammonia levels was obtained at a current of 40 A and a time of 150 minutes of 66%. Based on the results of the diversity analysis or Tukey's further test, it shows that at the 5% level in each treatment, variations in current strength and contact time have a significant effect on the TDS content of tofu industry liquid waste.

Ammonia Content of Tofu Industry Liquid Waste

After Electrocoagulation Process, The breakdown of protein in soybeans which is the raw material for making tofu occurs because the heating process produces amino acids and then becomes ammonia and other compounds. Ammonia (NH_3) is an alkaline compound in the form of a gas that can dissolve in water (Ariyetti *et al*., 2020).

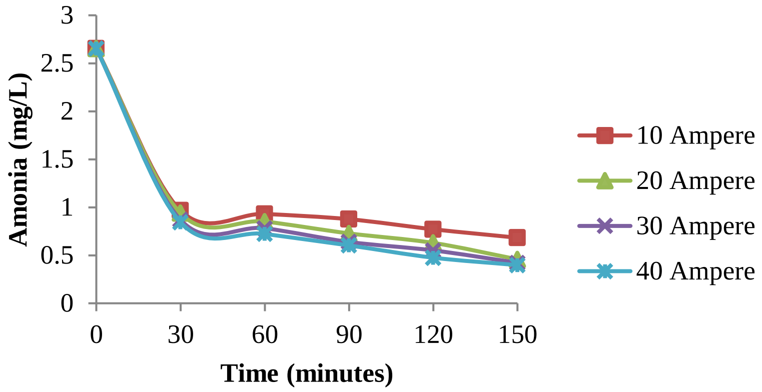

Figure 5. Graph of the Effect of Contact Time on Variations in Current and Amino Levels in Tofu Industry Liquid Waste

Based on the graph, it shows that variations in current strength and contact time affect the decrease in ammonia levels. Ammonia levels can be reduced due to the binding of $Al(OH)_3$ and NH_3 coagulants. "AlN" becomes flock so that ammonia levels decrease (Mande Seyf-Laye *et al*., 2020). The best treatment obtained ammonia levels that decreased from the initial characteristics of 2.653 mg/L to 0.398 mg/L at a current strength of 40 A with a contact time of 150 minutes. The best efficiency of increasing ammonia levels was obtained at a current of 40 A and a time of 150 minutes of 85%. Based on the results of the diversity analysis or Tukey's further test, it shows that at the 5% level in each treatment, variations in current and contact time have a significant effect on the ammonia levels of tofu industry liquid waste.

pH Value of Tofu Industry Liquid Waste After Electrocoagulation Process

The process of forming H_2 bubbles at the cathode also produces OH^- ions which cause the pH of tofu liquid waste to increase in pH which causes the pH of the waste which was initially acidic to approach neutral (Sutanto and Artanti, 2019).

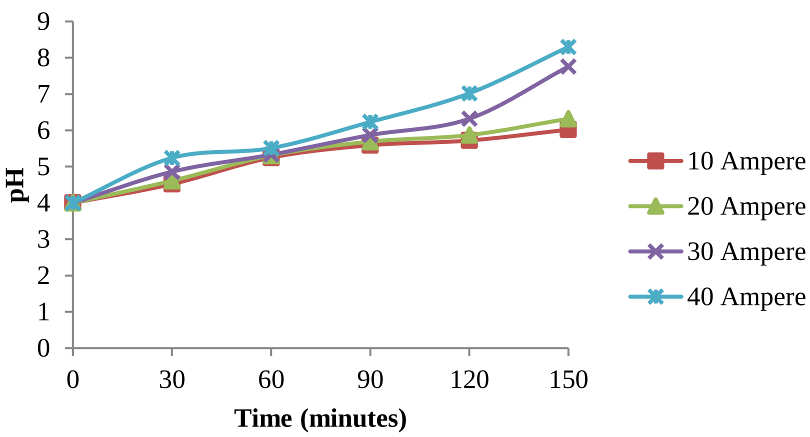

Figure 6. Graph of the Effect of Contact Time on Variation of Current Strength on pH Value of Tofu Industry Liquid Waste

Based on the graph, it shows that variation of current strength and contact time affects the increase in pH value. The best treatment obtained a pH value that increased from the initial characteristics of 4 to 8,30 at a current strength of 40 A with a contact time of 150 minutes. The best efficiency of increasing pH value was obtained at a current of 40 A and a time of 150 minutes of 108%. Based on the results of the diversity analysis or Tukey's further test, it shows that at the 5% level in each treatment, variations in current strength and contact time have a significant effect on the pH value of tofu industry liquid waste.

Chemical Kinetic Analysis of Chemical Oxygen Demand (COD) Levels in the Electrocoagulation Process of Tofu Industry Liquid Waste

Based on the results of the linear curve, the reaction rate constant value with variations in current strength and contact time and the R2 regression value can be seen in Table 3.

Table 3. Results of Reaction Rate for the First Orde and the Second Orde toward COD Changes

Current	First Orde		Second orde	
	$k1(s^{-1})$	R^2	$k1(s^{-1})$	R^2
40 A	0,0164	0,9904	3×10^{-5}	0,8699

Based on Table 3, R^2 in the table is close to one on average. R^2 of second-orde chemical kinetics has not met the correlation coefficient requirement of ~1, so that the COD levels in this study follow first-orde kinetics. The most significant concentration is R^2 variation of 40 A current of first-orde reaction of 0.9904 and k value of 0.0164. This means that the COD level decreases by 0.0164 per minute.

Chemical Kinetic Analysis of Total Suspended Solid (TSS) Levels in the Electrocoagulation Process of Tofu Industry Liquid Waste

Based on the results of the linear curve, the reaction rate constant value is obtained with variations in current strength and contact time and the R^2 regression value can be seen in Table 4.

Table 4. Results of Chemical Kinetics for the First Orde and the Second Orde on TSS Level

Current	First Orde		Second Orde	
	$k1(s^{-1})$	R^2	$k1(s^{-1})$	R^2
40 A	0,0182	0,9952	9×10^{-5}	0,8944

Based on Table 4, R^2 in the table is close to one on average. R^2 of the 2nd orde decrease kinetics has not met the correlation coefficient requirement of ~1, so that the suspended residue levels in this study follow the 1st kinetics orde. The most significant concentration is R^2 variation of current strength of 40 A first-orde reaction of 0.9952 and k value of 0.0182. This means that the suspended residue levels decrease by 0.0182 per minute.

Conclusion

The best condition for processing tofu industry liquid waste using electrocoagulation is at an electrical current of 40 A with a contact time of 150 minutes which produces the highest reduction efficiency of Chemical Oxygen Demand (COD), Total Suspended Solid (TSS), Total Dissolved Solid (TDS), Ammonia levels respectively of 90.35%, 92%, 66%, 85% and the highest increase in pH value of 108%. First orde kinetics of the decrease in Chemical Oxygen Demand (COD) and Total Suspended Solid (TSS) levels at a current of 40 A with R^2 and k values respectively are (0.9904; 0.0164); (0.9952; 0.0182).

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