PENGOLAHAN AIR LIMBAH MENGGUNAKAN ELEKTROKOAGULASI UNTUK INDUSTRI SAUS TOMAT

WASTEWATER TREATMENT USING ELECTROCOAGULATION FOR TOMATO KETCHUP INDUSTRY

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Abstrak

Salah satu limbah industri makanan yang paling berbahaya adalah cairan yang dihasilkan dari produksi saus tomat yang mengandung banyak zat organik dan padatan tersuspensi. Elektrokoagulasi, sebuah metode untuk mengolah limbah cair saus tomat, adalah metode yang ramah lingkungan, mudah digunakan, dan hemat lahan. Banyak orang menggunakan elektroda berbentuk pelat untuk elektrokoagulasi sedangkan elektroda silinder biasanya memiliki konsumsi daya yang lebih rendah selama proses berlangsung. Dengan mempertimbangkan kondisi tersebut, penelitian ini bertujuan untuk mengetahui penggunaan perbedaan kuat arus, pH dan material anoda yang ideal. Selain itu, juga untuk menentukan konsumsi energi spesifik dan jumlah lumpur yang dihasilkan dari reaktor silinder. Kualitas arus listrik sebesar 30 A, 35 A, dan 40 A merupakan variabel yang digunakan dalam penelitian ini. Variabel kedua adalah pH, yang berkisar antara 6,7 dan 8. Bahan anoda yang digunakan adalah besi dan parameter yang diuji adalah pH, BOD dan Fosfat. Hasil penelitian menunjukkan bahwa pada pH 8, kuat arus 40 A dengan menggunakan anoda besi memiliki persentase penyisihan BOD dan Fosfat sebesar 83,52 ± 0,44% (1.358,00 mg/L) dan 74,90 ± 0,98% (189,41 mg/L). Konsumsi energi spesifik yang diperoleh untuk masing-masing parameter adalah 1,71 Wh/gBOD dan 20,38 Wh/gP.

Kata kunci: Elektrokoagulasi, Ferro, Konsumsi energi, Pengolahan, pH.

Abstract

One of the most dangerous industrial food wastes is the liquid resulted from the production of tomato sauce which contains many organic substances and suspended solids. Electrocoagulation, a method for processing tomato sauce liquid waste, is environmentally friendly, easy to use, and land efficient. Many people use plate-shaped electrodes for electrocoagulation whereas the cylindrical electrodes usually have lower power consumption during the process. By considering conditions, this research aims to determine the ideal use of differences in current strength, pH and anode material. In addition, it also wanted to determine the specific energy consumption and amount of sludge produced from the cylindrical reactor. The quality of the electric current of 30 A, 35 A, and 40 A is the variable used in this research. The second variable is pH, which ranges between 6.7 and 8. The anode material used is iron and the parameters tested are pH, BOD and Phosphate. The results showed that at pH 8, current strength of 40 A using an iron anode had a removal percentage of BOD and Phosphate of 83.52 ± 0.44% (1,358.00 mg/L) and 74.90 ± 0.98% (189. 41 mg/L). The specific energy consumption obtained for each parameter is 1.71 Wh/gBOD and 20.38 Wh/gP.

Keywords: *Electrocoagulation, Energy consumption, Ferro, pH, and Treatment.*

1. INTRODUCTION

The development of industry in fulfilling the human needs generally followed by negative effects. Because a human food need is continuing to increase, the food processing industry has become one of the major producers of industrial waste. The grocery industry continues to produce sauces, which generate substantial amount of waste and require a lot of resources such as water, raw materials, and energy. Therefore, sauce production can cause significant environmental problems, including greenhouse gas emissions, production waste, and water pollution (Elferink et al., 2008). One of the most common wastes produced from the food industry is liquid waste, which can pollute waters.

Most of the waste produced from tomato sauce production contains high concentrations of chemical oxygen demand (COD), biological oxygen demand (BOD), and suspended solid material (TSS) with concentrations of 3,600 mg/L; 2,935.4 mg/L; and 7,860 mg/L respectively (Yuliani et al., 2017; Martín et al., 2011). Simple wastewater treatment, such as flocculation-coagulation (Martín et al., 2011) and biological treatment (Nugroho and Sumantri, 2020) can overcome high pollutant concentrations in tomato sauce wastewater. This method requires substantial land, has difficult operations, and produces a lot of sludge and chemicals from the addition of coagulants (Abdelwahab et al., 2020).

Electrocoagulation is a method of processing liquid waste that produces coagulant with electrical energy (Hashim et al., 2017; Heffron, 2015). Electrocoagulation involves the in-situ formation of a coagulant with electrical energy in a reactor without the use of chemicals. Iron, aluminium (Fekete et al., 2016), stainless steel (Dura and Breslin, 2019), and copper (Oden and Sari-Erkan, 2018) are some examples of frequently used electrodes. pH, current strength, type of electrode used, and others variation can contribute to the efficiency of the electrocoagulation process (Sridhar et al., 2014; Dalvand et al., 2011; Adhoum and Monser, 2004). In the electrocoagulation process, pH influences solubility level of various metal ions (Dermentzis et al., 2016). Studies have shown that electrocoagulation is an effective and efficient treatment alternative in industrial wastewater treatment (Sadoon and Ridha, 2020; Un and Aytac, 2013), On the other hand, little research has been conducted regarding the use of electrocoagulation in the sauce industry. Taking into account the background that has been outlined, this research is conducted to determine how effective cylindrical electrocoagulation in the treatment of liquid waste in the food industry to ensure safe quality standards for discharge into the environment.

2. METHODS

The materials used were 25 L sample bottle, spatula, 100 mL beaker, 500 mL beaker, 1,000 mL beaker, 300 mL Winkler bottle, 150 mL Winkler bottle, 100 mL Erlenmeyer, tomato ketchup industry wastewater. BOD testing follows SNI 6989-72-2009. The BOD test with Biochemical Oxygen and Phosphate Required SM 4500-PD (Spectrophotometry). The electrocoagulation reactor can be seen in Figure 1.

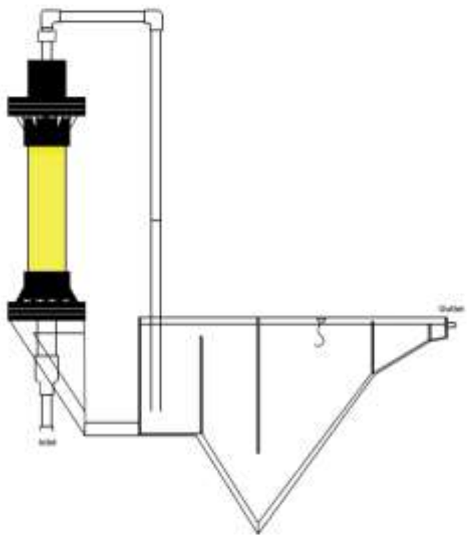

Figure 1. Electrocoagulation cylindrical reactor

3. RESULTS AND DISCUSSION

The characteristics of tomato sauce liquid waste were tested first. pH, BOD, and phosphorus parameters were tested and the results of the test displayed in Table 1.

Table 1. Characteristics of tomato industry liquid waste

Parameter	Unit	Concentration Value	Quality standards
BOD5	mg/L	7,178	100
pH	-	3.75	6-9
Phosphate	mg/L	526.15	1

Based on Government Regulation no. 22 of 2021 on Environmental Protection, Organisation and Management and East Java Governor Regulation no. 72 of 2013 concerning Quality Standards for Industrial Liquid Waste, BOD and Phosphate concentrations do not meet quality standards.

Processing tomato sauce liquid waste with a coagulation reactor shows different results between range of pH, time and current strength. The results of the percentage allowance for BOD parameters can be seen in Figure 2.

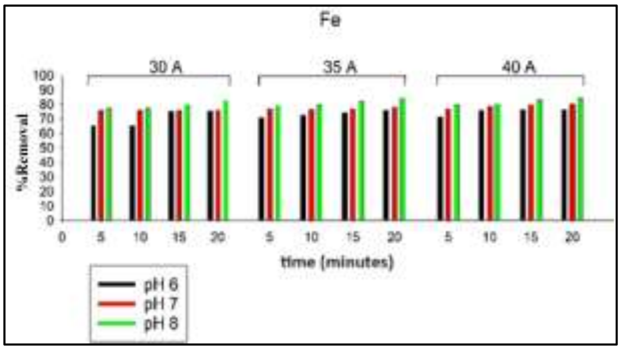

Figure 2. Results of percentage allowance for BOD parameters

Conditions at lower pH (< pH 7) will form more Fe2+ ions, resulting in lots of metal ions, whereas at pH 7 and 8, many hydroxy complexes $Fe(OH)_2$(s) and $Fe(OH)_3$(s) started to arise. These compound acts as a coagulant in the electrocoagulation process. The hydroxo complexes that are formed are the result of the oxidation of Fe^{2+} ions from the anode which bind with water and oxygen, thus producing coagulants $Fe(OH)_2$(s) and $Fe(OH)_3$(s) (Díaz et al., 2018).

The process of forming $Fe(OH)_2$ (s) and $Fe(OH)_3$ (s) compounds can be seen in the following reaction (Segura et al., 2017):

$$Fe \rightarrow Fe^{3+} + 3e^{-} \quad (1)$$
$$Fe + {}_2H_2O \rightarrow Fe\,(OH)_2(s) + H_2(g) \quad (2)$$
$$4\,Fe^{2+} + 10\,H^{-}2O + O_2(g) \rightarrow 4\,Fe\,(OH)_3(s) + 8H^{+} \quad (3)$$

Another result of the electrochemical reaction in the electrocoagulation process is the formation of floc due to the electro flotation process. The flocs that rise to the surface are caused by H_2 gas which is formed during the process. H_2 gas is formed from protons that are converted through cathode reduction (Brillas and Martínez, 2015). The proton reduction reaction can be seen in the equation:

$$2H^{+} + 2e^{-} \rightarrow 2\,H_2(g) \quad (4)$$

The electro flotation process that occurs is also proven by the presence of floc on the water surface in the sedimentation tank. It is known that the pH value can influence the formation size of the gas bubbles. The size range of bubbles produced in the electrocoagulation process is 20-70 µm. Neutral pH is known to produce the smallest bubble sizes. Apart from lifting pollutants that are adsorbed on the coagulant, the small size of the bubbles can make the flow more turbulent than normal-sized bubbles so that the destabilization of the solution is more even due to stirring (Gönder et al., 2017).

The coagulant that is formed generally produced from Fe^{2+} ions bonding with OH- ions to form $Fe(OH)_2$ compounds which are able to bind organic pollutants. According to Matilainen et al. (2010), Fe^{3+} ions have a higher charge density than Fe^{2+} ions. A high charge density will affect the number of valence electron charges on the resulting metal cation. This will reduce the need for coagulants because the more valence charges contained in metal cations, the more pollutants will bind to these cations.

The formation of Fe^{3+} ions as cations is also influenced by the high current and voltage applied during the electrocoagulation process. Based on the results of COD analysis, processing using an iron anode with a current strength of 40 A resulted in the highest removal percentage for all pH variations when viewed from steady state. This shows that at a current strength of 40 A, the oxidation and reduction processes that occur at the anode and cathode run very quickly. The average voltage obtained when setting a current strength of 40 A is 38.71 V. In addition, the formation of H_2 gas occurs quickly because the higher the current strength, the more H_2 gas produced so that it can separate pollutants efficiently (Kobya et al., 2006). This is proven by the formation of coagulant and foam on the water surface in high quantities in a short time, so that a high removal percentage value is obtained. An increase in the removal percentage due to an increase in current strength was also found in research conducted by Elazzouzi et al. (2021), where when the current strength of 0.5 A is increased to 5 A, it can increase COD and BOD removal from 50% to 80% and 60% to 86% respectively in municipal liquid waste using aluminium anodes.

The high removal of organic matter in the electrocoagulation process is caused by the coagulant mechanism that binds pollutants. There are several mechanisms that occur between pollutants and coagulants that have been formed. These mechanisms include: complexation, destabilization, and adsorption (Segura et al., 2017). Complexation is a mechanism for removing pollutants by coagulants that bind to functional groups of organic pollutants. Pollutants will act as ligands for coagulants and bind to central metal ions, which in this study are Fe^{3+} and Fe^{2+}. The organic pollutant removal reaction in the complexation mechanism can be seen in the equation (Ghernaout, 2019):

$$L\text{-}H(aq) + (OH)OFe(s) \rightarrow L\text{-}OFe(s) + H_2O \quad (5)$$

The ligand is denoted as L-H which is in the liquid phase. The ligand will then bond with the metal cation in the $Fe(OH)_3$ compound to form a complex bond. This bond causes the formation of coagulant lumps which will settle (Segura et al., 2017).

The next mechanism is destabilization. Destabilization is the most commonly known removal of organic pollutants. The destabilization mechanism is caused by electrons produced by electrochemical processes, making the charge on the pollutant unstable. Pollutants that are no longer stable can easily bind with coagulants to form flocs on the surface and sediment at the bottom of the sedimentation tank. Another mechanism is adsorption, namely the absorption of pollutants by coagulants. This adsorption is caused by appropriate physical and chemical bonds between the coagulant surface and the pollutant (Ghernaout, 2019).

The use of a cylindrical reactor can also affect the pollutant removal process. A cylindrical reactor with an electrode configuration can provide more even stirring when the water flows through the reactor. This is because the electrodes arranged in the reactor provide an uneven path so that the water flow becomes turbulent. Turbulent flow causes stirring. Contact between pollutants and coagulants will be better due to stirring, so that the removal process becomes more effective. The same results were also obtained by Un and Aytac, (2013), using a cylindrical reactor with continuous flow, obtaining a high COD removal of 98.46%. Iron anodes are more suitable at pH values between 7 and 8 due to the formation of hydroxo complex compounds $Fe(OH)_2$ (s) and $Fe(OH)_3$ (s) in this pH range. This compound will become a coagulant that can separate pollutants from the solvent (Gönder et al., 2017).

Meanwhile, phosphate processing parameters are lower than BOD parameters. The results of the percentage removal for the Phosphate parameter can be seen in Figure 3.

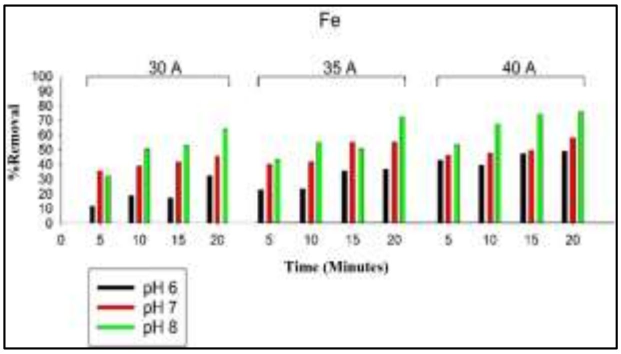

Figure 3. Percentage of Phosphate Removal

Based on the removal percentage in Figure 3, the highest results were obtained at pH 8 and a current strength of 40 A using an iron anode. According to Ghernaout (2019), phosphate removal by coagulants in the electrocoagulation process is caused by complexation and precipitation mechanisms. The figure shows that the pH value affects the Phosphate removal value. Removal At pH 6 variations, low removal values were obtained at currents of 30 A and 35 A. At pH 6 with a current of 40 A, the average removal percentage was 74.90 ± 0.98%. This is in accordance with research conducted by Shalaby et al. (2014), high currents cause the formation of OH- ions in large quantities in a short time so that the pH value will quickly increase.

The initial value pH at pH 6 varies to 7.98 after processing, which is a suitable condition for coagulants to bind pollutants. At pH 8 with a current of 40 A, the highest removal value was obtained with 75.88%. The increase in the removal value is due to the final pH result which is still in the 6-8 range, namely 8.62. Mahvi et al. (2011), stated that this pH value range is the best pH range for phosphate removal as proven through research using artificial liquid waste and obtained the highest percentage value for phosphate removal at pH 8 of 93% using an iron anode with a batch system. The same thing was found in the research of Irdemez et al. (2006), using an iron anode at pH 9 conditions, phosphate removal was obtained at 61% in urban waste processing.

Specific energy consumption calculations can be used to determine optimum conditions and can compare the most optimal energy for each condition. This research produces energy consumption during BOD removal which can be seen in Table 2.

Table 2. Energy consumption during BOD decline

Anode	Current	pH	Energy Consumption (Wh/gBOD)
Fe	30 A	pH 6	0.85
		pH 7	0.90
		pH 8	0.78
	35 A	pH 6	1.33
		pH 7	1.39
		pH 8	1.22
	40 A	pH 6	1.71
		pH 7	2.03
		pH 8	1.71

Table 3. Energy consumption during Phosphate reduction

Anode	Current	pH	Energy Consumption (Wh/gBOD))
Fe	30 A	pH 6	27.34
		pH 7	20.33
		pH 8	13.68
	35 A	pH 6	34.15
		pH 7	24.33
		pH 8	17.53
	40 A	pH 6	28.86
		pH 7	30.25
		pH 8	20.38

This research proves that iron anodes are capable of treating waste with high pollutant content, but iron has higher yields. Similar results were also obtained by Gönder et al. (2017), which processes car wash waste water with an iron anode for 30 minutes using pH 2-10 in batch systems. Syaichurrozi et al. (2021), shows that the higher the current strength, the more it will affect the allowance results, where a variation of current strength of 2.5 A is used; 3.0 A; and 3.5 A.

An iron anode with a pH of 8 with a current of 40 A was chosen as the optimum condition considering the final concentration which is closest to the quality standard. The pH 8 condition used functions in addition to optimizing the results of electrocoagulation processing, it can also help to meet quality standards as the quality standards applied state that the range of pH values that meet is 6-9. In strong current conditions, these conditions can be considered in terms of the specific energy consumption resulting from processing. Specific energy consumption determines the amount of energy needed to remove each gram of pollutant. Tables 2 and 3 show that greater specific energy consumption values are produced on iron anodes with values of 1.71 Wh/gBOD and 20.38 Wh/gP. Kobya et al. (2003), states that the resulting energy consumption is 0.65 Wh/gCOD to obtain a removal percentage of 77%. The high specific energy consumption is also accompanied by a high removal capacity where under pH 8 conditions with a current of 40 A using an iron anode, a greater removal percentage is obtained and the final concentration value is closer to the quality standard that has been applied.

4. CONCLUSION

This research focuses on the quality of electric currents of 30 A, 35 A, and 40 A. pH is the second variable, and its value ranges between 6.7 and 8. For iron anodes, the parameters pH, BOD, and Phosphate were tested. The results showed that the iron anode had a current strength of 40 A at pH 8, with a BOD removal percentage of 83.52 ± 0.44% (1,358.00 mg/L) and 74.90 ± 0.98% (189.41 mg/L). L). In each parameter, 1.71 Wh/gBOD and 20.38 Wh/gP are the specific energy consumption.

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