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Neutralization of Acidity (pH) and Reduction of Total Suspended Solids (TSS) by Solar-Powered Electrocoagulation System

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Abstract

This study investigates the effect of electrocoagulation contact time on the pH and TSS of wastewater discharged from the wastewater treatment plant (WWTP) of the Psychiatric Hospital of West Java Province. The experiment followed the pretest-posttest control group design. This study involved testing 56 wastewater samples six times before and after treatment. Each treatment was repeated four times, and there was one control group for each repetition. The electrocoagulation tool used in this study consisted of six 1-mm electrode plates that were 8 cm apart, a current strength of 5A, a voltage of 12V, and a 50-Watt solar panel. The data were analyzed using descriptive and inferential statistics. The results showed that all electrocoagulation contact time treatments had a significant effect on increasing the pH and the TSS. Additionally, the electrocoagulation tool was found to be effective, stable, portable, and environmentally friendly, with a self-cleaning system that reduced operational costs and saved electricity through the use of solar panels. This study contributes to the development of an effective electrocoagulation toll for wastewater treatment and the determination of the optimal contact time for the tool, providing a practical solution to overcome the problems of pH and TSS in wastewater. These findings can be applied to other wastewater treatment plants, thus improving the quality of discharged wastewater.

Keywords: Wastewater; Electrocoagulation Contact Time; pH; TSS; Solar Panel.

1. Introduction

Hospital waste is all waste generated from hospital activities in solid, liquid, and gas forms. Wastewater is all wastewater, including feces originating from hospital activities, which may contain pathogenic microorganisms and toxic and radioactive chemicals that are harmful to the health. Therefore, every hospital must treat its wastewater so that it meets the standard requirements and does not have a direct effect on the health [1]. There are 334 hospitals in West Java Province that are making efforts to secure waste from Indonesian healthcare facilities. Based on the recapitulation of wastewater discharge, the daily average of hospital wastewater discharge is 0.35 m^3/bed. Of the 334 hospitals, only 39 have reported their wastewater discharge, including the Psychiatric Hospital of West Java Province [2].

The Psychiatric Hospital of West Java Province is a healthcare facility located in West Bandung Regency that has a wastewater treatment plant (WWTP) using an aerobic-anaerobic biofilter system. The basic principle of the system is to utilize aerobic and anaerobic bacteria in the filter to decompose pollutants in water that occur in the process of releasing nitrogen ions that were previously bound to ammonia (NH_3) into nitrates and nitrites. As a result, the degree of acidity

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(pH) in water decreases and tends to be acidic, and increases the total suspended solids (TSS), which can be harmful to the environment [3, 4]. pH is a degree that indicates the acidity or alkalinity of a solution. pH is defined as the cologarithm of the activity of dissolved hydrogen ions (H^+) [5]. The standard for pH of wastewater is 6–9, which is in accordance with the wastewater quality standards set by the Minister of Environment and Forestry of the Republic of Indonesia under Regulation Number P.68/Menlhk-Setjen/2016 concerning Domestic Wastewater Quality Standards. Wastewater whose pH does not meet the standards, especially if it is continuously discharged into the environment, can cause aquatic organisms to die and disrupt ecosystems [6].

Total suspended solids (TSS) are all types of solids that come from total solids that are retained on a filter with a maximum particle size of 2.0 µm [7, 8]. The standard for TSS in wastewater is 30 mg/L, which is in accordance with the wastewater quality standards set by the Minister of Environment and Forestry of the Republic of Indonesia under Regulation Number P.68/Menlhk-Setjen/2016 concerning Domestic Wastewater Quality Standards. The high level of TSS in wastewater that is contained in water bodies can cause the high turbidity of the water bodies. As a result, sunlight, which is needed by autotrophs to carry out natural remediation (photosynthesis) in the river, will be hampered from entering the riverbed [9].

According to the preliminary study of routine wastewater testing conducted by the authors, the pH value of the Wastewater Treatment Plant of the Pyschiatric Hospital of West Java Province was 4-6 and the TSS level was 35–45 mg/L [10]. On the other hand, the wastewater testing conducted by the environmental laboratory showed that the pH value of the wastewater treatment plant was 4.5 and the TSS level was 45 mg/L. The previous studies showed that the pH value and the TSS level did not meet the quality standards. Treatments can be done using the latest technology that involves either physical, chemical, and biological systems or a combination of the three [11]. One of the combinations of physical and chemical systems is electrocoagulation [12, 13].

Electrocoagulation is the process of coagulation and deposition of fine particles contained in wastewater using electrical energy. Electrocoagulation is a more advanced technology and has more advantages compared to chemical coagulation that can damage the environment [14–18], one of which is that electrocoagulation can increase the pH value and decrease the TSS level in wastewater [18–20]. Various treatments were done to the wastewater using aluminum electrodes with different contact times and voltages. The treatment results using aluminum electrodes at 12V for 60 minutes showed positive results, that is, an increase in the degree of acidity by 16%.

Amri et al. [21] also suggested that electrocoagulation using aluminum electrodes can increase the pH value of wastewater. Various treatments were done with different voltages and flow rates [21]. The treatment results at a voltage of 12V and a flow rate of 0.087 L/m also showed positive results, that is, an increase in the degree of acidity from 3.6 to 6.7 and a decrease in the level of TSS by 90.90% from 1100 mg/L to 100 mg/L [21]. Other researchers gave different treatments in terms of contact time, which is a factor in the electrocoagulation process [22]. The results showed that increasing the contact time of electrocoagulation can increase the efficiency of pollutant removal [23–25].

Electrocoagulation is quite effective in reducing the values of turbidity, color, free ammonia, TSS, and heavy metals as well as improving the pH value in wastewater treatment in the non-fishery industry [26–28]. However, electrocoagulation has not been widely applied to hospital wastewater management. Hospital wastewater has relatively the same characteristics in terms of pollutant load as domestic wastewater.

Previous studies have reported the use of electrocoagulation for wastewater treatment from various sources. For example, Raju et al. [29] investigated the use of electrocoagulation for the removal of suspended solids from textile wastewater, while Omwene et al. [30] investigated the effect of electrocoagulation on the removal of suspended solids and chemical oxygen demand (COD) from municipal wastewater. Meanwhile, Rookesh et al. [31] investigated the removal of COD and TSS from landfill leachate using electrocoagulation. Lastly, Kobya et al. [32] investigated the removal of pollutants from textile wastewater using electrocoagulation.

While the abovementioned studies have provided valuable insights into the use of electrocoagulation for wastewater treatment, there is still a gap in the literature regarding the use of solar-powered electrocoagulation for wastewater treatment. This is important because the use of solar panels may provide a sustainable and cost-effective solution for wastewater treatment in areas with limited access to electricity. To address this gap, this study aims to investigate the use of solar-powered electrocoagulation to neutralize the pH and reduce the TSS in wastewater. This study evaluates the effectiveness of the system in treating the wastewater from the wastewater treatment plant of the Psychiatric Hospital of West Java Province. The findings of this study may contribute to the development of sustainable and cost-effective solutions for wastewater treatment, particularly in areas with limited access to electricity.

2. Materials and Methods

This study is a pretest-posttest true experimental control group design. Before the treatment, randomization was carried out in each experimental and control group so that both groups had the same characteristics. Subsequently, a pretest was carried out in all experimental groups, followed by a posttest. The posttest results of all groups were referred to as the effect of treatment [33]. This study was conducted between May and June 2022.

The population was all wastewater from the wastewater treatment plant (WWTP) of the Psychiatric Hospital of West Java Province. The sample was chosen using simple random sampling by means of chemical deoxygenation. The sample size was determined randomly because the sample was relatively homogeneous and the entire population had the same opportunity to be chosen.

The experiments were done six times for 10, 20, 30, 40, 50, and 60 minutes. Each experiment was repeated four times. Therefore, there were 24 samples in the experimental group. In addition, one sample was in the control group for each repetition, resulting in 28 samples in total. Moreover, there were seven samples for each repetition. Each sample consisted of 3,000 ml of wastewater, and thus each repetition consisted of 21,000 ml of wastewater. In other words, the sample size was 84,000 ml of wastewater for four repetitions.

This study used a tool, that is, an electrocoagulation bath with a configuration of six aluminum plates equipped with (1) an integrated total solids spectrophotometer, which was used to measure TSS in wastewater; (2) a stopwatch, which was used to measure the contact time in the electrocoagulation process; (3) a multitester, which was used to measure the electrical voltage in the electrocoagulation process; (4) a stabilizer, which was used to stabilize the electrical voltage in the electrocoagulation process; (5) a 12V and 5A transformer; and (6) a mini generator as a power backup.

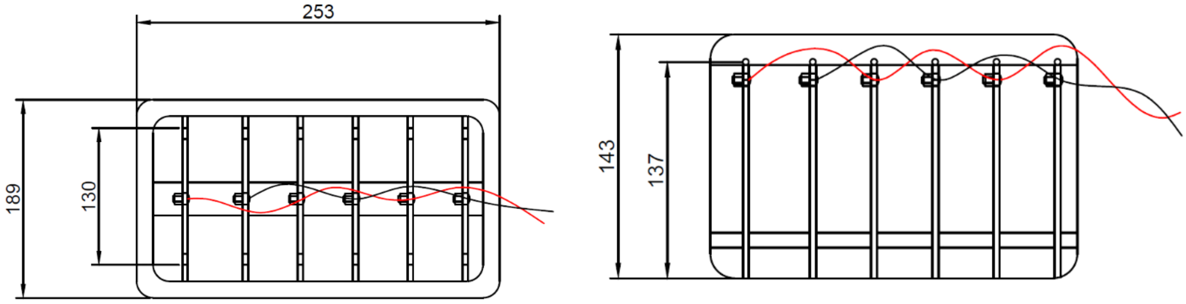

Figure 1. Electrocoagulation bath design in cm (left to right: top view, lateral view)

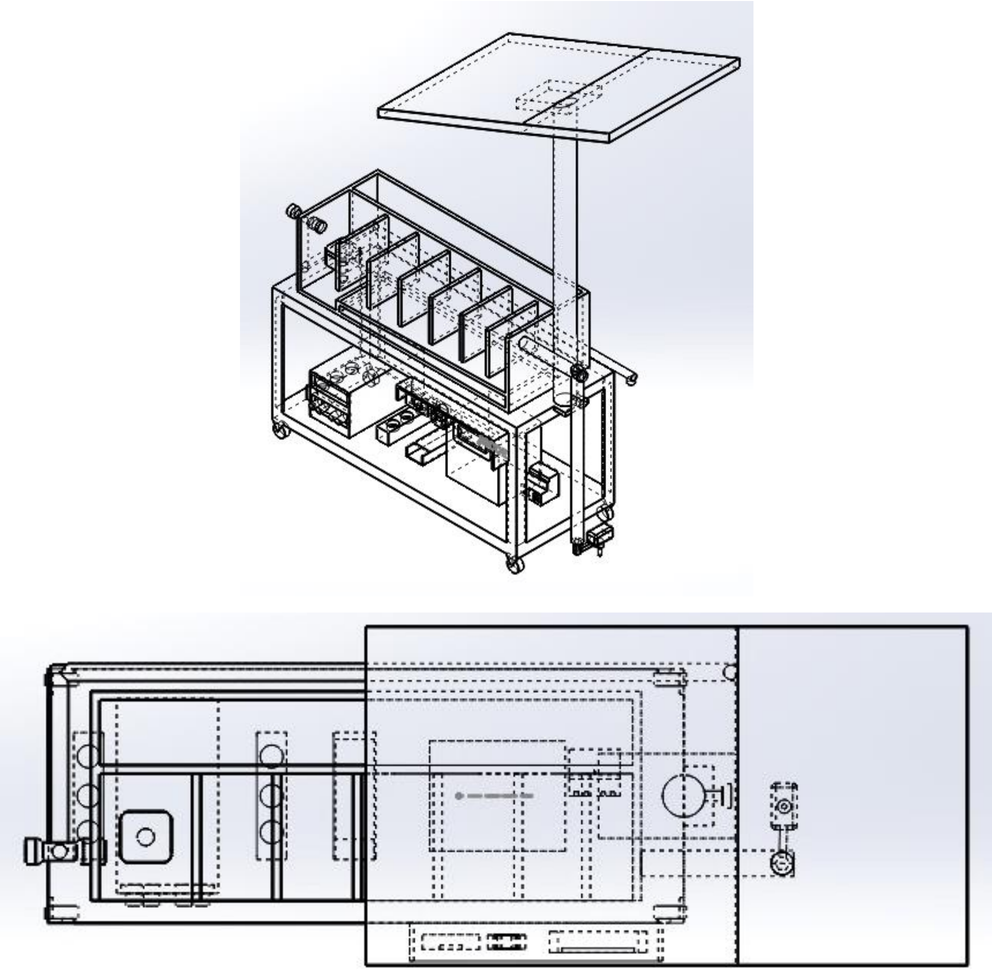

Figure 2. Solar-powered electrocoagulation

The wastewater was contacted with six aluminum plates in the electrocoagulation bath for 10, 20, 30, 40, 50, and 60 minutes to determine the effect of contact time on the degree of acidity (pH) and the level of total suspended solids (TSS). The pH was determined using a pH meter with the Indonesian National Standard number 06-6989.11-2004, while the TSS was determined using a gravimetric analysis with a balance with the Indonesian National Standard number 06-6989.3-2004. The following Figure 3 shows the research flowchart.

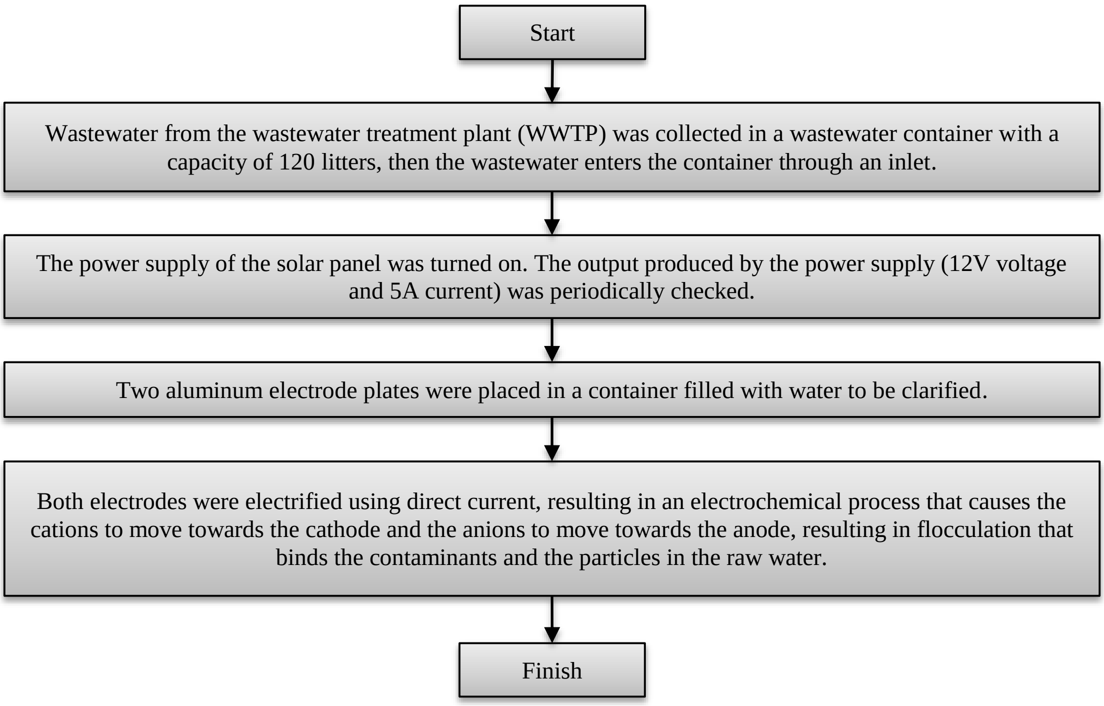

Figure 3. Flowchart of the methodology

Based on the results of the experiment, a p-value of $0.0001 < 0.005$ was obtained, which means that all treatments had an effect on the increase in pH and the decrease in TSS. In addition, a p-value of $0.0001 < 0.005$ was obtained from the results of the ANOVA test, which means there was a significant difference among the six treatments.

3. Results

Electrocoagulation is the process of coagulation and deposition of fine particles in wastewater using electrical energy. The process is carried out in an electrolysis container in which there are two direct current conductors known as electrodes [34]. Electrocoagulation produces metal cations in situ electrochemically using an anode (usually aluminum or iron). The cations are hydrolyzed in water to form hydroxides, whose species is determined by the pH of the solution. The highly charged cations destabilize colloidal particles by forming polyvalent polyhydroxide complexes. These complexes have high absorption properties and form aggregates with pollutants [35, 36].

One of the important parameters in the electrocoagulation process is contact time. Contact time is also associated with reaction rate, which is expressed as a change in concentration over time. The longer the electrocoagulation process, the more H_2 and OH^- are formed. As a result, the number of complexes that bind pollutants and the amount of hydrogen gas increase [37–39]. The electrocoagulation process is the development of the electrolysis process, that is, the decomposition of electrolytes by direct current using two electrodes, namely the cathode and anode [40–42].

In the processes of electrolysis and electrocoagulation, the cathode acts as the negative pole. At the cathode, a reduction reaction occurs because cations (positive ions) are attracted to the cathode, thus receiving additional electrons that reduce the oxidation number. The cathode will produce hydrogen ions, which remove the flocculants formed in the electrocoagulation process. After the electrocoagulation process is finished, white spots will stick to the cathode as a sign of the release of hydrogen ions there [43]. In contrast to the cathode, the anode acts as the positive pole. At the anode, an oxidation reaction occurs because anions (negative ions) are attracted to the anode, thus releasing electrons, which increase the oxidation number. As a result, the flocculants formed in the electrocoagulation process will stick to the anode as coagulants [44, 45].

Aluminum is a silvery-white metal and the thirteenth element in the periodic table. Pure aluminum is not found in nature because of its tendency to easily bond with other elements [46]. Aluminum is the most common electrode material used in the electrocoagulation process. The aluminum electrode is oxidized as Al^{3+}. The resistivity of aluminum is $2.65×10^{-8}$ ohms. In many cases, aluminum electrodes are more effective in terms of removal compared to other electrodes [47].

Aluminum has been widely used in the electrocoagulation process. When aluminum is used as the anode, metal ions are released from the anode and hydrolyzed ionic monomers are formed, depending on the pH of the solution. The reactions that occur at the electrodes, according to Verma et al. [48], are as follows:

Oxidation reaction at the anode:

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

Reduction reaction at the cathode:

$$3H_2O + 3e^- \rightarrow (3/2)H_2 + 3OH^-$$

All reactions during the electrolysis:

$$Al^{3+} \rightarrow Al(OH)_n^{(3-n)} \rightarrow Al_2(OH)_2^{4+} \rightarrow Al_3(OH)_4^{5+} \rightarrow Al_{13} \rightarrow \text{complex} \rightarrow Al\,(OH)_3$$

The use of electrocoagulation (EC) for wastewater treatment has gained increasing attention in recent years due to its advantages, such as high efficiency, low energy consumption, and environmentally friendly operation. Several studies have been conducted to investigate the effectiveness of EC in removing various pollutants from wastewater, including pH and TSS. For example, Khandegar & Saroha [49] used EC to remove TSS from textile wastewater, while Li et al. [50] used EC to remove pH from landfill leachate. However, the effectiveness of EC in different countries still needs to be investigated. In Iran, Nouri et al. [51] investigated the use of EC to remove zinc and copper from aqueous solutions. In Turkey, Koyuncu et al. [52] investigated the use of EC for domestic wastewater treatment. In Indonesia, Alam et al. [53] investigated the use of EC to remove Fe from mining wastewater. Maha Lakshmi & Sivashanmugam [54] in India investigated the use of EC for oil tanning, while Tak et al. [55] in Korea investigated the use of EC to remove color and COD from livestock wastewater. In Jordan, Al-Shannag et al. [56] investigated the use of EC to remove TSS and COD from paper mill wastewater. In China, Sia et al. [57] investigated the use of EC to remove TSS, COD, and color from palm oil mill effluent. In Saudi Arabia, Al-Othman et al. [58] examined the use of EC for municipal wastewater treatment. Lastly, in Brazil, Valente et al. [59] investigated the use of EC to remove TSS from dairy industry wastewater.

Overall, while there are many studies on the use of EC for wastewater treatment, few studies have focused on the effectiveness of EC in different countries. Therefore, this study aims to investigate the effectiveness of EC for the removal of pH and TSS from wastewater from a psychiatric hospital in West Java, Indonesia, and to compare the results with similar studies conducted in other countries. The findings of this study will contribute to a better understanding of the effectiveness of EC in wastewater treatment and provide insights for future research and application of this technology in different countries.

The results of the pH examination in this study are presented in the following tables. Table 1 shows that the pH value before and after each repetition did not change and was considered to not meet the standard requirements for wastewater set by the Minister of Environment and Forestry. The WWTP of the Psychiatric Hospital of West Java Province had a low or acidic pH value due to the decomposition of nitrogen ions that were previously bound to ammonia (NH_3) into nitrates and nitrites. The hydrogen ions released from the nitrogen ions became free, causing the pH of the wastewater to become acidic.

Table 1. pH values of the control group without any treatment (60 minutes)

Repetition	pH Values				Quality Standard
	Before	Description	After	Description	
1	3.63	Does not meet the requirements	3.63	Does not meet the requirements	6-9
2	3.71		3.71		
3	3.69		3.69		
4	3.7		3.7		

Table 2 shows that the pH value before treatment did not meet the standard requirements for wastewater set by the Minister of Environment and Forestry. After 10 minutes of treatment, there was a change in the pH value, but it did not meet the standard requirements for wastewater yet. However, after 20 to 60 minutes of treatment, the pH value finally met the standard requirements for wastewater. After 60 minutes of treatment, the pH value increased, approaching the pH value of alkaline.

Table 2. pH value with various electrocoagulation contact times

Repetition	pH Value				Quality Standard
	Before	Description	After	Description	
10 Minutes Treatment					6-9
1	3.79	Does not meet the requirements	5.94	Does not meet the requirements	
2	3.73		5.99		
3	3.77		5.95		
4	3.78		5.94		
20 Minutes Treatment					
1	3.72	Does not meet the requirements	6.44	Meets the requirements	
2	3.75		6.41		
3	3.74		6.44		
4	3.72		6.47		
30 Minutes Treatment					
1	3.76	Does not meet the requirements	6.65	Meets the requirements	
2	3.77		6.69		
3	3.73		6.71		
4	3.77		6.68		
40 Minutes Treatment					
1	3.75	Does not meet the requirements	7.09	Meets the requirements	
2	3.76		7.15		
3	3.73		7.18		
4	3.78		7.16		
50 Minutes Treatment					
1	3.76	Does not meet the requirements	7.38	Meets the requirements	
2	3.76		7.41		
3	3 ,75		7.39		
4	3.77		7.38		
60 Minutes Treatment					
1	3.75	Does not meet the requirements	7.76	Meets the requirements	
2	3.76		7.81		
3	3.77		7.77		
4	3.75		7.79		

The results of the data analysis showed that a 10-minute electrocoagulation contact time could increase the pH value of the wastewater, although it did not meet the standard requirements yet. This was because the 10-minute contact time was not sufficient for the cation reaction to reduce water to hydrogen (H_2) and hydroxide (OH^-), which can affect the pH value. The ideal contact time to improve the quality of wastewater is between 15 and 30 minutes, which can increase the pH value, while the optimum contact time for the electrocoagulation process is within the initial 15 minutes [60]. Meanwhile, the optimum contact time for the electrocoagulation process to improve the quality of wastewater is 30 minutes, which can increase the pH value [60, 61]. On the other hand, 45 minutes is sufficient to form flocculants via $Al(OH)_3$ as a coagulant, which can affect the pH value of the wastewater [62]. Considering the fact that the electrocoagulation process consists of cation and anion reactions, the cation reaction of H^+ from the acid will result in the reduction of hydrogen, which will be released as gas bubbles. Meanwhile, the anion reaction at the anode will produce gas, foam, and $Al(OH)_3$ [63]. At 50 minutes of contact time, there was a considerable change in the pH value [64]. Electrocoagulation contact time can increase th e efficiency of pollutant removal [49, 65]. Lastly, the 60-minute contact time of electrocoagulation with aluminum electrodes was found to be the most effective in increasing the pH value [66–68].

The changes in pH in the electrocoagulation process were due to the electrolysis process through aluminum, which consists of a cathode and an anode. At the cathode, a reduction reaction occurs because the negative ions attract the positive ions, resulting in the formation of H_2 and OH^-. Meanwhile, at the anode, the pH value of the wastewater increases. This is in line with the previous study by Kobya et al. [69] that the cathode in the electrocoagulation process will produce H_2 and OH^-, which will affect the pH value. The longer the contact time and the higher the voltage used in electrocoagulation, the greater the reduction of wastewater pollutants that occurs [69]. In this sense, if the electrocoagulation contact time is extended, there is a possibility that the pH will become very alkaline (>9), which can also be harmful to the environment [70].

pH is an important parameter in the electrocoagulation process as it can affect the solubility of metal ions and the formation of flocculants, which can affect the efficiency of pollutant removal. The pH value that is too low or too high may result in incomplete coagulation or destabilization of flocculants, leading to poor treatment efficiency. Generally, the optimal pH value for electrocoagulation ranges between 6 and 8.5. According to Arroyo et al. [71], pH affects the electrocoagulation process due to its effect on the electrochemical reactions that occur at the anode and cathode. At a low pH, the concentration of H+ ions increase, leading to a decrease in the solubility of metal ions and a decrease in the rate of coagulation. On the other hand, at a high pH, the concentration of OH- ions increases, resulting in the formation of insoluble metal hydroxides that can reduce the efficiency of pollutant removal.

The results of the TSS examination in this study are presented in the following tables. Table 3 shows that the TSS value before and after each repetition did not change and was considered not meeting the standard requirements set by the Minister of Environment and Forestry because it exceeded the quality standard of 30 mg/L. The WWTP of the Psychiatric Hospital of West Java Province had a high TSS level because the biofilter was full of mud. Excess mud in the biofilter causes suspended particles to be carried away, resulting in the high TSS level of the wastewater.

Table 3. TSS level without any treatment (60 minutes)

Repetition	TSS Level				Quality Standard
	Before	Description	After	Description	
1	122	Does not meet the requirements	122	Does not meet the requirements	30
2	123		123		
3	123		123		
4	122		122		

Table 4 shows that the TSS level before treatment did not meet the standard requirements for wastewater. At 10 to 30 minutes of treatment, there was a reduction in the TSS level, but it did not meet the standard requirements for wastewater yet. After 40 to 60 minutes of treatment, the TSS level finally met the standard requirements for wastewater. After 10 to 30 minutes of treatment, the TSS level was considered not meeting the requirements because it was above the standard requirement for wastewater, which is 30 mg/L. This was because the electrocoagulation process was not maximized between 10 and 30 minutes. As a result, there was not much $Al(OH)_3$, and flocculants were not formed to precipitate suspended particles. After 40 to 60 minutes of treatment, the TSS level was considered meeting the standard requirements for wastewater because it was below 30 mg/L. This was because the reaction in the electrocoagulation process was maximized between 40 to 60 minutes. As a result, there was a lot of $Al(OH)_3$, and flocculants were formed to precipitate suspended particles.

Table 4. TSS level with various electrocoagulation contact times

Repetition	TSS Level				Quality Standard
	Before	Description	After	Description	
10 Minutes Treatment					30
1	122	Does not meet the requirements	39	Does not meet the requirements	
2	124		37		
3	123		36		
4	123		38		
20 Minutes Treatment					
1	123	Does not meet the requirements	36	Does not meet the requirements	
2	122		34		
3	124		34		
4	122		35		
30 Minutes Treatment					
1	122	Does not meet the requirements	34	Does not meet the requirements	
2	123		33		
3	123		32		
4	124		31		
40 Minutes Treatment					
1	124	Does not meet the requirements	30	Meets the requirements	
2	124		28		
3	123		29		
4	122		28		

50 Minutes Treatment				
1	122	Does not meet the requirements	25	Meets requirements
2	121		23	
3	123		24	
4	124		24	
60 Minutes Treatment				
1	122	Does not meet the requirements	20	Meets requirements
2	121		19	
3	124		19	
4	123		18	

The ideal contact time to improve the quality of wastewater is between 40 to 60 minutes, which can reduce the TSS level [21], whereas the optimum contact time to improve the quality of wastewater in the electrocoagulation process is 30 minutes [61, 72]. After 45 minutes, flocculants were formed via $Al(OH)_3$. The formed flocculants bind a lot of suspended and precipitated substances, so they may reduce the TSS level in wastewater [62, 73]. Electrocoagulation consists of cation and anion reactions. The cation reaction of H^+ from the acid will result in the reduction of hydrogen, which will be released as gas bubbles, while the anion reaction at the anode will produce gas, foam, and flocculants of $Al(OH)_3$ [74].

The changes in TSS level in the electrocoagulation process occurred because of the electrolysis process through aluminum, which consists of a cathode and an anode. In contrast to the cathode, an oxidation process of the positive pole occurs at the anode, which releases the coagulant (Al^{3+}), which is aluminum, into the wastewater. This coagulant will form flocculants, which will be precipitated to reduce the TSS level and improve the quality of the wastewater. This is in line with the previous study by Feng et al. [75], in which the anode in the electrocoagulation process will form a coagulant ($Al3^+$), which will attract suspended particles to form flocculants that will precipitate to the bottom of the bath. The longer the contact time and the higher the voltage used in electrocoagulation, the greater the pollutants that will be removed from the wastewater [75].

TSS can affect the electrocoagulation process because it can interfere with the coagulation and flocculation of suspended particles in the wastewater. TSS can also lead to fouling on the electrode surfaces, which can reduce the effectiveness of the process. The amount and nature of the suspended solids in the wastewater can also affect the performance of electrocoagulation. A study conducted by Bazrafshan et al. [76] investigated the effect of TSS on the performance of electrocoagulation for dairy industry wastewater treatment [76]. The results showed that the efficiency of chemical oxygen demand (COD) and total suspended solids (TSS) removal decreased with increasing concentrations of initial TSS. The study suggested that the presence of TSS in wastewater can lead to a decrease in the efficiency of electrocoagulation, so it should be taken into account when designing and performing electrocoagulation systems.

4. Conclusion

A solar-powered electrocoagulation (SPEC) system has been shown to be an efficient and environmentally friendly technology for wastewater treatment, particularly in terms of neutralizing the acidity (pH) and reducing the total suspended solids (TSS). Through a review of previous studies, it is clear that electrocoagulation has been widely investigated for its effectiveness in removing various pollutants from wastewater. However, the effectiveness of this technology in different countries still needs to be investigated. The results of this study have practical implications for the development of sustainable and efficient wastewater treatment systems. This study motivates the academic community to continue researching and developing practical and actionable solutions for wastewater treatment. By exploring the potential of the SPEC system, researchers can contribute to the development of sustainable and environmentally friendly technologies for wastewater treatment, which are critical for protecting the environment and ensuring public health.

4.1. Suggestions and Limitations

Among the contributions of this study are as follows:

- The results of this study can increase knowledge in wastewater management, especially in relation to increasing the pH value and reducing the TSS level in wastewater.
- The results become an input for WWTP managers in treating wastewater, especially in increasing the pH value and reducing the TSS level in wastewater.
- It becomes an alternative to wastewater management efforts.

- Further research is needed to investigate other chemicals in wastewater after the electrocoagulation process is carried out.
- A real field application of the results of this study is necessary in order to solve the problem of wastewater quality standard requirements, especially on the pH and TSS parameters.

Among the limitations of the study are in relation to the differences among implementations in the field, namely:

- In this study, the electrocoagulation bath used a batch system, while in the field implementation, a continuous system was used. In principle, the wastewater retention time will be different between batch and continuous systems. Therefore, it is necessary for further research to investigate the effect of contact time electrocoagulation using a continuous system.
- In this study, the electrocoagulation bath did not use effluent to remove wastewater. This caused the mixing of solid particles that precipitated or floated, affecting the TSS level when moving the sample into the bottle. Therefore, it is necessary to measure TSS using total solids integrated spectrophotometry.
- In this study, only one bath of electrocoagulation was used. Therefore, the difference in treatment was not carried out simultaneously, leading to the possibility of bias in the research.
- In this study, the number of samples required was determined according to the minimum number of samples required for inspection, but did not consider the amount of wastewater discharge. Therefore, it is necessary to carry out further research by considering the amount of wastewater discharge.

5. Declarations

5.1. Author Contributions

Conceptualization, E.F. and I.A.S.; methodology, I.A.S. and A.R.; software, E.F.; validation, E.F. and I.A.S.; formal analysis, E.F, I.A.S., A.R., and A.E.S.; investigation, I.A.S.; resources, E.F.; data curation, E.F.; writing—original draft preparation, E.F. and I.A.S.; writing—review and editing, E.F.; visualization, E.F.; supervision, E.F. and I.A.S.; project administration, I.A.S.; funding acquisition, E.F. and I.A.S. All authors have read and agreed to the published version of the manuscript.

5.2. Data Availability Statement

The data presented in this study are available upon request from the corresponding author.

5.3. Funding and Acknowledgements

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5.4. Conflicts of Interest

The authors declare no conflict of interest.

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