



Application of Electrocoagulation in Stabilizing pH and Removing Pollutants from Domestic and Urban Wastewater Using Aluminum Electrodes



Ardista Izdhihar Kaloka^{a*}, Nurul Faizah^a, Rizal Arifin^a, Anisa Fatma Aulia^a,
Muhammad Benaldo Anugrah Putra^a, Ni'mah Wati^a, Icha Nur Prayadi^a

^a*Department of Industrial Chemical Engineering, Faculty of Vocation, Sepuluh Nopember
Institute of Technology, Surabaya 60111, Indonesia
Corresponding author: ardista.izdhihark@its.ac.id*

Abstract

This study investigates the application of electrocoagulation using aluminum electrodes to stabilize pH and remove pollutants from various real wastewater sources in Surabaya, Indonesia, including laundromats, fast food restaurants, campus canteens, mechanical workshops, and tofu industries. A batch-mode electrocoagulation process was conducted using 10 A of current over 60 minutes, and the performance was evaluated based on pH changes, turbidity, and Total Suspended Solids (TSS) removal. The highest TSS removal efficiency of 98% was observed in machine shop wastewater, while laundromat samples also achieved high performance with 97% reduction. Electrocoagulation demonstrated strong pH stability in effluents with buffering compounds such as those from campus canteens and workshops, whereas fluctuating pH and turbidity levels were found in tofu and fast-food effluents, indicating the need for process optimization. Turbidity decreased significantly across all samples, confirming effective floc formation during electrolysis. The findings confirm that electrocoagulation is a promising method for treating both domestic and urban wastewater. However, integrating additional processes such as adsorption or filtration is recommended to enhance performance for complex wastewater compositions and ensure compliance with discharge standards.

Keywords: Aluminum electrode; Electrocoagulation; pH stabilization; TSS Removal; Turbidity.

1. Introduction

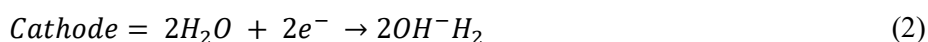
Environmental issues caused by waste continue to escalate alongside the increasing scale of household and industrial activities. In addition to solid waste, liquid waste also poses a serious threat to environmental sustainability and human health. Wastewater often contains microscopic pollutants that are invisible to the naked eye but have long-term impacts, not only on directly exposed individuals but also on future generations. Therefore, the development of effective wastewater treatment technologies is urgently needed, particularly for effluents originating from factories, hospitals, and domestic sources. Conventional treatment methods such as chemical coagulation face various limitations, including high operational costs, potential health risks due to chemical residues, and prolonged treatment durations [1]. This technique has been successfully applied to a wide range of wastewater types, including textile industry effluents, peat water, domestic wastewater, hospital waste, and industrial chemical wastewater.

Electrocoagulation is a wastewater treatment process that utilizes electrical current to precipitate suspended solids and contaminants from water. The process begins by passing an electric current through electrodes submerged in the solution. When the current flows, positive ions (cations) are released from the anode and negative ions (anions) from the cathode. These ions then react with pollutants in the water to form larger flocs, which can subsequently settle out [2]. Electrocoagulation consists of an electrochemical cell in which electrodes are placed and connected to an external power source. The formation of coagulants—namely metal ions—is carried out in situ by dissolving the anode material. The electrocoagulation process typically involves several key steps: sacrificial dissolution of the anode material under electrical current to generate metal cations; formation of hydroxyl ions at the cathode; generation of metal hydroxides with strong adsorptive properties to bind pollutants; oxidation of pollutants into less toxic compounds; neutralization of charged pollutants with metal ions; aggregation and adsorption of neutralized pollutants; and flotation of contaminants using gases generated within the system [3]. Electrocoagulation systems offer several

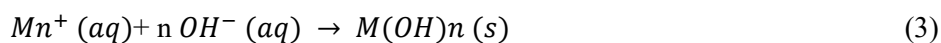
advantages, such as minimal chemical usage, short reaction times, and the ability to maintain pH stability due to the absence of salt accumulation [4]. However, the efficiency of the process strongly depends on operational parameters such as current density, electrolysis duration, and pH. Higher current density can improve pollutant removal by enhancing gas bubble generation, which aids in floc flotation, although excessive current may lead to electrode passivation and reduced performance [2]. Similarly, longer electrolysis duration can increase the release of metal ions, but overly extended times may reduce effectiveness due to saturation or re-dissolution phenomena [5].

The electrolysis principle can be used to clarify the electrocoagulation (EC) mechanism. The anode and cathode, which are immersed in an electrolyte solution, both receive an electric current during this procedure. At the electrodes' surface, the current serves as a non-spontaneous driving force to start electrochemical reactions. Ions in the electrolyte move between the cathode and the anode during the reaction. Through processes including condensation and aggregation, contaminants are destabilized and removed more easily when cations are reduced at the cathode and anions are oxidized at the anode. Chemically speaking, EC mostly entails the slow breakdown of a sacrificial anode—usually composed of iron or aluminum—under the effect of an applied current. Many high-valence metal cations are produced in situ as a result of this dissolution. After that, these cations are hydrolyzed to create amorphous metal hydroxide precipitates, which have potent destabilizing and adsorption capabilities. The precipitates encourage the aggregation of colloidal particles and dissolved pollutants into bigger flocs by binding to them. It is simpler to separate these flocs from the water by flotation or sedimentation. Bubbles of hydrogen gas (H_2) are created when water molecules are reduced concurrently by the cathodic process. By creating turbulence and increasing system mixing, these bubbles improve the interaction between coagulants and contaminants. Additionally, the flocs are lifted to the surface by the buoyant force of the H_2 bubbles, which facilitates flotation and impurity removal. The entire procedure is quite effective at eliminating a variety of contaminants, such as oils, dyes, suspended particles, and heavy metals. Because it produces less sludge and uses fewer chemical additives than traditional processes, it is also regarded as environmentally benign. In the end, electrocoagulation effectively treats water and wastewater by combining physical separation with electrochemical processes [6].

Metal cations are released at the anode during the electrocoagulation process, whereas hydroxide ions (OH^-) and hydrogen gas (H_2) are created at the cathode as a result of the following reactions:



The metal oxidizes and creates metal cations (Mn^+) when an electric current passes through the metal electrodes. Water molecules are reduced concurrently, resulting in the production of H_2 and OH^- . Following that, the metal cations undergo the following processes to create monomeric and polymeric hydroxide complexes that function as coagulants:



Amorphous metal hydroxide precipitates are generated by the coagulants formed during the electrocoagulation process. These precipitates are known for their strong adsorption capacity, which plays a crucial role in water treatment. They act by capturing and binding dissolved pollutants, including heavy metals, dyes, and organic compounds. Additionally, they help trap suspended solids and colloidal particles present in the wastewater. This dual action significantly enhances the overall coagulation and flocculation efficiency. As a result, contaminants are effectively separated from the aqueous phase and can be removed through sedimentation or flotation. Simultaneously, hydrogen gas (H_2) is produced at the cathode as part of the electrochemical reaction. The formation of H_2 bubbles introduces turbulence into the system, which improves mixing and contact between pollutants and coagulants. Moreover, the rising bubbles assist in lifting the flocs to the surface, aiding in the flotation and removal of the aggregated pollutants. Altogether, this mechanism contributes to a highly effective and sustainable method for wastewater [7].

This study evaluates the effectiveness of the electrocoagulation process in treating real wastewater samples collected from various sources in Surabaya, Indonesia. These sources include laundromats, fast food restaurants,

campus canteens, mechanical workshops, and tofu industries. The research focuses on examining the impact of electrocoagulation on pH stability, turbidity reduction, and total suspended solids (TSS) removal in different wastewater profiles, providing insight into the applicability of EC across various wastewater sectors.

2. Material and Method

2.1. Material

The materials required in this experiment include various types of wastewater samples obtained from several points in the Surabaya area, Indonesia, representing a wide range of domestic and industrial activities. The sampling points included locations such as a laundry, fast food restaurant, tofu industry, campus canteen, as well as several workshops scattered around the area. To increase the conductivity of the solution and support the electrocoagulation process, raw solar salt was used as the electrolyte material mixed into each wastewater sample. In addition, hydrochloric acid (HCl) and sodium hydroxide (NaOH) solutions were used in this process as pH adjusters, in order to stabilize the solution conditions at a neutral pH value, which is around pH 7, before the electrocoagulation treatment is carried out. In this process, aluminum plates were chosen as electrodes because of their known high effectiveness in producing coagulant during electrocoagulation as well as their ability to help maintain the pH stability of the solution during the process.

2.2 Methods

The schematic of the tool is shown in (Figure 1), which operates as a batch process.

Apparatus of electrocoagulation process :

- (1) Water tank storage
- (2) Peristaltic Pump
- (3) Power Supply & Voltmeter
- (4) Ampere Meter
- (5) Alligator Clips
- (6) Aluminium Electrodes
- (7) Electrocoagulation Reactor
- (8) Effluent of Fluid Valve

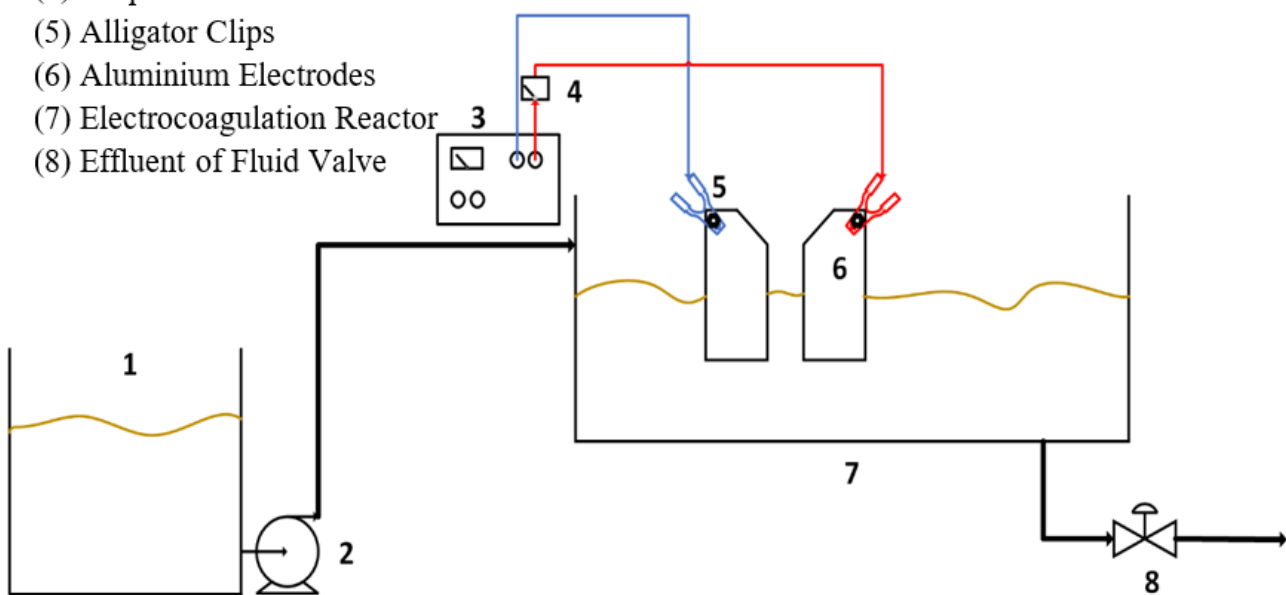


Figure 1. Apparatus of electrocoagulation process

Wastewater samples were first stored in a holding tank with a total capacity of 10 liters before being flowed into the electrocoagulation reactor. The flowing process is carried out continuously using a peristaltic pump to ensure a stable flow to the reactor. The electrocoagulation reactor used has a total capacity of 15 liters, but its effective capacity during the process is limited to 10 liters. Inside the reactor, aluminum electrodes measuring 20 cm × 8 cm × 0.2 cm were installed vertically with a distance of 4 cm between electrodes and immersed to a depth of 8 cm into the solution. These electrodes were then connected to a direct current source in the form of a DC power supply with a current strength of about 10 amperes, which served as an energy source for the electrocoagulation process. The electrocoagulation process was carried out over a time span of 15 to 60 minutes, depending on the duration specified

in each treatment. After the process, sample solutions were taken at every 15-minute interval for further analysis, with measured parameters including pH, turbidity level, and solids concentration using the gravimetric method [8].

3. Results and Discussion

3.1. Initial Characterization of waste

A comprehensive waste characterization process is conducted prior to subsequent treatment stages in order to ascertain the initial condition of waste samples originating from various sources of urban and household activities in the Surabaya area, as well as to determine the extent of pollution contained therein. The purpose of this characterisation is to determine the effluent's physical and chemical characteristics that may have an impact on how well the next treatment procedure works. This stage involves the analysis of several water quality indices, such as acidity (pH), turbidity, and total suspended solids (TSS). Together, these metrics show the initial pollution level of each sample collected and give a crucial indication of the solid material content, clarity, and basicity or acidity of the effluent. Each of the waste sources—the Laundromat at Gebang, the Laundromat at Bendul Merisi, the Fastfood Restaurant, the Campus Canteen, the Machine Shop, and the Tofu Industry—had an initial pH value of 8; 6.31; 6; 7; 6; and 5.5, respectively. In the meantime, the six effluent sources' initial turbidity values were 0.9, 20; 6.94; 242; 0.8; and 26.3 NTU.

According to Kepmen LH No. Kep-51/MENLH/10/1995, waste that is safe to release into the environment has a pH between 6.0 and 9.0. Several samples deviate from this range based on these findings. According to Permen LHK No. 68 of 2016, Indonesia adopts the maximum level of TSS, which is 30 mg/L, as a reference for the turbidity parameter. According to these criteria, the majority of samples exhibit turbidity and pH levels above the threshold, rendering them unsuitable for direct release into the environment. Thus, an electrocoagulation procedure was used to raise the wastewater's quality. The effluent's visual state prior to the electrocoagulation process is depicted in Figure 2.

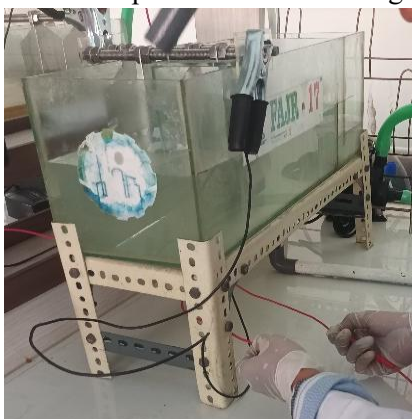


Figure 2. Effluent before electrocoagulation process

3.2 Characterization of Sewage Treatment Results

Characterization of the samples was done once more to assess the efficacy of the electrocoagulation method after the effluent treatment process. Following the electrocoagulation process, Figure 3 displays the visual state of the effluent. The separation of suspended solids from wastewater is shown by a change in color and clarity. A overview of the treatment outcomes, including operational circumstances and measurable outcomes, is also provided in Table 1. These findings serve as the foundation for more research on the effectiveness and behavior of electrocoagulation in various wastewater conditions.

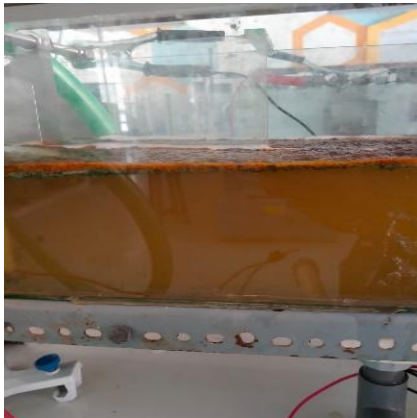


Figure 3. Effluent after electrocoagulation process

Table 1. Electrocoagulation Process Data

Source	Type of wastewater	Current	Electrode	Time	pH	NTU	TSS Removal
Laundromat at Gebang, Surabaya, Indonesia	Domestic Wastewater	10 Ampere	Aluminium	60	8	52.7	97%
Laundromat at Bendul Merisi, Surabaya, Indonesia	Domestic Wastewater	10 Ampere	Aluminium	60	8.39	29.5	97%
Fastfood Restaurant at Surabaya, Indonesia	Urban Wastewater	10 Ampere	Aluminium	60	7.2	25.4	69%
Canteen of campus at Surabaya, Indonesia	Urban Wastewater	10 Ampere	Aluminium	60	7	39.7	82%
Machine Shop at Surabaya, Indonesia	Urban Wastewater	10 Ampere	Aluminium	60	7	29.3	98%
Tofu Industry at Surabaya, Indonesia	Urban Wastewater	10 Ampere	Aluminium	60	8.62	103	86%

3.3 Effect of Electrocoagulation on pH Stabilization

Aluminium electrodes served as the anode and cathode in this 60-minute batch system electrocoagulation experiment. A digital meter was used to obtain pH readings every 15 minutes, that is, at the 0th, 15th, 30th, 45th, and 60th minutes, in order to track pH variations during the electrocoagulation process. In order to visualize the trend of pH changes during the electrocoagulation process, the pH measurement results were then presented in the form of a graph, with the y-axis displaying the pH value and the x-axis showing time (minutes).

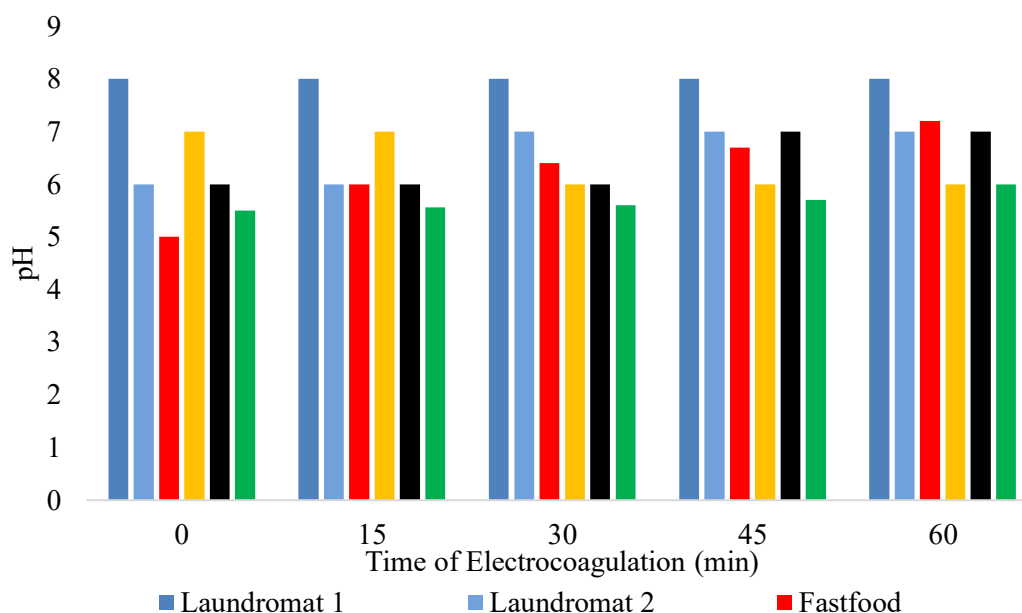


Figure 3.3 Effect of Electrocoagulation on pH of Sample Wastewater

Experimental data of Laundromat at Gebang, Surabaya, Indonesia showed that the pH value at the 0, 15, 30, 45, and 60 minutes had a constant pH result of 8. Then, at Laundromat Bendul Merisi, pH values were recorded at 0, 15, 30, 45, and 60 minutes as 6.31; 8.56; 7.73; 5.4; and 8.39, respectively. Experimental data of Fast-Food waste in Surabaya, Indonesia showed that the pH values at 0, 15, 30, 45, and 60 minutes were 6; 6; 7; 7; and 7.2, respectively. Then the experimental data of the campus canteen in Surabaya, Indonesia was carried out with time variables of 0, 15, 30, 45, and 60 minutes, resulting in pH values of 6; 6; 7; 7; and 7, respectively. Furthermore, the experimental data of the machine workshop waste in Surabaya, Indonesia shows that the pH values at the 0, 15, 30, 45, and 60 minutes are 6; 6; 6; 7; and 7, respectively. The experimental data showed that the pH of Tofu Industry waste conducted with time variables of 0, 15, 30, 45, and 60 minutes, resulting in pH values of 5.50; 5.56; 5.10; 5.70; and 8.62, respectively. In order to maximize floc formation and pollutant separation, the electrocoagulation process is pH dependent. When the anode oxidizes, metal ions are released. These metal hydroxides then combine with hydroxyl ions at the cathode to adsorb pollutants. The efficiency of this process is affected by pH, current density, and produces hydrogen gas at the cathode and oxygen at the anode [9].

At the beginning of the experiment, Laundromat at Gebang effluent had the highest pH (8), while Tofu Industry effluent had the lowest pH at 5.50. After 15 minutes of electrocoagulation, there was a drastic increase in pH for the Laundromat at Bendul Merisi (from 6.31 to 8.56). The sudden pH increase at 15 minutes could be attributed to localized cathodic reactions intensifying, suggesting non-uniform current distribution, while Tofu Industry waste experienced a slight increase to 5.56. Similar behavior was reported by [10] where pH increased rapidly during the early minutes of electrocoagulation due to accelerated cathodic reactions releasing OH^- ions. This suggests that the localized current distribution in the cell may have caused non-uniform reaction intensities. In contrast, the mild pH change in Tofu Industry waste may be attributed to the higher concentration of proteins and organic acids acting as buffers, which limit the free increase of OH^- concentration, as noted in [11]. However, the pH 6 of the Campus Canteen and Fast Food effluents stayed constant, and the pH 6 of the Machine Shop effluent did not alter either. This stability is due to the presence of chemical compounds such as phosphate (70-80%), surfactant (20-30%), carbonate, bicarbonate, ammonia, nitrogen, dissolved solids content, turbidity, BOD (Biochemical Oxygen Demand), and COD (Chemical Oxygen Demand) in the laundry wastewater. These compounds act as a buffer, neutralizing the OH^- ions generated at the cathode. As a result, the pH of the solution does not change significantly during electrocoagulation.

After 30 minutes, there was a decrease in Laundromat at Bendul Merisi waste to 7.73 and Tofu Industry waste to 5.10, while Fast Food and Campus Canteen waste increased to 7. At the 45 minute, Laundromat at Bendul Merisi waste significantly decreased to 5.4, while Tofu Industry waste increased to 5.70. Meanwhile, the Fast Food, Campus Canteen and Machine Workshop effluents remained stable at 7. This was brought on by the electrocoagulation process's

rise in pH, which was mostly explained by the evolution of hydrogen gas at the cathode, as well as the solution's increased concentration of hydroxyl ions (OH^-) as a result of the electrochemical reaction that produced a high removal efficiency [12]. The electrolysis processes that take place during the electrocoagulation process, in which aluminium acts as both the anode and cathode, are the cause of these oscillations. A reduction reaction takes place at the cathode, drawing in negative ions and producing H_2 and OH^- ions perform [13].

After 60 minutes of electrocoagulation, the pH of Laundromat at Bendul Merisi effluent increased back to 8.39, while Tofu Industry effluent spiked to 8.62. Fast Food waste experienced a slight increase to 7.2, while Campus Canteen and Machine Workshop remained stable at 7. More efficient precipitation and floc formation may be the reason of this, as they can lower the H^+ ion concentration. The results of the pH measurement indicate that the pH rises with increasing electrocoagulation time. Because of the electrochemical reaction at the cathode that creates hydroxide ions (OH^-) by the reduction of water, pH rises during the electrocoagulation process. The pH of the solution gradually rises as a result of these ions. Furthermore, aluminum hydroxide compounds like $\text{Al}(\text{OH})_3$ are created when aluminum ions (Al^{3+}) released from the anode go through a hydrolysis reaction. These compounds work as flocculants to bind and precipitate contaminants [14].

Overall, electrocoagulation was effective in stabilizing pH in effluents with high buffer compound content, such as the Campus Canteen and Machine Shop. However, Tofu Industry effluent experienced an increase in pH from 5.50 to 8.62, possibly due to the release of hydroxide ions (OH^-). Laundromat at Bendul Merisi effluent showed significant fluctuations, from 6.31 to 8.56 in the first 15 minutes, dropping to 5.4 in the 45th minute, then rising again to 8.39, indicating a less stable electrocoagulation process. Fast Food Waste increased from pH 6 to 7.2, while Laundromat at Gebang remained stable at 8. Variability implies that the composition of the effluent affects the effectiveness of electrocoagulation, requiring the employment of alternative methods for optimal results. Other methods, such as electrocoagulation-adsorption of activated carbon, can be employed to optimize the pH neutralization process and increase the effectiveness of specific effluent treatment by stabilizing the pH between 6 and 9 in accordance with the established quality criteria. Additionally, supporting electrolytes like NaCl are given throughout the electrocoagulation process since this mineral salt is affordable, easily accessible, and efficient at eliminating metals. NaCl, which also has a high electrical conductivity (DHL), acts as the best DHL binder and accelerates the floc formation process by binding colloids through ions generated by the electrode [15].

3.4 Turbidity on Electrocoagulation Process

The experiment was conducted using batch electrocoagulation for 60 minutes with aluminum electrodes. During the experiment, turbidity measurements were taken every 15 minutes using a turbidity meter. Then the experimental results were plotted on a graph, with time on the x-axis and turbidity on the y-axis. Experimental data from Laundromat at Gebang, Surabaya, Indonesia showed that the turbidity values at minutes 0, 15, 30, 45, and 60 were 98.2; 76.1; 34.5; 27.1; and 21.4 NTU, respectively. Then the experimental data of Laundromat at Bendul Merisi was conducted with time variables of 0, 15, 30, 45, and 60 minutes, resulting in turbidity values of 108; 87.5; 75; 54.2; and 32.5 NTU, respectively. Experimental data of Fast-Food waste in Surabaya, Indonesia showed that the turbidity values at 0, 15, 30, 45, and 60 minutes were 225; 160; 103.5; 74; and 43.1 NTU respectively. Then the experimental data of the campus canteen in Surabaya, Indonesia was carried out with time variables of 0, 15, 30, 45, and 60 minutes, resulting in turbidity values of 198; 102; 87.5; 60; and 39.7 NTU, respectively. Furthermore, experimental data from a machine workshop in Surabaya, Indonesia showed that the turbidity values at the 0, 15, 30, 45, and 60 minutes were 310; 256; 198; 80; and 56.7 NTU, respectively. As well as experimental data from the Tofu Industry in Surabaya, Indonesia conducted with time variables of 0, 15, 30, 45, and 60 minutes, resulting in turbidity values of 107; 84.2; 62.5; 45; and 26.3 NTU, respectively. Because it can demonstrate the degree to which particles floating in water have disrupted its clarity, turbidity is one of the metrics used to assess the quality of waste [16]. Determining the initial features of wastewater before to the treatment process is mostly dependent on the assessment of the turbidity level. The Nephelometric Turbidity Unit (NTU), a standard unit that indicates the degree of turbidity in water based on the amount of light scattered by suspended particles, is used to measure turbidity precisely [17].

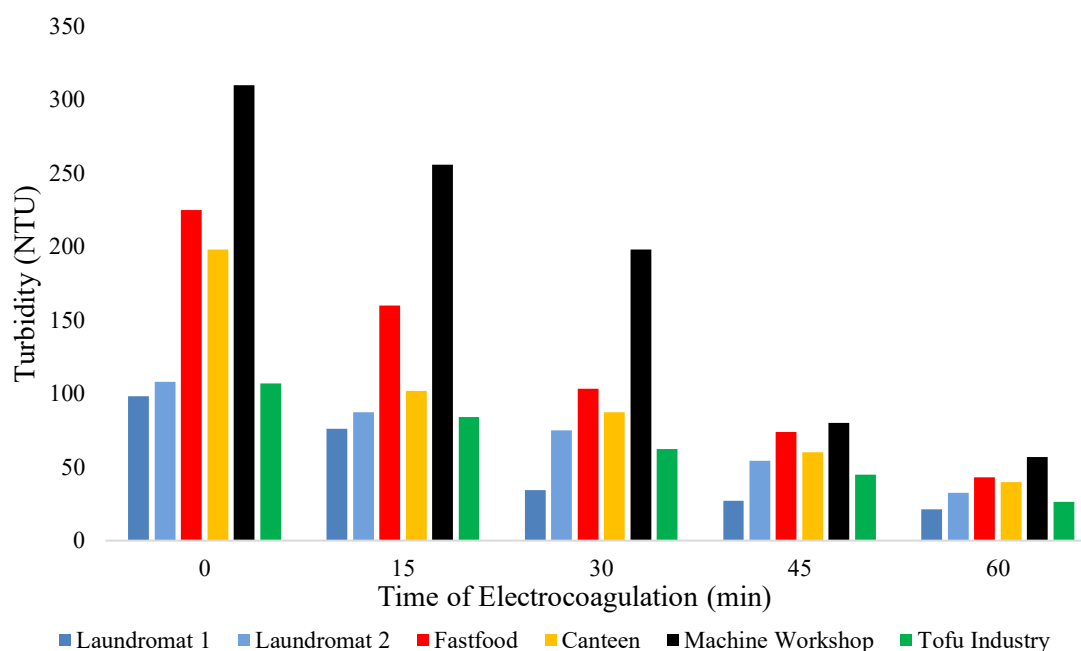


Figure 3.4 Effect of Electrocoagulation on Turbidity of Sample Wastewater

At the beginning of the experiment, machine shop waste had the highest turbidity of 310 NTU, while Laundromat at Gebang waste had the lowest at 98.2 NTU. After 15 minutes of electrocoagulation, there was a significant decrease in various types of waste, including Laundromat at Gebang waste down to 76.1 NTU, Laundromat at Bendul Merisi waste down to 87.5 NTU, Fast Food waste down to 160 NTU, campus canteen waste down to 102 NTU, machine workshop waste down to 256 NTU, and Tofu Industry waste down to 84.2 NTU, showing the effectiveness of electrocoagulation. This suggests that better turbidity reduction is facilitated by longer electrocoagulation times. The creation of Al^{3+} metal ions on the aluminium plate at the anode is what causes the drop in turbidity value. These ions combine with hydroxide ions (OH^-) from the cathode to generate the coagulant $\text{Al}(\text{OH})_3$. This coagulant creates flocs that sink to the reactor's bottom by bindlamharing to contaminated chemicals in wastewater. Furthermore, bubbles of H_2 gas form on the cathode surface while bubbles of O_2 gas form on the anode. Because of the movement of gas bubbles, these gases force the minute flocs that the coagulant forms during the electrocoagulation process to grow and settle, forming a black foam that makes the wastewater appear clearer and lowers the turbidity [18]. Bubbles of hydrogen formed at the cathode surface have a tendency to ascend and instantly explode at the free surface [19]. If deviations do happen, though, they may be the result of unstable particles forming and aggregating over time, which raises turbidity [20].

In the 30 minute, there was a decrease in various types of waste, including Laundromat at Gebang waste down to 34.5 NTU, Laundromat at Bendul Merisi waste down to 75 NTU, Fast Food waste down to 103.5 NTU, campus canteen waste down to 87.5 NTU, machine workshop waste down to 198 NTU, and Tofu Industry waste down to 62.5 NTU. This is consistent with the literature, which claims that the electrocoagulation process gradually reduces turbidity [21]. However, the electrocoagulation process may be the reason of the effluent's increased turbidity; as an electric current flows through the system, aluminium ions from the anode and hydroxide ions from the cathode rise, creating flocs on the electrode. The electrode's capacity to draw in dissolved solids in water is reduced in this situation [22].

At the 45 minute, there was a decrease in various types of waste, including Laundromat at Gebang waste down to 27.1 NTU, Laundromat at Bendul Merisi waste down to 54.2 NTU, Fast Food waste down to 74 NTU, campus canteen waste down to 60 NTU, machine workshop waste down to 80 NTU, and Tofu Industry waste down to 45 NTU. More contact with contaminants is made possible by the longer duration, which further lowers turbidity [23]. If deviation does occur, though, it might be due to an excessively low electric current, which would result in fewer Al^{3+} ions from the anode. As a result, there would be insufficient coagulant to absorb and precipitate the suspended particles, which would reduce the efficacy of removing turbidity [24].

At the 60 minute, there was a decrease in various types of waste, including Laundromat at Gebang waste down to 21.4 NTU, Laundromat at Bendul Merisi waste down to 32.5 NTU, Fast Food waste down to 43.1 NTU, campus canteen waste down to 39.7 NTU, machine workshop waste down to 56.7 NTU, and Tofu Industry waste down to 26.3 NTU. The length of time of the electrocoagulation process causes a higher influx of positive ions into the solution. These ions neutralize the colloidal particles, causing them to agglomerate and consequently causing a decrease in turbidity [25]. However, if there is a deviation in the form of an increase in turbidity again, this occurs due to the electrocoagulation process, the flow of electric current causes aluminum ions from the anode and hydroxide ions from the cathode to increase, forming flocs on the electrode. This condition causes the electrode's ability to attract dissolved solids in water to decrease ganti manikandan [26].

All things considered, electrocoagulation was successful in lowering the effluent's turbidity. Nonetheless, if the electrocoagulation procedure is not carried out as efficiently as possible. This may be the result of an increase in aluminium ions from the anode and hydroxide ions from the cathode brought on by the electric current flow, which forms flocs on the electrode. The electrode's capacity to draw in dissolved solids in water is reduced in this situation [11]. In contrast to single EC and AD procedures, an integrated Electrocoagulation Adsorption (EC-AD) process can be used as a solution; prior research indicates that this approach has the highest pollutant removal effectiveness. The voltage and kind of adsorbent employed affect how effective EC-AD is. Increased electric flow from higher voltage produces more aluminium hydroxide ($\text{Al}(\text{OH})_3$) coagulant, which improves the effectiveness of pollutant removal. Utilizing activated carbon as an adsorbent also helped because of its huge surface area, which allowed for a greater number of active sites. The efficacy of pollutant removal rises with increased adsorbent dosage because it increases the overall surface area [27].

3.5 Total Suspended Solid (TSS)

Total suspended solids (TSS) are insoluble solid particles suspended in water that are big enough to pass through a 2.0 μm porous sieve. TSS often originates from a number of sources, including as building construction, agriculture, household and industrial waste, and soil erosion. Water bodies that have high levels of TSS will become more turbid, which will directly prevent sunlight from penetrating them. This affects how autotrophic organisms like water plants and phytoplankton disturb their photosynthesis process. The general balance of the aquatic ecosystem is upset when photosynthesis is disturbed because less dissolved oxygen is produced in the water, which can stress and even kill aquatic life [28]. To determine the TSS level in water samples, the following formula is used, which describes the difference in filter mass before and after filtering solid particles.

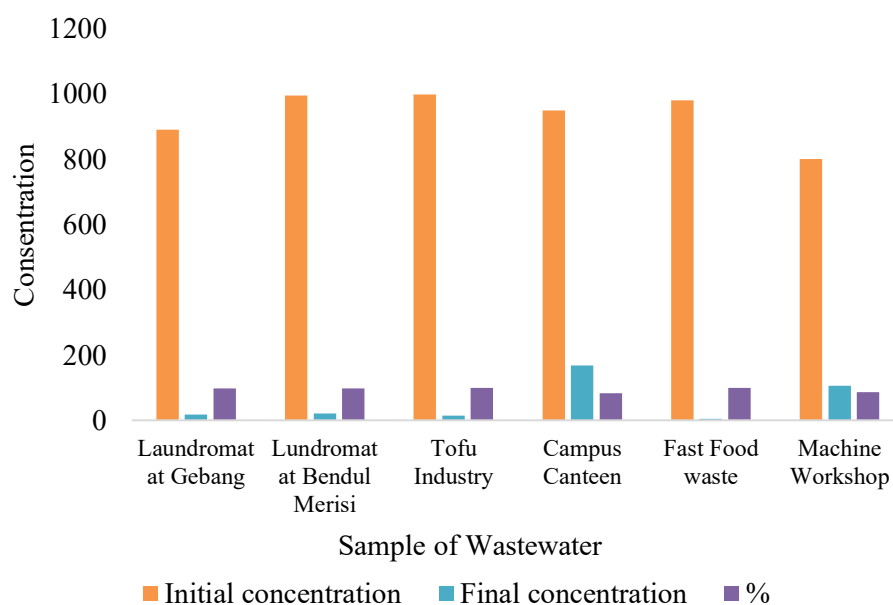


Figure 3.5 Effect of Electrocoagulation on TSS on Sample Wastewater

$$\%TSS = \frac{(Initial\ concentration - Final\ concentration)}{Initial\ concentration} \times 100\% \quad (4)$$

Experiments were conducted using batch electrocoagulation for 60 minutes with aluminum electrodes. The highest efficiency was achieved in the waste of Machine Workshop in Surabaya, Indonesia with 98% reduction from 800 mg/l to 106, 14 mg/l. Followed by Laundromat at Gebang, Surabaya, Indonesia and Laundromat at Bendul Merisi, Surabaya, Indonesia with a 97% decrease from 890 mg/l to 17.92 mg/l and 995 mg/l to 20.2 mg/l, respectively. Furthermore, Tofu Industry waste in Surabaya, Indonesia decreased by 86% from 998 mg/l to 14.77 mg/l. Campus Canteen waste in Surabaya, Indonesia experienced a decrease of 82% from 950 mg/l to 168.5 mg/l. And Fast Food waste in Surabaya, Indonesia decreased by 69% from 980 mg/l to 4.06 mg/l. This decline demonstrates how well the electrocoagulation process lowers the solute concentration in wastewater. This is because of the redox reaction that forms $Al(OH)_3$ flocs when the aluminium electrode plate releases Al^{3+} ions. As a coagulant, the $Al(OH)_3$ molecule binds metal ions and organic materials, which subsequently agglomerate. H_2 gas then precipitates and floats the trapped colloids out of the solution, lowering the solute levels [5].

According to the experiment's findings, certain wastes have satisfied the 30 mg/L wastewater quality criteria specified in Regulation P.68 / Menlhk-Setjen / 2016 of the Minister of Environment and Forestry of the Republic of Indonesia about Domestic Wastewater Quality criteria. Waste that has met the standard includes Laundromat at Gebang, Laundromat at Bendul Merisi, Tofu Industry waste, Fast Food waste, each of which has a final TSS level below the specified threshold. This demonstrates that electrocoagulation can be a successful wastewater treatment technique. The production of $Al(OH)_3$ is the cause of the rise in the percentage of TSS elimination.

Based on the results of the experiment, some wastes have met the wastewater quality standards in the Regulation of the Minister of Environment and Forestry of the Republic of Indonesia number P.68 / Menlhk-Setjen / 2016 concerning Domestic Wastewater Quality Standards which is 30 mg / L. Waste that has met the standard includes Laundromat at Gebang, Laundromat at Bendul Merisi, Tofu Industry waste, Fast Food waste, each of which has a final TSS level below the specified threshold. This proves that electrocoagulation can be an effective method for wastewater treatment. The increase in the percentage of TSS removal occurs due to the formation of $Al(OH)_3$. The amount of charge flowing throughout the electrocoagulation process will directly correlate with the lengthier contact time used. Levels are eliminated as a result of additional metal ions adhering to the electrode [29]. However, the garbage from the campus canteen and the machine factory in Surabaya, Indonesia, still do not fulfill quality standards, maybe because of the waste's higher concentration of complex organic compounds. Pollutant loads can rise, and environmental contamination may occur if waste that doesn't satisfy regulations is dumped straight into water bodies [30]. Consequently, a more efficient treatment technique is required to lower the effluent's pollutant levels.

A combination of coagulation-flocculation and filtration techniques can be used to stabilize total suspended solids (TSS) levels in wastewater in compliance with quality standards, which limit TSS levels to 30 mg/L, hence increasing efficacy in lowering TSS levels. In order to create micro flocs, the coagulation process involves rapidly churning wastewater and coagulant to destabilize colloids and suspended small particles [31]. Additionally, the flocculation procedure involves gently stirring the coagulated solution to allow the micro flocs to mix to create bigger flocs and settle more readily. Sedimentation will then deposit the flocs that have developed, allowing the suspended particles to settle fully. A filtration procedure is necessary as an extra step to boost efficiency because some flocs can still get out and move on to the following stage. The residual suspended particles in the wastewater are filtered out using natural filter media, specifically rice husk charcoal, which doubles as activated charcoal [32].

4. Conclusions

This study concludes that the electrocoagulation process using aluminum electrodes is effective in treating various real wastewater sources in Surabaya, offering efficient pH stabilization and significant reductions in turbidity and Total Suspended Solids (TSS), especially in effluents with buffering compounds. Instead of listing specific removal rates, this version emphasizes the method's overall reliability and performance trends. Electrocoagulation also demonstrated good pH stabilization in wastewater with buffering capacities, such as those from campus canteens and workshops. However, wastewater with complex compositions—especially those high in protein or surfactant content,

like tofu industry and fast-food restaurant effluents—showed pH fluctuations and inconsistent turbidity reduction. These observations underscore the importance of influent characterization and reveal the process's limitations in handling complex waste types. To enhance treatment effectiveness and meet discharge standards, integration with complementary methods such as adsorption or filtration is recommended.

Acknowledgment

This research supported by Biotechnology Laboratory of Department of Industrial Chemical Engineering, Institut Teknologi Sepuluh Nopember.

References

- [1] E. Wiyanto, B. Harsono, A. Makmur, R. Pangputra, J. Julita, and M. S. Kurniawan, "Penerapan Elektrokoagulasi Dalam Proses Penjernihan Limbah Cair," *Jetri J. Ilm. Tek. Elektro*, vol. 12, pp. 19–36, 2017, doi: 10.25105/jetri.v12i1.1449.
- [2] M. Ammar, E. Yousef, M. A. Mahmoud, S. Ashraf, and J. Baltrusaitis, "A Comprehensive Review of the Developments in Electrocoagulation for the Removal of Contaminants from Wastewater," *Separations*, vol. 10, no. 6, 2023, doi: 10.3390/separations10060337.
- [3] T. Jovanović *et al.*, "Mechanism of the electrocoagulation process and its application for treatment of wastewater: A review," *Adv. Technol.*, vol. 10, no. 1, pp. 63–72, 2021, doi: 10.5937/savteh2101063j.
- [4] M. Anugrah, "The Effect of Voltage Variation, Plate Area and Electrocoagulation Time on TSS Reduction of Laundry Wastewater Using Aluminum Electrode," *CHEMVIRO J. Kim. dan Ilmu Lingkungan*, vol. 2, no. 1, pp. 113–122, 2024.
- [5] Rakhmania *et al.*, "Recent Applications of the Electrocoagulation Process on Agro-Based Industrial Wastewater: A Review," *Sustain.*, vol. 14, no. 4, pp. 1–19, 2022, doi: 10.3390/su14041985.
- [6] Z. Guo, Y. Zhang, H. Jia, J. Guo, X. Meng, and J. Wang, "Electrochemical methods for landfill leachate treatment: A review on electrocoagulation and electrooxidation," *Sci. Total Environ.*, vol. 806, p. 150529, 2022, doi: 10.1016/j.scitotenv.2021.150529.
- [7] H. Muvel, M. K. Jindal, P. K. Tewari, and V. Anand, "Advancements in electrocoagulation for oily wastewater treatment: Mechanisms, efficiency, and applications," *J. Water Process Eng.*, vol. 68, no. August, p. 106291, 2024, doi: 10.1016/j.jwpe.2024.106291.
- [8] S. Soeprijanto, D. F. Nury, and L. Pudjiastuti, "Treatment of Oily Wastewaters from Tanjung Perak Port by Electrocoagulation Using Aluminum Electrodes," *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 543, no. 1, 2019, doi: 10.1088/1757-899X/543/1/012098.
- [9] S. Boinpally, A. Kolla, J. Kainthola, R. Kodali, and J. Vemuri, "A state-of-the-art review of the electrocoagulation technology for wastewater treatment," *Water Cycle*, vol. 4, no. June 2022, pp. 26–36, 2023, doi: 10.1016/j.watcyc.2023.01.001.
- [10] W. T. Mohammed and F. Y. Al Jaberi, "Effecting of pH parameter on simulated wastewater treatment using electrocoagulation method," *Eng. J.*, vol. 24, no. 4, pp. 73–88, 2018, doi: 10.31026/J.ENG.2018.04.05.
- [11] Widyarani, Y. Victor, L. Sriwuryandari, E. A. Priantoro, T. Sembiring, and N. Sintawardani, "Influence of pH on biogas production in a batch anaerobic process of tofu wastewater," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 160, no. 1, 2018, doi: 10.1088/1755-1315/160/1/012014.
- [12] M. Ebba, P. Asaithambi, and E. Alemayehu, "Investigation on operating parameters and cost using an electrocoagulation process for wastewater treatment," *Appl. Water Sci.*, vol. 11, no. 11, pp. 1–9, 2021, doi: 10.1007/s13201-021-01517-y.
- [13] N. Boudjema, D. Ben Salem, E. Lobna, O. Abdelkader, and N. Mameri, "Treatment of contaminated river water by batch electrocoagulation system using aluminium and iron electrodes: Performance of process and statistical analysis," *Water. Air. Soil Pollut.*, vol. 235, no. 10, pp. 1–14, 2024, doi: 10.1007/s11270-024-07495-6.

- [14] A. Morales-Figueroa, E. A. Teutli-Sequeira, I. Linares-Hernández, V. Martínez-Miranda, M. A. García-Morales, and G. Roa-Morales, "Optimization of the Electrocoagulation Process with Aluminum Electrodes for Rainwater Treatment," *Front. Environ. Sci.*, vol. 10, no. July, pp. 1–12, 2022, doi: 10.3389/fenvs.2022.860011.
- [15] C. H. Huang *et al.*, "Effect of chloride ions on electro-coagulation to treat industrial wastewater containing Cu and Ni," *Sustain.*, vol. 12, no. 18, 2020, doi: 10.3390/su12187693.
- [16] S. A. Bakry, M. E. Matta, and K. Zaher, "Electrocoagulation process performance in removal of TOC, TDS, and turbidity from surface water," *Desalin. Water Treat.*, vol. 129, pp. 127–138, 2018, doi: 10.5004/dwt.2018.23070.
- [17] M. Sadar, "Turbidity Measurement : A Simple , Effective Indicator of Water Quality Change," *Aqualab Sci.*, pp. 1–5, 2017.
- [18] P. P. Das, M. Sharma, and M. K. Purkait, "Recent progress on electrocoagulation process for wastewater treatment: A review," *Sep. Purif. Technol.*, vol. 292, no. March, p. 121058, 2022, doi: 10.1016/j.seppur.2022.121058.
- [19] R. Lamhar *et al.*, "Foam investigation and optimization by response surface methodology of electrocoagulation process for textile wastewater decolorization in single-channel reactor," *Chem. Eng. Res. Des.*, vol. 213, no. November 2024, pp. 52–65, 2025, doi: 10.1016/j.cherd.2024.11.019.
- [20] C. Zhou, H. Y. Zhang, J. W. Chen, X. L. Liu, R. Wang, and W. Y. Tan, "Variations in heavy metals and turbidity in wastewater from wet flue gas desulfurization by electrocoagulation," *Desalin. Water Treat.*, vol. 141, pp. 82–88, 2019, doi: 10.5004/dwt.2019.23464.
- [21] M. K. N. Mahmad, M. A. Z. M. R. Rozainy, I. Abustan, and N. Baharun, "Electrocoagulation Process by Using Aluminium and Stainless Steel Electrodes to Treat Total Chromium, Colour and Turbidity," *Procedia Chem.*, vol. 19, pp. 681–686, 2016, doi: 10.1016/j.proche.2016.03.070.
- [22] S. F. A. Al-Rubaye, N. A. Alhaboubi, and A. H. Al-Allaq, "Factors Affecting Electrocoagulation Process for Different Water Types: A review," *Al-Khwarizmi Eng. J.*, vol. 20, no. 1, pp. 17–32, 2024, doi: 10.22153/kej.2024.10.001.
- [23] E. Issaka, "From complex molecules to harmless byproducts: Electrocoagulation process for water contaminants degradation," *Desalin. Water Treat.*, vol. 319, no. June, p. 100532, 2024, doi: 10.1016/j.dwt.2024.100532.
- [24] M. Ebba, P. Asaithambi, and E. Alemayehu, "Development of electrocoagulation process for wastewater treatment: optimization by response surface methodology," *Heliyon*, vol. 8, no. 5, p. e09383, 2022, doi: 10.1016/j.heliyon.2022.e09383.
- [25] N. Idusuyi, M. A. Adebayo, C. A. Igwegbe, O. T. Aghogho, A. James, and R. A. Kazeem, "A sustainable approach to dairy wastewater treatment through electrocoagulation: From beverage cans to clean water," *Waste Manag. Bull.*, vol. 3, no. 1, pp. 96–106, 2025, doi: 10.1016/j.wmb.2024.12.012.
- [26] Manikandan and R. Saraswathi, "Electrocoagulation technique for removing Organic and Inorganic pollutants (COD) from the various industrial effluents: An overview," *Environ. Eng. Res.*, vol. 28, no. 4, pp. 0–2, 2023, doi: 10.4491/eer.2022.231.
- [27] S. N. A. Jalil, N. Amri, A. A. Ajien, N. F. Ismail, and B. Ballinger, "A hybrid electrocoagulation-adsorption process for fluoride removal from semiconductor wastewater," *J. Phys. Conf. Ser.*, vol. 1349, no. 1, 2019, doi: 10.1088/1742-6596/1349/1/012056.
- [28] E. Fikri, I. A. Sulistiawan, A. Riyanto, and A. E. Saputra, "Neutralization of Acidity (pH) and Reduction of Total Suspended Solids (TSS) by Solar-Powered Electrocoagulation System," *Civ. Eng. J.*, vol. 9, no. 5, pp. 1160–1172, 2023, doi: 10.28991/CEJ-2023-09-05-09.
- [29] H. Setyawati, D. Galuh, and E. Yunita, "Effect Of Electrode Distance And Voltage On Cr, Cod, And Tss Reduction In Waste Water Tanning Industry Using Electrocoagulator Batch," *J. Sustain. Technol. Appl. Sci.*, vol. 2, no. 1, pp. 24–30, 2021, doi: 10.36040/jstas.v2i1.3574.

- [30] A. Munandar, K. Nabila, and R. N. Azizah, "Chemical Oxygen Demand (COD) and Total Suspended Solid (TSS) Removal from Rubber Wastewater Factory Using Electrocoagulation Technique," *Indones. J. Environ. Manag. Sustain.*, vol. 7, no. 1, pp. 27–31, 2023, doi: 10.26554/ijems.2023.7.1.27-31.
- [31] R. Esteki, M. H. Ehrampoush, H. Nasab, and A. A. Ebrahimi, "Investigating the improvement of the quality of industrial effluents for reuse with added processes: coagulation, flocculation, multi-layer filter and UV," *Sci. Rep.*, vol. 14, no. 1, pp. 1–10, 2024, doi: 10.1038/s41598-024-54310-7.
- [32] S. Qothrunada, Z. Nisa, R. Novembrianto, and F. Rosariawari, "Treatment of Laundry Wastewater Using Different Coagulants: Alum and HCA," vol. 2024, pp. 112–116, 2024, doi: 10.11594/nstp.2024.4119.