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Effectiveness of Aluminium Electrode-Based Electrocoagulation in Monopolar Configuration in Removing Suspended Solids and Turbidity from Car Wash Wastewater

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Abstract

The increasing demand for car wash services in Malaysia has led to the release of untreated car wash wastewater into water bodies, negatively impacting the environment and aquatic life. The primary goal of this research is to optimise the operational parameters of electrocoagulation for removing suspended solids, colour, and turbidity from car wash wastewater. Additionally, this study also analyses the sludge volume index (SVI) at the end of each treatment cycle. It assesses the occurrence of the passivation effect during electrocoagulation by weighing the electrodes after every cycle. This research identifies the optimal parameters for efficiently removing total suspended solids (TSS), turbidity, and colour from car wash wastewater. The electrocoagulation (EC) process was carried out using aluminium electrodes, with current density levels ranging from 20 to 100 A/m^2, initial pH values between 6 and 11, and contact times varying from 30 to 180 minutes, to assess the removal efficiency of pollutants. The distance between the electrodes and the settling time was consistently maintained at 5 centimetres and 30 minutes, respectively. The optimal operating parameters identified included a current density of 45 A/m^2, an initial pH of 7, and a contact time of 140 minutes. Under these specified conditions, the removal efficiencies achieved were 92.09% for turbidity, 92.70% for colour, and 96.34% for suspended solids. The study also assessed the sludge volume index (SVI), which indicated poor sludge settleability (295.05 mL/g), and the electrode passivation effects, where the formation of a hydroxide layer reduced long-term electrode effectiveness. The electrocoagulation process has significant potential for removing physical contaminants from car wash wastewater, particularly turbidity, suspended solids, and colour. Future efforts to enhance removal efficiency could include minimising the spacing between electrodes and increasing their total working surface area.

1. Introduction

Malaysia is a rapidly developing country in the post-globalisation era, as evidenced by the advancement of various industry sectors. Unfortunately, this is not reflected in the public's attitudes, as many still do not prioritise the issue of pollution that occurs in the environment. This can be seen in the increasing pollution problem over time, largely due to a lack of awareness about the importance of environmental conservation. Water pollution in Malaysia is a serious problem that responsible parties frequently face, as it has been consistently increasing every year and is a growing concern. Based on released statistics, rivers near human settlements and industrial areas are deteriorating and concerning, with over 30 rivers in Malaysia classified as Class III, Class IV, and Class V due to pollution from various industrial activities, sewage, farming, and littering [1]. There are various types of wastewaters, including industrial, commercial, domestic, and agricultural. Wastewater from car wash industries has contributed to excessive pollutant levels being introduced into bodies of water if not properly treated to comply with established standards, ultimately causing adverse effects on the environment and human health.

Car wash stations have become increasingly common services in cities across Malaysia [2]. The rise in the number of vehicles can be attributed to population growth, Malaysia's population was 32.4 million in 2018, and improving economic conditions. According to statistics from the Malaysian car industry, 580,124 units of passenger and commercial vehicles were produced and assembled in the country in 2016, followed by 576,635 units in 2017 and 280,947 units in the first half of 2018 (January to June) [3]. This increase in vehicles on the road is expected to boost the car wash service industry further.

However, the carwash industry is one of the leading consumers of large volumes of clean water. An average car wash produces approximately 150 to 400 litres of wastewater per car [4]. Additionally, in Malaysia, various methods of washing vehicles are available, including manual car washes, automatic car washes, and semi-automatic car washes. All of these methods for washing the car offer various types of cleaning. For example, manual car washing stations often provide a wider range of services than automatic car washes, including exterior washing, waxing, and engine cleaning [5]. In contrast, automatic car washes use a system where vehicles are driven onto a pad and cleaned by brushes on a moving frame and high-pressure spray guns [6]. Lastly, semi-automated car washes combine manual and automatic methods, making them more practical and convenient.

Furthermore, the wastewater produced by carwash operations often contains a mixture of dirt, oils, grease, metals, and detergents, posing significant environmental concerns [7]. This wastewater contains oil and grease, harbouring hazardous materials such as benzene, lead, zinc, chromium, arsenic, pesticides, herbicides, nitrates, and other metals. Additionally, it includes detergents, which can be toxic to fish, and phosphates, which can cause excessive growth of nuisance plants in water bodies [8]. When this wastewater is discharged into waterways, the detergents can form foams, which diminish oxygen levels and harm fish mucus membranes. This process can damage aquatic ecosystems, disrupting the balance of aquatic life and compromising water quality.

Therefore, numerous wastewater treatment technologies have been developed, including ion exchange, aerobic and anaerobic treatment, advanced oxidation methods, solvent extraction, microbial reduction, and activated sludge. Additionally, technologies that employ electrochemistry principles, which are relatively new, are now available, such as electrocoagulation, electrochemical oxidation, and electrooxidation. Among these, electrocoagulation has emerged as a promising technique for removing a wide range of pollutants from wastewater [9]. By leveraging electrical current and chemical reactions, electrocoagulation efficiently removes suspended solids, ion metals, turbidity, colour, BOD, and COD from wastewater [10]. Its versatility and effectiveness make it a recommended approach for addressing various wastewater treatment challenges and improving water quality. Hence, the main objective of this research is to optimise the operating parameters of electrocoagulation in removing suspended solids, colour, and turbidity from car wash wastewater. In addition, the sludge volume index (SVI) at the end of every treatment cycle will be analysed, and the occurrence of the passivation effect during electrocoagulation will be evaluated by weighing the electrode for every cycle. This research also highlights how key operating conditions, such as current density, contact time, and initial pH, significantly influence the effectiveness of electrocoagulation in treating wastewater from car washes.

2. Materials and Methods

This study selected electrocoagulation as the primary treatment method for wastewater from the entire car wash industry. The wastewater samples were collected from the selected carwash station in Parit Raja, Johor, Malaysia. This is a fully manual carwash that locals run. Due to the high demand for car wash services in the surrounding areas, Parit Raja has numerous full-service manual and automated car wash stations.

This study used the grab sampling method to collect discrete samples over time at a chosen vehicle wash location. The car wash wastewater was collected at the outlet using 2-litre TFE plastic bottles, which are securely

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closed. The sample was taken to the Micropollutant Research Centre (MPRC) Laboratory for treatment. Before using the wastewater, the sample was stored at 4°C in a cold room.

On-site in-situ analysis was carried out, including temperature and pH measurements. Meanwhile, a laboratory examination was conducted to identify the early characteristics of effluent from the car wash, including turbidity, suspended solids, and colour concentrations, following Method 1060 [11].

2.1 Preparation of Electrodes

The electrodes chosen for this study are made of aluminium (Al) (Fig. 1). Each electrode has the following dimensions: 20 cm in length, 5 cm in width, and 1 mm in thickness. The electrodes were consistently spaced 5 cm apart from one another. The electrodes were thoroughly washed with distilled water to remove any particulates that might have remained on the surface. The electrodes used in this electrolysis process measure 20 cm x 5 cm x 1 mm. However, the total working area is calculated based on the surface area submerged in a 1-litre beaker containing car wash wastewater. Consequently, the actual working area of the electrodes is 0.022 m^2, as the portion of the electrodes that is immersed in the sample measures 11 cm × 5 cm.

Fig. 1 *Aluminium electrode used for the electrocoagulation process*

2.2 Experimental Setup

In the study of electrocoagulation treatment, the optimal current density, pH level, and contact time were identified to maximise removal efficiency. Additionally, parameters such as suspended solids, colour, and turbidity were measured to evaluate the initial characteristics of car wash wastewater.

Electrocoagulation experiments were conducted using vertical immersion of aluminium (Al) electrodes, spaced consistently at a 5 cm gap between both, and allowed a settling time of 30 minutes. In monopolar electrode mode (Al-Al), a direct current (DC) power source was directly linked to the electrodes. For each experiment, one litre of the car wash sample was poured into a 1-litre glass beaker. The anode and cathode electrodes were connected to the positive and negative terminals of the DC power supply, respectively, as shown in Fig. 2.

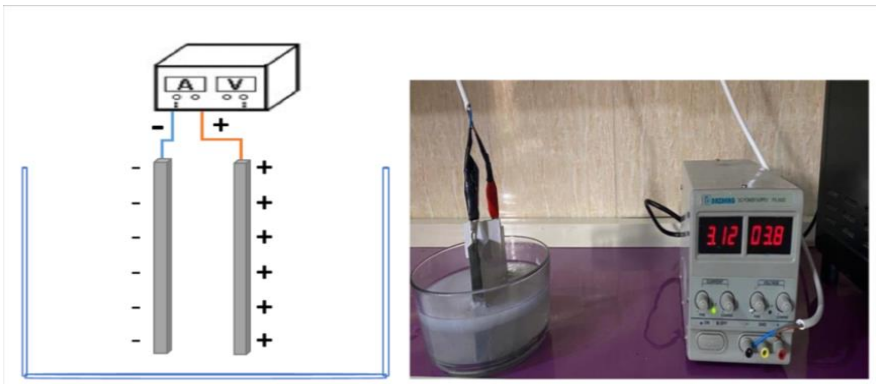

Fig. 2 *Apparatus and equipment set up for the electrocoagulation process*

The electrocoagulation process involves applying current densities within the range of 20 to 100 A/m^2. This process is crucial for effective separation and purification in various applications, such as wastewater treatment. However, one limitation arises from the use of the DC power supply model SAIKE PS-1502DD. This model is designed to display electrical current in amperes (A) but does not directly measure current density in amperes per square meter (A/m^2). This discrepancy makes it challenging to monitor and adjust the current density accurately during the electrocoagulation process, which is essential for optimising its efficiency and effectiveness. Thus, a straightforward mathematical computation is needed to convert the data into current density values. The fact that the current can only be adjusted between 0.6 A and 2.0 A is a restriction of this model. To determine the optimal current densities of 27 A/m^2, 45 A/m^2, 64 A/m^2, and 82 A/m^2, the total working area of 0.022 m^2 was multiplied by each desired current density. The calculated results indicated that the necessary currents to be set on the DC power supply for each respective current density were as follows: 0.6 A for 27 A/m^2, 1.0 A for 45 A/m^2, 1.6 A for 64 A/m^2, and 2.0 A for 82 A/m^2. These values are summarised in Table 1 below, which outlines the relationship between the current densities, calculated currents, and the total working area. The current values for the DC power supply were calculated using Equation 1.

$$Current\ (A) = Current\ Density\ (A/m^2) x\ Total\ working\ area\ for\ a\ run\ (m^2) \quad (1)$$

Table 1 *List of the value of current to its current density*

Current density (A/m^2)	Current to be set at the DC power supply (A)
27	0.60
45	1.00
64	1.60
82	2.00

In each experiment, the settling time was consistently established at 30 minutes to ensure reproducibility of the results. The pH levels of the car wash wastewater solutions were carefully measured using a HACH Sension 3 pH meter before and after the electrocoagulation process. To identify the optimal initial pH for the experiments, sodium hydroxide (NaOH) or sulfuric acid (H_2SO4) was systematically added to the car wash wastewater sample, allowing for precise adjustments to the solution's acidity or alkalinity. Before each measurement, the pH meter was carefully calibrated with distinct buffer solutions to guarantee highly accurate readings. Alongside pH measurements, additional analyses specifically tested for turbidity, suspended solids, and colour were conducted in accordance with established standard methods, providing a comprehensive assessment of the wastewater's characteristics [11]. This rigorous approach ensured that all parameters were thoroughly evaluated for effective wastewater treatment.

2.3 Optimisation Studies

2.3.1 Optimum Current Density

During this experiment phase, a series of current densities ranging from 20 to 100 A/m^2 was systematically applied to identify the optimum value for wastewater treatment. After each experimental run, precise pipetting was performed to extract the supernatant layer from the middle section of the sample. This step is vital as it ensures that the measurements reflect the quality of the clarified wastewater. Once extracted, several critical parameters were analysed: the turbidity, which indicates the cloudiness of the water; the concentration of suspended particles; and the intensity of colour in the water. These metrics serve as indicators of the treatment's effectiveness. Throughout the experiment, specific conditions were meticulously controlled. The initial pH of the wastewater was consistently maintained at 7, a neutral value that is conducive to the treatment process. Additionally, the settling time was fixed at 30 minutes to ensure consistent results across all trials, and the electrode spacing was uniformly set at 5 cm to provide a stable environment for electrochemical reactions. The optimum current density was used in subsequent experiments (sections 2.3.2 and 2.3.3). All experiments were duplicated, and the average values were reported.

2.3.2 Optimum Initial pH

During this stage, the initial pH values of the samples were investigated to determine the optimal starting point for the process. The initial pH of the samples varied between pH 6 and 11. The carwash effluent was brought up to the desired initial pH by adding sulfuric acid (H_2SO_4) and sodium hydroxide (NaOH) in the proper ratios. The electrode spacing was maintained at 5 cm, the settling period was maintained at 30 minutes, and the optimised current density previously determined in the previous optimisation stage was applied to this current stage. After each procedure, the sample was dried for half an hour. The supernatant layer was collected to analyse further colour, SS, and turbidity residual concentrations. The initial pH level that produced the greatest efficiency in removing the target contaminants was identified as the optimal condition for electrocoagulation (EC) treatment. To ensure reliability, the experiments were conducted multiple times, and the average results from these trials were documented and reported.

2.3.3 Optimum Contact Time

The optimum current density and initial pH determined from sections 2.3.1 and 2.3.2 were employed in this stage. The contact time intervals of 10 minutes, from 30 to 180 minutes, were investigated to find the optimum contact time. Following the same procedure as in previous optimisation stages, the sample was left to settle for half an hour. Then, the supernatant layer of treated car wash wastewater was removed to measure the final concentrations of turbidity, suspended solids, and colour. The experiments were duplicated, and the mean values were reported.

2.4 Sludge Volume Index at the Optimum Condition

A scientific approach will ascertain the Sludge Volume Index (SVI) from wastewater from car washes during this stage. Begin by gathering a representative sample of the car wash's effluent. To attain homogeneity, ensure the sample is thoroughly mixed, particularly if it has a significant sludge or suspended particulate content. Next, transfer the homogenised sample into a graduated cylinder or a 1-litre Imhoff cone. After placing the cylinder on a level, solid surface, give the sample 30 minutes to settle without being moved. After this, note the amount of settled sludge in millilitres (ml) at the bottom of the cylinder. At the same time, measure the quantity of suspended solids in the original sample expressed in milligrams per litre (mg/L). This can be done by filtering a certain volume of the sample, evaporating the liquid in the filter paper, and then weighing the solid residue to determine the concentration. This computation helps to assess the sludge's settleability, which maximises the efficacy of the wastewater treatment process. Lastly, the sludge volume index (SVI) will be calculated using Equation 2:

$$SVI = \frac{Volume\ of\ settled\ sludge\ (ml)}{Concentration\ of\ suspended\ solids\ (\frac{mg}{L})}\ x\ 1000 \tag{2}$$

2.5 Electrode Passivation Effects at the Optimum Condition

In this stage, the electrode passivation effect was determined by identifying the change to the % removal target contaminants, i.e. turbidity, suspended solids, and colour. For knowledge, the test to see the electrode passivation effect can only be carried out when the optimum condition value has been obtained for the optimum current density value, optimum initial pH, and optimum contact time. Then, after the optimum value is obtained, the electrocoagulation process was carried out for several cycles to see a decrease in terms of % removal of target contaminants. If there is no decrease in % removal, the electrodes used for the electrocoagulation process will work well even after several cycles. In addition, electrode passivation effects can also be measured in terms of the weight of the electrodes at the beginning, before being used in the electrocoagulation process, and the weight after being used in several cycles.

2.6 Analytical Methods

This study focused on the comprehensive analysis of car wash wastewater samples, assessing their quality before and after the electrocoagulation treatment. Electrocoagulation, a process that enhances the removal of contaminants, was systematically evaluated for its effectiveness by comparing key water quality parameters before and after the treatment. The parameters investigated included turbidity, measured using Method 2130B, which indicates the cloudiness of the water; suspended solids, analysed through Method 2540D, which assesses the particulate matter in the wastewater; colour, determined by Method APHA 2120F, reflecting the visual quality of the water; and pH, measured according to Method 4500, providing insight into the acidity or alkalinity of the samples [11]. These tests were significant for investigating the efficiency of electrocoagulation as the principal wastewater treatment method for car washes. The colour test was carried out directly using the DR6000 Spectrophotometer using the ADMI method according to Method APHA 2120F. The examination was carried out using a DR6000 spectrophotometer. The control was represented by deionised water. To guarantee accurate colour measurement, the specimens were filtered using filter paper with a pore size of 0.45 μm before analysis.
The pH test was conducted following Method 4500, using a conductivity pH meter of the HACH Sension 3 brand to measure the wastewater sample from the car wash before and after treatment. The pH meter was calibrated using distinct solutions before each utilisation to guarantee precise outcomes. Next, to evaluate suspended

particles in car wash wastewater, 10 millilitres of deionised water were added as a blank to one sample cell, and 10 millilitres of raw or treated car wash wastewater were added to another cell for analysis. The analysis was done using Method 2540D, measured using a spectrophotometer DR6000. Turbidity was measured using EUTECH TN-100 by following Method 2130B. All the analysis was repeated three times, after which the mean was determined. Lastly, the electrocoagulation process involves using electrodes that will undergo weight changes throughout the treatment period to determine if the electrode used in this process faces passivation effects. Using a digital balance, the mass of each electrode was carefully measured at the beginning of the experiment to verify the exact starting weight. After that, the weight of both electrodes was measured after being used in several cycles in the electrocoagulation process. The removal efficiency of colour, suspended particles, and turbidity will be calculated using Equation 3.

$$Removal\ efficiency\ (\%) = \frac{(A_0 - A)}{A_0}\ x\ 100 \quad (3)$$

Where:
A_0 = the concentration of the test parameters before the treatment procedure
A = the test parameter concentration during the treatment procedure

3. Results and Discussion

3.1 Initial Characteristics of Car Wash Wastewater Samples

The initial characteristics of car wash wastewater play a vital role in evaluating how effectively certain pollutants can be removed during treatment processes. This study concentrates on three important parameters: total suspended solids, colour, and turbidity, which provide insight into the quality of the wastewater. Table 2 provides a detailed overview of the initial attributes of the raw car wash wastewater, highlighting the concentrations and conditions of these parameters prior to any treatment.

Table 2 *Characteristics of raw car wash wastewater from the selected station*

Parameter	Concentration	Average Concentration	Acceptable Limits of Sewage Discharge of Standards A and B	
			A	B
Suspended solids, mg/L	172-555	277.33	50	100
Turbidity, NTU	142-358	202.50	50	50
Colour, PtCo	581-1310	776.67	100	200
pH	8.05-9.73	9.25	6.0-9.0	5.5-9.0

Note: The raw data for the initial characteristics can be obtained from Appendix A.

It can be observed that, the initial characteristics of raw wastewater from vehicle washes exceed the permissible limits for both Category A and B. In particular, these high contaminant levels exceptionally pose a significant threat to the environment. Therefore, it is essential to ensure that the wastewater is treated before it is released into the environment.

3.2 Optimisation Studies Through Batch Electrocoagulation Process

In this research, specific parameters were kept constant: the electrode distance was set at 5 cm, the settling time at 30 minutes, the voltage at 15V, the volume of treated car wash wastewater at 1 litre, and the total working area of the aluminium electrodes at 0.022 m². In a single-mode setup, aluminium electrodes served as the cathode and anode. Alligator clips were used to secure the 5 cm × 20 cm electrodes, which were then linked straight to a DC power source. The capacity of the electrocoagulation process to eliminate suspended particles, colour, and turbidity from effluent from car washes was used to evaluate its efficacy. Fig. 3 illustrates the car wash wastewater before and after undergoing electrocoagulation treatment. The raw data for the optimisation studies can be obtained from Appendix B1-B9.

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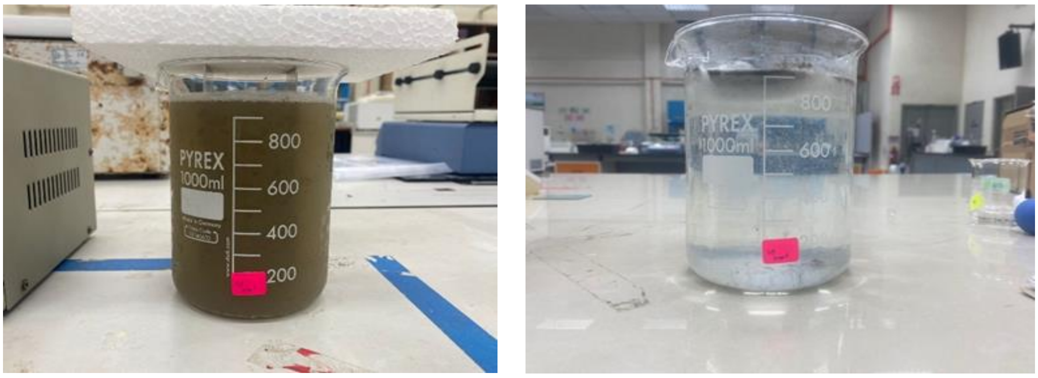

(a) **(b)**

Fig. 3 *Car wash wastewater before (a); and after (b) the electrocoagulation process*

3.3 Optimum Current Density

The experimental results provided comprehensive insights into the efficiencies of the electrocoagulation process for removing turbidity, colour, and suspended solids from water at varying current densities. Specifically, at current densities of 27 A/m^2, 45 A/m^2, 64 A/m^2, and 82 A/m^2, the removal efficiencies for turbidity were recorded as 36.88%, 42.29%, 40.00%, and 31.25%, respectively. Regarding colour removal, the efficiencies were slightly lower, with values of 36.20%, 38.89%, 37.65%, and 32.52% at the same current densities. Furthermore, the removal efficiencies for suspended solids displayed a similar trend, yielding rates of 34.96%, 41.19%, 38.62%, and 34.00%.

The results shown in Fig. 4 clearly illustrate these findings of current density variations' impact on the treatment process's effectiveness and notably highlight that the peak removal efficiencies for turbidity, colour, and suspended solids occurred at a current density of 45 A/m^2. This observation is significant as it reveals that the removal efficiencies began to decline before and after reaching this optimal point. As such, a current density of 45 A/m^2 was determined to be the most effective condition for conducting further experiments, ensuring the best possible outcomes in the electrocoagulation process.

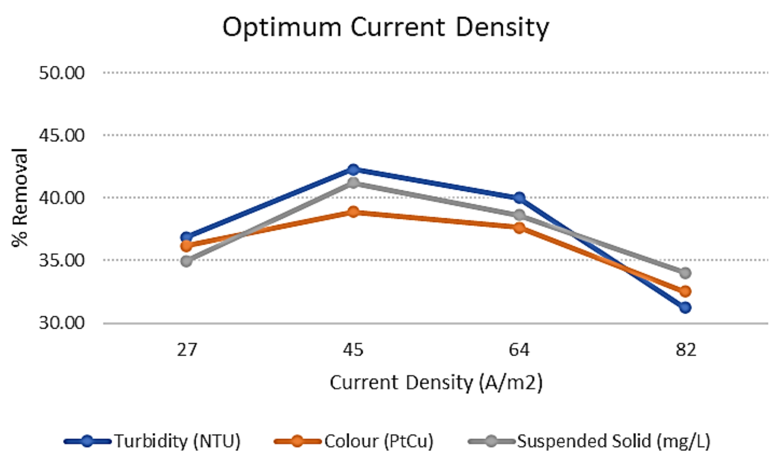

Fig. 4 *The effect of current density on percentage removal efficiencies*

3.4 Optimum pH

Fig. 5 illustrates the removal efficiencies of turbidity, colour, and suspended solids as influenced by initial pH levels. The Turbidity removal efficiencies at pH 6, 7, 9, and 11 were recorded at 37.56%, 50.70%, 42.25%, and 38.73%, respectively. For colour removal, the efficiencies were 33.17%, 42.11%, 36.10%, and 33.66%. Additionally, the removal efficiencies for suspended solids were measured at 38.55%, 51.40%, 44.51%, and 41.15%.

The data analysis in Fig. 5 shows that the highest removal efficiencies for turbidity, colour, and suspended solids occur at a pH level of 7. This optimal pH indicates a significant peak in treatment effectiveness, as the removal efficiencies show a marked decline both below and above this point. Such a trend emphasises the importance of maintaining a neutral pH of 7 as the ideal starting condition for electrocoagulation processes utilising aluminium electrodes to treat car wash wastewater effectively. Consequently, maintaining a pH of 7 and a current density of 45 A/m^2 would provide the best operational conditions for the subsequent experiments.

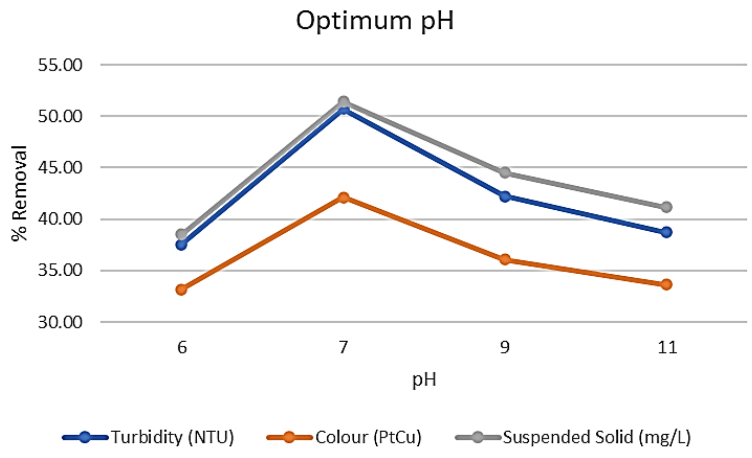

Fig. 5 *The effect of pH on percentage removal efficiencies*

3.5 Optimum Contact Time

Fig. 6 illustrates how electrolysis duration affects the removal efficiency of car wash wastewater in terms of turbidity, colour, and suspended solids. According to the graph below, the turbidity elimination efficiencies as a percentage were 22.44%, 36.82%, 43.14%, 51.42%, 54.25%, 57.01%, 59.31%, 62.53%, 86.78%, 88.08%, 90.13%, 92.09%, 83.27%, 83.14%, 81.97%, and 81.58%. Next, the percentage of removal efficiencies for colour were 4.69%, 21.01%, 42.53%, 59.38%, 70.27%, 70.95%, 71.45%, 72.13%, 89.97%, 90.53%, 92.14%, 92.70%, 83.29%, 82.92%, 33 82.16%, and 81.79%. Other than that, the removal efficiencies for suspended solids were 31.98%, 49.42%, 58.72%, 61.05%, 74.74%, 76.23%, 77.28%, 78.18%, 94.35%, 94.71%, 95.38%, 96.34%, 90.28%, 89.89%, 89.50%, and 89.21% respectively.

The graph showing removal efficiencies against contact time, the highest removal efficiencies for turbidity, colour, and suspended solids were recorded at 140 minutes (2 hours and 20 minutes). After this point, the percentage removal values began to decrease. As a result, 140 minutes was established as the optimal contact time for the aluminium electrocoagulation process based on the removal efficiencies of all tested parameters: colour, suspended solids, and turbidity.

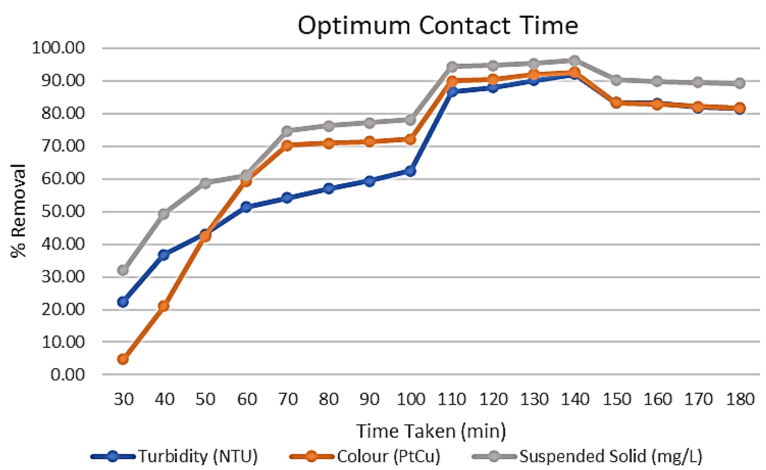

Fig. 6 *The effect of contact time on percentage removal efficiencies*

3.6 Sludge Volume Index (SVI) at Optimum Condition

Table 3 shows the result of the volume of settled sludge after the electrocoagulation process and the result of the sludge volume index (SVI), which is 163.75 mL/L and 295.05 mL/g. Based on the SVI result, it is considered high, indicating that the sludge has poor settling characteristics and is likely to be bulky or fluffy.

Table 3 *Result of volume of settled sludge and Sludge Volume Index (SVI)*

Reading	R1	R2	R3	R4	Average	SD	MLSS	SVI
Value	160	160	170	165	163.75	4.79	55	295.05

3.7 Sludge Volume Index (SVI) at Optimum Condition

Table 4 shows the data on the weight of aluminium electrodes (anode and cathode) over four cycles during the electrocoagulation process. From the data, the initial weight from both electrodes' anode and cathode in Cycle 1 slightly increased, with the anode weight increasing from 28.53g to 28.93g, and the cathode weight increasing from 28.42g to 28.82g. Next, in Cycle 2, the anode weight increased from 28.60g to 29.09g, and at the cathode, it increased from 28.50g to 28.91g. Additionally, in Cycle 3, the anode weight increased from 28.60g to 29.44g, while the cathode weight increased from 28.50g to 29.23g. Lastly, in Cycle 4, both electrodes (anode and cathode) continue to show an increase in weight, with the anode value increasing from 28.60g to 29.50g and the cathode value increasing from 28.50g to 29.44g. Thus, the observed weight increase on both the anode and cathode could be attributed to the formation of a hydroxide layer on the electrode surfaces. This can cause the electrodes to be reduced in terms of effectiveness to be used in the subsequent few cycles of the electrocoagulation process.

Table 4 *Result of volume of settled sludge and Sludge Volume Index (SVI)*

(Aluminium: Contact time: 140 minutes: pH: 7: Current density: 45 A/m^2)

Cycles	Initial weight, g (Anode)	Final weight, g (Anode)	Initial weight, g (Cathode)	Final weight, g (Cathode)
1	28.53	28.93	28.42	28.82
2	28.60	29.09	28.50	28.91
3	28.60	29.44	28.50	29.23
4	28.60	29.50	28.50	29.44

3.8 Result of Sludge Volume Index (SVI) at Optimum Condition

According to the study, the highest percentage removal efficiencies for turbidity, colour, and suspended solids were achieved under the optimum conditions of a contact time of 140 minutes, a pH of 7, and a current density of 45 A/m^2. Under these conditions, the process achieved removal efficiencies of 92.09% for turbidity, 92.70% for colour, and 96.34% for suspended solids. In comparison, Atiyah and Abdul-Majeed [12] reported a turbidity removal efficiency of 99.90% at a contact time of 90 minutes and a voltage of 30V, using aluminium foil as the electrode in their treatment process. Other than that, Rubí-Juárez. [13], found that the removal efficiency of turbidity and colour is 98% and 96% at a neutral pH of 7 with a current density of 150 A/m^2 for 60 minutes contact time, proving exceptional efficacy in wastewater treatment by drastically lowering the number of pollutants. While increasing the current density may lead to higher removal percentages of contaminants, it is often not economically feasible. This study determined that the current density of 45 A/m^2 is sufficient to achieve optimal removal efficiencies without incurring high operational costs. Mirshahghassemi [14] found that the maximum turbidity removal occurred at pH 7.3 after 20.3 minutes of electrolysis with a current density of 4.2 mA/cm2. It had an 85.5% removal efficiency.

Additionally, based on the results obtained in this study regarding electrode passivation effects, both electrodes (anode and cathode) exhibit a steady increase in weight as the cycles progress. By Cycle 4, the anode's final weight reaches 29.50g, while the cathode's final weight reaches 29.44g. This is due to the formation of a hydroxide layer on the electrode surface. This point can be supported by a study conducted by Ingelsson et al. [15], which stated that the precipitation of material on the electrodes during long-term operation leads to a passivating effect, which reduces treatment performance and increases power consumption. Furthermore, [16] identified electrode passivation as the main challenge in electrocoagulation (EC). It was observed that the electrodes' initially homogeneous and smooth morphology gradually transformed into a heterogeneous structure after repeated use. The formation of a passive film on the electrode surface increases energy consumption and decreases the efficiency of contaminant removal.

Lastly, based on the results obtained in this study, the sludge volume index (SVI) is 295.05 mL/g. The SVI result indicates a high value, suggesting that the sludge has poor settling qualities and is likely to be voluminous or fluffy. Pandey and Thakur [17] stated in their study that the best result for the sludge volume index (SVI) was 56.67 mL/g. As a conclusion from the study carried out, the value of the sludge volume index is very high, which is very different from the previous study, in which the value of the SVI was 295.05 mL/g, indicating inadequate sludge settleability, potentially requiring process optimisation to improve sludge compaction and separation efficiency.

4. Conclusion

This study demonstrates the effectiveness of electrocoagulation in treating car wash wastewater. Optimal treatment conditions were identified at pH 7, a current density of 45 A/m^2, and a contact time of 140 minutes. Under these conditions, significant removal efficiencies were observed: 92.09% for turbidity, 92.70% for colour, and 96.34% for suspended solids. Additionally, this study evaluated the Sludge Volume Index (SVI) and electrode passivation during multiple cycles of electrocoagulation treatment on car wash wastewater. Under optimal conditions, the high SVI of 295.05 mL/g indicated bulky, poorly settling sludge, making handling and disposal challenging.

Additionally, electrode passivation was observed, with both anode and cathode experiencing weight gain due to the formation of a hydroxide layer. This layer can diminish the effectiveness of the electrode in subsequent cycles, potentially impacting overall treatment efficiency. In conclusion, these results suggest that the treated wastewater may be suitable for reuse in car wash operations. Therefore, the study highlights the potential of electrocoagulation as a viable method for wastewater treatment. However, to further enhance treatment efficiency, future research should explore optimising the process by using a more versatile DC power supply, reducing electrode spacing, and increasing electrode surface area, despite potential cost increases.

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Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Author Contribution

The authors are responsible for the study conception, research design, data collection, data analysis, result interpretation and manuscript drafting.

Appendix A: Initial Characteristics of Car Wash Wastewater

Characteristic \ Sampling Date	14/10/2024	21/10/2024	28/10/2024	4/11/2024	11/11/2024	18/11/2024	Average	St. Dev.
pH	8.05	9.30	9.73	9.28	9.49	9.65	9.25	0.62
Turbidity (NTU)	160	142	153	145	358	257	202.50	87.61
Colour (PtCo)	780	615	576	581	1310	798	776.67	279.14
Suspended solids (mg/L)	246	179	172	169	555	343	277.33	151.59

Appendix B: Raw Data of Optimisation Studies

Table B1 *Optimisation of current density for turbidity removal*

Time taken (min)	Current (A/m^2)	pH	Initial Reading	Turbidity (NTU) R1	R2	R3	Average	St. Dev.	Removal Efficiency %
30	27	7.02	160	101	102	100	101.00	1.00	36.88
30	45	7.04		91	93	93	92.33	1.15	42.29
30	64	7.05		97	95	96	96.00	1.00	40.00
30	82	7.02		110	110	110	110.00	0.00	31.25

Table B2 *Optimisation of current density for colour removal*

Time taken (min)	Current (A/m2)	pH	Initial Reading	Colour (PtCu) R1	R2	R3	Average	St. Dev.	Removal Efficiency %
30	27	7.02	780	498	497	498	497.67	0.58	36.20
30	45	7.04		476	476	478	476.67	1.15	38.89
30	64	7.05		485	487	487	486.33	1.15	37.65
30	82	7.02		527	526	526	526.33	0.58	32.52

Table B3 *Optimisation of current density for suspended solids removal*

Time taken (min)	Current density (A/m^2)	pH	Initial Reading	Suspended solids (mg/L) R1	R2	R3	Average	St. Dev.	Removal Efficiency %
30	27	7.02	246	160	160	160	160.00	0.00	34.96
30	45	7.04		146	144	144	144.67	1.15	41.19
30	64	7.05		152	150	151	151.00	1.00	38.62
30	82	7.02		163	162	162	162.33	0.58	34.01

Table B4 *Optimisation of pH for turbidity removal*

Time taken (min)	Current density (A/m^2)	pH	Initial Reading	Turbidity (NTU) R1	R2	R3	Average	St. Dev.	Removal Efficiency %
30	45	6.03	142	89	88	89	88.67	0.58	37.56
30	45	7.02		70	71	69	70.00	1.00	50.70
30	45	9.04		81	83	82	82.00	1.00	42.25
30	45	11.02		87	87	87	87.00	0.00	38.73

Table B5 *Optimisation of pH for colour removal*

Time taken (min)	Current density (A/m^2)	pH	Initial Reading	Colour (PtCu) R1	R2	R3	Average	St. Dev.	Removal Efficiency %
30	45	6.03	615	412	411	410	411.00	1.00	33.17
30	45	7.02		357	355	356	356.00	1.00	42.11
30	45	9.04		393	393	393	393.00	0.00	36.10
30	45	11.02		408	408	408	408.00	0.00	33.66

Table B6 *Optimisation of pH for suspended solids removal*

Time taken (min)	Current density (A/m^2)	pH	Initial Reading	Suspended solids (mg/L) R1	R2	R3	Average	St. Dev.	Removal Efficiency %
30	45	6.03	179	110	109	111	110.00	1.00	38.55
30	45	7.02		87	88	86	87.00	1.00	51.40
30	45	9.04		99	98	101	99.33	1.53	44.51
30	45	11.02		104	105	107	105.33	1.53	41.15

Table B7 *Optimisation of contact time for turbidity removal*

Time taken (min)	Current density (A/m²)	pH	Initial Reading	Turbidity (NTU)					Removal Efficiency %
				R1	R2	R3	Average	St. Dev.	
30	45	7.04	153	118	119	119	118.67	0.58	22.44
40	45	7.05	153	97	96	97	96.67	0.58	36.82
50	45	7.03	153	87	87	87	87.00	0.00	43.14
60	45	7.02	153	75	74	74	74.33	0.58	51.42
70	45	7.04	145	66	67	66	66.33	0.58	54.25
80	45	7.01	145	63	62	62	62.33	0.58	57.01
90	45	7.04	145	59	59	59	59.00	0.00	59.31
100	45	7.01	145	53	55	55	54.33	1.15	62.53
110	45	7.05	358	48	47	47	47.33	0.58	86.78
120	45	7.01	358	42	44	42	42.67	1.15	88.08
130	45	7.03	358	35	36	35	35.33	0.58	90.13
140	45	7.04	358	28	29	28	28.33	0.58	92.09
150	45	7.01	257	43	43	43	43.00	0.00	83.27
160	45	7.05	257	43	43	44	43.33	0.58	83.14
170	45	7.04	257	47	46	46	46.33	0.58	81.97
180	45	7.05	257	48	47	47	47.33	0.58	81.58

Table B8 *Optimisation of contact time for colour removal*

Time taken (min)	Current density (A/m²)	pH	Initial Reading	Colour (PtCu)					Removal Efficiency %
				R1	R2	R3	Average	St. Dev.	
30	45	7.04	576	549	549	549	549.00	0.00	4.69
40	45	7.05	576	455	455	455	455.00	0.00	21.01
50	45	7.03	576	331	331	331	331.00	0.00	42.53
60	45	7.02	576	234	234	234	234.00	0.00	59.38
70	45	7.04	592	176	176	176	176.00	0.00	70.27
80	45	7.01	592	172	172	172	172.00	0.00	70.95
90	45	7.04	592	169	169	169	169.00	0.00	71.45
100	45	7.01	592	165	165	165	165.00	0.00	72.13
110	45	7.05	1310	132	131	131	131.33	0.58	89.97
120	45	7.01	1310	124	124	124	124.00	0.00	90.53
130	45	7.03	1310	102	104	103	103.00	1.00	92.14
140	45	7.04	1310	95	96	96	95.67	0.58	92.70
150	45	7.01	798	133	134	133	133.33	0.58	83.29
160	45	7.05	798	136	137	136	136.33	0.58	82.92
170	45	7.04	798	142	143	142	142.33	0.58	82.16
180	45	7.05	798	146	145	145	145.33	0.58	81.79

Table B9 *Optimisation of contact time for suspended solids removal*

Time taken (min)	Current density (A/m²)	pH	Initial Reading	Suspended solids (mg/L)					Removal Efficiency %
				R1	R2	R3	Average	St. Dev.	
30	45	7.04	172	117	117	117	117.00	0.00	31.98
40	45	7.05	172	87	87	87	87.00	0.00	49.42
50	45	7.03	172	71	71	71	71.00	0.00	58.72
60	45	7.02	172	67	67	67	67.00	0.00	61.05
70	45	7.04	223	57	56	56	56.33	0.58	74.74
80	45	7.01	223	53	53	53	53.00	0.00	76.23
90	45	7.04	223	50	51	51	50.67	0.58	77.28
100	45	7.01	223	48	49	49	48.67	0.58	78.18
110	45	7.05	555	32	31	31	31.33	0.58	94.35
120	45	7.01	555	30	29	29	29.33	0.58	94.71
130	45	7.03	555	25	26	26	25.67	0.58	95.38
140	45	7.04	555	20	21	20	20.33	0.58	96.34
150	45	7.01	343	33	34	33	33.33	0.58	90.28
160	45	7.05	343	34	35	35	34.67	0.58	89.89
170	45	7.04	343	36	36	36	36.00	0.00	89.50
180	45	7.05	343	37	37	37	37.00	0.00	89.21

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