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Electrocoagulation using Aluminium and Stainless Steel Electrodes for the Removal of Turbidity, Colour and Suspended Solids from Full-Handwashing Car Wash Wastewater

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Abstract: The increasing demand for carwash services in Malaysia has become one of the contributors to the release of untreated carwash wastewater into water bodies which adversely impact the environment, especially the aquatic life. The objective of this study is to investigate the effectiveness of electrocoagulation in treating turbidity, suspended solids and colour from the carwash wastewater which has been collected from Ijan Car Wash Station in Parit Raja. This treatment has been conducted by using aluminium and stainless steel as the electrodes in a monopolar electrode configuration. The optimum conditions for electrocoagulation such as current density, retention time, and initial pH have been determined based on its performance in reducing turbidity, suspended solids, and colour. The range of the tested current density was 27 - 82 A/m^2, 10 until 120 minutes electrolysis time and initial pH from 6 to 10. The electrode distance and settling time were kept constant 5 cm and 30 minutes respectively. The result shows that the optimum condition for electrocoagulation process of Al-St electrode pair was determined at the current density of 27 A/m^2, electrolysis time of 110 minutes, and the initial pH of 8 which has removal efficiencies of the turbidity, colour and suspended solid of 90.3 %, 88.12 % and 94.27 % respectively. The electrocoagulation process also has the potential to be utilized in removing physical properties of car wash wastewater based on its effective removal, especially turbidity, suspended solids and colour. For the future work, reduces in terms of spacing between electrodes and increase the total working area of electrodes could give more effect for the removal efficiencies

Keywords: Electrocoagulation, carwash wastewater, aluminium electrode, stainless steel electrode, suspended solids, turbidity, colour

1. Introduction

The rapidly growing population, especially in Malaysia, has become one of the main results of exponential cars. The car is the wheeled vehicle that is used for transportation in our daily life. Therefore, the demand for car wash stations or industry is also growing every year as the number of cars increases. For every daily wash, the car wash industry, especially the full handwashing car wash, uses a large amount of water for the cleaning process, generating approximately 150 to 350 liters of water. The car wash industry in Malaysia has increased drastically increased over the past five years and it is foretold to continue to increase for a couple of years. It has boosted the car wash industry, leading to an increase in car wash service stations, particularly with rapid development and the high population of the focal point area [1].

The carwash industry is one of the leading consumers of large volumes of clean water. The amount of water used per car varies between 150 and 600 L depending on the size of the vehicle and the equipment used [2]. Therefore, car

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washing services are among the activities that consume large freshwater capacities and benefit from wastewater recycling. Furthermore, the average water consumption per car wash installation is 400 dm^3 per car when washed by hand with a hose and 150 dm^3 per car using conventional facilities [3]. There are three types of significant carwash industries: full hand washing, semi-automated and fully automated car washing that operate worldwide, especially in Malaysia.

Furthermore, the use of all these car wash industries added with snow foam can indicate the highest concentration of phosphate, total phosphorus, oil and grease, total suspended solids, chemical oxygen demand, and surfactants [1]. After the cleaning process using various chemical agents, the wastewater heavily contaminated with high impurities was discharged to the drain and directly into the aquatic and terrestrial environment [1]. It is due to the presence of suspended solids such as sand and particles, oil and grease, detergents, hydrofluoric acid, and surfactants [4]. If it is not adequately treated to comply with the stipulated standards and regulations, this may generate an adverse impact on the environment and health. Therefore, it is essential to treat it properly before discharge it into the environment, considering the large amount of water consumed per car throughout the day and the various chemical agents used in the vehicle washing industry, to maintain and preserve it for future generations.

Therefore, the most effective and accessible solutions to treat or manage the contamination of the environment from getting worse are the treatment of car wash wastewater through the resource point. This method does not need to be collected in one treatment plant because the individual treatment process took sufficient time to remove most impurities and contaminants. Therefore, the treatment that can be applied is electrocoagulation using aluminium and stainless steel as the electrode. Electrocoagulation is the treatment process by which an electrical current is applied to flocculate contaminated wastewater without adding coagulation. The electrocoagulation method has the potential to remove various pollutants of the water quality without generating secondary pollution using compact equipment and apparatus [5]. Furthermore, this treatment does not require chemical aids, and is easily integrated with a conventional waste control system [6, 7]. Moreover, by using the electrocoagulation process, the flocs that form tend to be much larger, less bound water, more stable, and acceptable to filtration, and the gas bubble generated can be separated easily during electrolysis.

This treatment also dominates in removing the smallest colloidal particles because it applies electric fieldsets faster, facilitating coagulation [8]. Furthermore, many previous research has found that the electrocoagulation process could provide palatable, clear, colorless, and odourless water and produce an effluent with a lower Total Dissolved Solids (TDS) content than with chemical treatment [9]. Therefore, the main objective of this research is to investigate the effectiveness of the electrocoagulation method in removing suspended solids, turbidity, and colour from the car wash wastewater using aluminum and stainless-steel electrodes. Furthermore, this study also indicates the effects of the optimal operating parameter, particularly in current density, electrolysis time or retention time, and initial operating pH, on the removal efficiency of the electrocoagulation process to treat the complete hand washing of the car wash wastewater.

2. Materials and Methods

In this research, the electrocoagulation process has been chosen as the primary treatment process to treat wastewater from the entire car wash industry. Carwash wastewater samples were collected from the Ijan Car Wash Station, located at Parit Haji Ali Laut in Parit Raja, Batu Pahat, Johor. It is located approximately at 1°52'13.6"N 103°07'33.7"E on GPS coordinates [Fig. 1(a)]. This car wash service serves as a full hand washing car wash to wash vehicles such as motorcycles, trucks, etc. [Fig. 1(b)].

Fig. 1 – (a) Location of sampling for electrocoagulation treatment; (b) hand washing process for car wash services

In this investigation, the grab sampling method was adopted, which the single sample was collected at a specific point of the car wash over a period of time. The sampling of the car wash wastewater has been taken at the outlet of the car wash service by using the 1.5 L plastic bottle. Before using the wastewater, it has been stored in a 4°C cold room at the Laboratory of Wastewater, Civil and Environmental Engineering, UTHM, and avoiding any changes in its characteristics or degradation [10].

The in situ analysis has been conducted on-site to assess the parameters of pH, temperature, dissolved oxygen, and electroconductivity. Meanwhile, laboratory analyses were also carried out for other target parameters such as Chemical Oxygen Demand (COD), turbidity, suspended solids, and colour according to Method 1060 [10].

Fig. 2 – Drainage outlet of car wash service, which is the sampling point

2.1 Preparation of Electrodes

For this research, the materials of the electrodes that have been chosen were aluminium (Al) and stainless steel (St). Each electrode has dimensions of 20 cm (length) x 5 cm (width) x 1 mm (thickness), as shown in Fig. 3. It is expected that impurities formed on the surface of the electrodes in several treatment processes. The impurities can be removed from the surface of the electrode by using sandpaper. The electrode was then thoroughly washed thoroughly by distilled water to remove the remaining solid residues, and it was allowed to dry after the washing process. Although the size of the electrodes was 20 cm x 5 cm x 1 mm, after each electrolysis run, the total working area calculated is the total surface area immersed in the car wash wastewater in the 1 L beaker only. Therefore, the actual working area is 0.022 m^2 since the electrode size of the electrode that is submerged in the sample was 11 cm x 5 cm. Every electrode side was also considered since its surface area was adequate, corresponding to the surface [11].

Fig. 3 – Aluminium electrode (left) and stainless steel electrode (right) used for the electrocoagulation process

2.2 Batch Experimental Setup

In the study of electrocoagulation treatment, the optimum current density, optimum pH, and retention time are obtained to determine which is intended to get a high probability of removal efficiency. Furthermore, during the electrocoagulation process, the distance between the electrode and the settling point is kept constant at 5 cm for 30 minutes. Furthermore, to determine the initial characteristic of total handwashing car wash wastewater, the targeting parameters such as turbidity, suspended solids, and color were measured.

Electrocoagulation experiments have been carried out in the batch mode using a 1 L glass beaker with a height of 11 cm by vertical positioning the aluminium and stainless steel electrodes with a spacing of 5 cm. As a result, the electrode made of aluminium and stainless steel with a dimension of 20 cm (length) x 5 cm (width) x 1mm (thickness) has been connected to a direct digital current (DC) power supply (MPS 3030DD Model) in monopolar configurations which are All – St and St - Al, respectively as illustrated in Fig. 4.

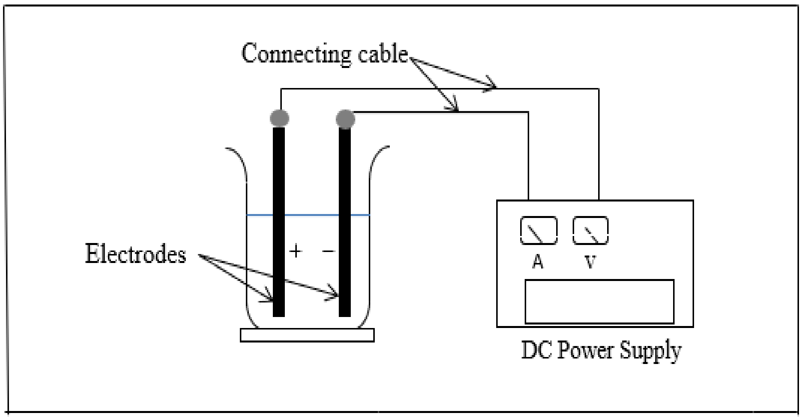


Fig. 4 – Apparatus and equipment set up for the electrocoagulation process

In the electrocoagulation process, the current densities that have been chosen were 20 A/m^2, 40 A/m^2, 60 A/m^2, 80 A/m^2, and 100 A/m^2. By multiplying the desired current density by the surface area of the electrodes for every process, the current needs can be determined from the current need for DC Power Supply Model, which is 0.2 A 0.4 A, 0.6 A, 0.8 A, and 1.0 A with respect to the tested current densities. DC power supply model SAIKE PS-1502DD could not measure the current density (A/m^2) directly because the apparatus only could be measured in ampere (A). Therefore, it needs to be converted by a simple mathematical calculation (Equation. 1) to get the current value. Since this model of the direct current power supply apparatus has a limitation that the current only can be set from 0.6 A until 2.0 A, so the desired densities that could be tested for the determination of optimum current density are 27 A / m^2 45 A/m^2, 64 A/m^2, and 82 A/m^2. All current densities have been multiplied by the total working area of 0.022 m^2. Thus, the current set to the DC power supply was 0.6A, 1.0A, 1.6A, and 2.0A with respect to its current density, as shown in Table 1 below.

$$\text{Current (A)} = \text{Current Density (A/m}^2\text{)} \times \text{Total working area for a test run (m}^2\text{)} \qquad (1)$$

Table 1 - List of the value of current with respect 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

For each experiment, the settling time has been kept constant at 30 minutes. The pH of the car wash wastewater solutions will be measured using the HACH SensION3 pH meter before and after the electrocoagulation process. To determine the optimum initial pH, either sodium hydroxide (NaOH) or sulphuric acid (H_2SO_4) was added to the car wash wastewater sample to adjust the pH of the solution. While for COD, turbidity, suspended solids and colour test have been carried out according to the standard methods [10].

2.3 Optimisation Studies

2.3.1 Current Density

Current densities have been applied at 27, 45, 64 and 82 A/m^2 in this stage of determining the optimal current density. After each run, the sample was left for 30 minutes to settle before the supernatant layer of the treated car wash wastewater was pipetted out from the middle portion to analyze the final turbidity, suspended solids, and colour content. The optimum current density was determined by analysing the turbidity, suspended solids, and colour removal efficiency. The distance between the electrodes and settling time was always kept constant at 5 cm for 30 minutes. The current density condition that showed the highest removal efficiency for the tested parameters will be applied in 2.3.2 and 2.3.3.

All the results have been calculated as an average value, and other resources used in the current study should be described in this section.

2.3.2 Optimum pH

At this stage, the optimum current density and retention time for each electrode mode is achieved in 2.3.1. The pH of 2, 6, 8, and 10 were applied for this process to determine the optimum initial pH. The pH of car wash wastewater was adjusted by using an appropriate amount of sodium hydroxide (NaOH) and sulfuric acid (H_2SO_4) solutions to obtain the desired initial pH. The distance between the electrode and settling time was kept constant at 5 cm for 30 minutes. After each process, the sample was allowed to dry for 30 minutes to settle before the supernatant layer of the treated car wash wastewater sample was pipetted from the middle portion to analyze the final turbidity, suspended solids and color. The same as in 2.3.1, the optimum initial pH condition has been determined by analysing the turbidity, suspended solids, and colour removal efficiencies. The initial pH condition that showed the highest removal efficiency for the test parameter was classified as the optimum initial pH and used to determine the following optimum parameter. Then, the experiment steps to the rest of the electrode's mode. All tests were performed in triplicate and then an average value was calculated.

2.3.3 Optimum Electrolysis Time

The optimum current density that has been achieved from 2.3.1 and 2.3.2 was used for these stages. The retention time from ten until 120 minutes with increments of ten has been chosen to conduct in these stages to determine the optimum retention time. After running each process, the sample was left to settle for 30 minutes before the supernatant layer of the treated car wash wastewater sample was pipetted from the middle portion to analyze the final turbidity, suspended solids and colour. The distance between the electrodes and settling time was kept constant at 5 cm for 30 minutes, respectively. The highest retention time condition has been used as the optimum electrolysis time. All test results have been analyzed in triplicate and an average value has been calculated.

2.4 Analytical Methods

The analytical methods have been performed by performing a regular analysis for the car wash wastewater sample before and after each electrocoagulation process. In this research, parameter analysis has been conducted before and after the treatment process to determine the performance of the electrocoagulation. Therefore, the parameters involved were turbidity (Method 2130B), suspended solids, colour (Method 2120), and pH (Method 4500) [10]. The significance of these tests was to investigate the effectiveness of the electrocoagulation method as the primary treatment of car wash wastewater. The colour test was measured directly using the DR6000 Spectrometer. The colour has been measured by the Platinum–Cobalt (PtCo) method according to Method 2120. Deionised water has been used as a control. The samples were screened using a filter paper with the opening of 0.45 μm before analysis using DR6000 to get the colour reading. The COD tests were conducted to determine the initial characteristics of the carwash wastewater sample. High range vials have been used, and the sample was then diluted before the process in vials. The pH test has been carried out according to Method 4500. HACH SensION 3 brand conductivity pH meter has been used to determine the pH of the car wash wastewater sample before and after the treatment process. The pH meter was calibrated using specific solutions to ensure the accurate pH value result. A pH modification was required by adding sulfuric acid (H_2SO_4) and sodium hydroxide (NaOH) solution to obtain the desired pH value in the stage of determining the optimum initial pH for the electrocoagulation process. All tests have been triplicated, and three readings have been taken, and the average values have been calculated. Turbidity analyzes were performed according to Method 2130B. All tests were performed in triplicate and the readings of each result were taken to get the average values. The removal efficiencies of turbidity, suspended solids, and colour were determined by using Equation 2.

$$\text{Removal efficiency (\%)} = (C_0 - C_e/C_0) \times 100 \qquad (2)$$

Where:
C_0 = Initial concentration of the parameter in the sample before the treatment
C_e = Final concentration of the parameter in the sample after the treatment

3. Results and Discussion

3.1 Initial Characteristics of Car Wash Wastewater Samples

The initial characteristics of car wash wastewater are essential to determining the percentage of removal efficiency of the selected parameters. It should be noted that this study only focused on suspended solids, color, and turbidity parameters. Table 2 shows the initial characteristics of the raw car wash wastewater.

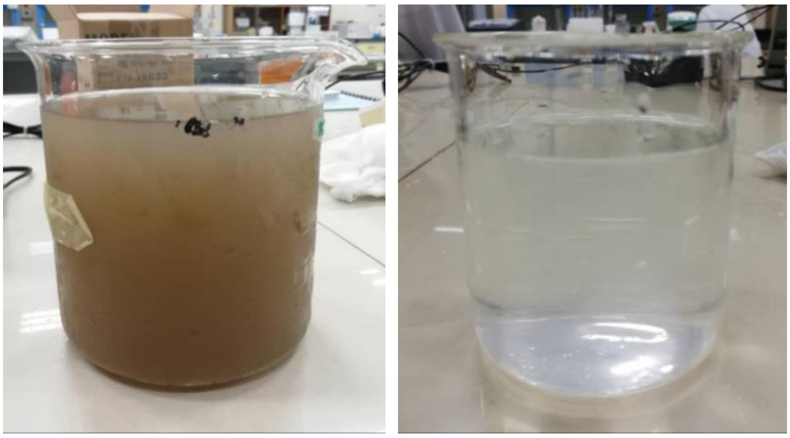
Table 2 - Characteristics of raw car wash wastewater from Ijan Car Wash Station

Parameter	Concentration	Average concentration	Acceptable conditions of sewage discharge of Standards A and B	
			A	B
Suspended solids, mg/L	119 - 445	297	50	100
Turbidity, NTU	113 - 311	218	50	50
Colour, PtCo	588 - 1273	897	100	200
pH	8.06 - 10.13	9.35	6.0 – 9.0	5.5 – 9.0
Chemical Oxygen Demand (COD), mg/L	388 - 407	395	120	200

According to the Effluent Standard Environmental Quality Act 1974, acceptable sewage discharge of clean water is acceptable. However, the concentrations of raw car wash wastewater exceed the acceptable concentrations stipulated in standards A and Standard B. The initial characteristics of raw car wash wastewater also show that the quality was not consistent. It depends on the number of cars and how bad the impurities on the vehicle that came from the carwashing.

3.2 Optimisation Studies Through Batch Electrocoagulation Experiments

For batch experiments, the distance between electrodes, settling time, voltage, the volume of car wash wastewater for each run and total working area of aluminium and stainless steel electrode should be kept constant at 5 cm, 30 minutes, 15V, 1 L and 0.01 m^2, respectively. This study used stainless steel and aluminium metal as the cathode and anode electrodes with a single-mode configuration. The 5 cm x 20 cm electrode was clipped to the alligator cables and connected directly to the direct current (DC) power supply. The performance of the electrocoagulation method was indicated by the suspended solids, color, and turbidity are being removed from car wash wastewater. Fig. 5 shows the car wash wastewater before and after the electrocoagulation process.



(a) (b)

Fig. 5 - Waste from car wash before (a) and after; (b) the electrocoagulation process

3.2.1 Result of Optimum Current Density

Based on the experiment, the turbidity removal efficiencies at current densities of 27 A/m^2, 45 A/m^2, 64 A/m^2, and 82 A/m^2 were 53.68%, 50.36%, 33.77%, and, 31.31% respectively. While for colour parameter, its percentage removal efficiencies were 42.55%, 40.84%, 30.10%, and 24.41%. And next, for the suspended solids parameter, the removal efficiencies were 58.02%, 56.43%, 49.83%, and 43.12%.

From the graph in Fig. 6, all percentage removal efficiencies of turbidity, colour, and suspended solids parameters have the highest removal at the current density of 27 A/m^2. The concentrations of the target parameters were slightly decreased after they reached a current density beyond 27 A/m^2. Therefore, the current density at 27 A/m^2 is determined as the optimum current density for the Al – St electrocoagulation process since it showed the highest result of all parameters tested. Thus, a further increase in current density results in a decrease in turbidity, color, and suspended solids removal efficiency. Therefore, a current density of 27 A/m^2 was selected as the optimum current density for the subsequent experiments.

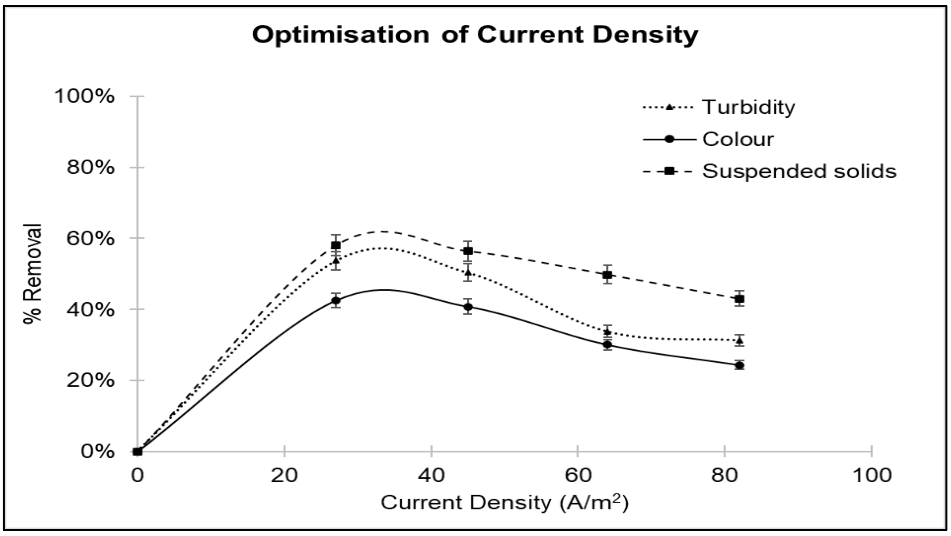


Fig. 6 - The effect of current density on percentage removal efficiencies at pH 7, 20 minutes electrolysis time, 5 cm distance between electrodes, and 30 minutes settling time

3.2.2 Results of Optimum pH

Fig. 7 shows the removal efficiencies of turbidity, color, and suspended solids after they were affected by initial pH. Turbidity percentage removal efficiencies at pH 7, 8, 9, and 10 were 53.68%, 61.41%, 11.50%, and 4.39%. Meanwhile, the percentage of color removal was 42.55%, 49.50%, 8.05% and 4.40%. Then for solid removal, efficiencies were 58.02%, 68.09%, 37.02%, and 13.86%, respectively. From the graph of removal efficiencies of the target parameters against pH, the highest removals recorded for turbidity, color and suspended solids were at pH 8. The removal efficiencies decreased after they reached pH 8. Therefore, pH 8 was determined as the optimum initial operating pH for the Al – St electrocoagulation process, since it showed the highest removals for all parameters tested. For the subsequent experiments, the treatment was conducted at pH 8 and the current density of 27 A/m^2.

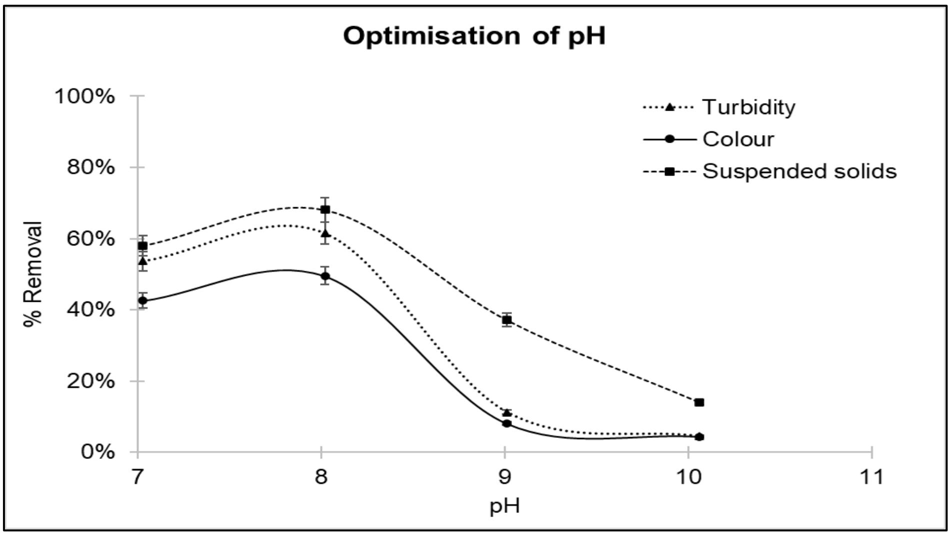


Fig. 7- Percentage of removal efficiency after being affected by different pH with constant current density, electrode distance, electrolysis time, and settling time at 27 A/m^2, 5 cm, 30 minutes, and 20 minutes respectively

3.2.3 Result of Electrolysis Time

The effect of electrolysis time was explored when two optimum parameters were kept constant, which are the pH was kept constant at pH 8 and the current density of 27 A/m^2. The distance between the electrodes and the settling time were also kept constant, which are at 5 cm and 30 minutes, respectively. From the graph (Fig. 8), the percentage elimination efficiencies of turbidity were 12.33%, 19.08%, 20.79%, 31.73%, 42.02%, 42.34%, 49.52%, 64.74%, 86.57%, 87.80%, 90.30%, and 88.50% respectively. Next, for the percentage of removal, efficiencies for colour were 8.29%, 11.54%, 14.34%, 23.08%, 32.94%, 33.02%, 40.19%, 52.56%, 83.91%, 84.69%, 88.12%, and 86.88%. The following optimum parameter was suspended solids and its removal efficiencies were 20.82%, 29.89%, 33.26%, 41.57%, 54.61%, 55.28%, 62.47%, 72.13%, 91.16%, 92.13%, 94.27% and 93.20%.

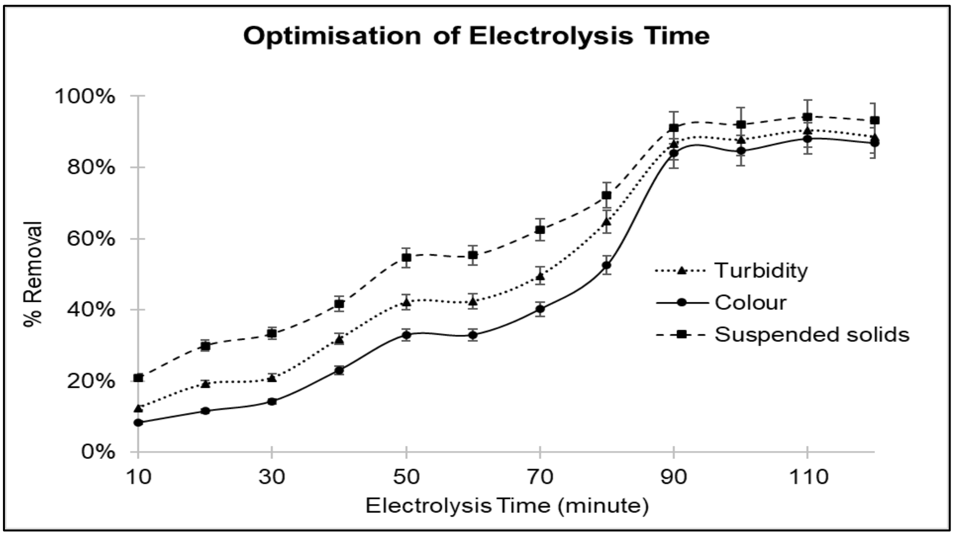


Fig. 8 - Percentage of removal efficiency affected by different electrolysis times from 10 to 110 minutes with 10 minutes time intervals. The current density value was 27 A/m², the electrode distance of 5 cm and the settling time of 10 minutes settling time have remained constants

The graph of percentage removal efficiencies compared to electrolysis time (minutes) revealed the highest elimination, which occurred at 110 minutes. However, after reaching the electrolysis time beyond 110 minutes, the graph started to decrease. Thus, 110 minutes was determined as the optimal electrolysis time for the Al – St electrocoagulation process.

From the results obtained in this study, the percentage removal efficiencies of turbidity, color and suspended solids having the highest elimination of physical properties at the optimum parameter of current density is 27 A/m² pH of 8, and electrolysis time of 110 minutes, which at 90.3 % for turbidity, 88.12 % for color and 94.27% for Suspended Solids. Compared to Rubí-Juárez et al. [12], the removal efficiency of turbidity and colour is 96%, and suspended solid is 46% at pH 7 with a current density of 105 A/m², for 60 minutes. It shows that the turbidity and colour are enough to reach high removal when setting the optimum pH 7 and 8. However, for the suspended solid, maybe it needs more time or current density to achieve high removal efficiency. For electrolysis time, it requires almost 2 hours to get 94 % removal. Kobya et al. [13] have stated that the effluent pH increased as the initial pH increased to 8. The increase in pH could be attributed to the electrochemical reduction of water reduction at the cathode surface, resulting in higher concentrations of hydroxyl ion concentrations.

In addition to that, Atiyah & Abdul-Majeed [14] get the best result for the turbidity removal efficiency, which almost reaches 99.9 % at 90 minutes of electrolysis time at pH 7. Same as the previous literature with a pH of 7, but the electrolysis time is extended and gives a better result for the turbidity parameter. In addition to that, the maximum removal of turbidity removal in the El-Ashtoukhy et al. [15] article was observed at pH 8, an electrolysis time of 14 minutes with a current density of 117 A/m² current density. Its removal efficiency was 85%.

The comparison above has proved that most of the electrocoagulation process of car wash wastewater has removal efficiency of turbidity, colour, and suspended solid when the operating condition is set as pH 7 to 8. It means that treating the car wash wastewater using the electrocoagulation process needs a soft acidic condition. Moreover, no review of the literature provides an acidic pH condition of pH to treat car wash wastewater using the electrocoagulation process. This situation could be explained by the oxidation of hydroxyl ions oxidation at the anode [16]. Therefore, the highest current density could be the most removal, as higher operation costs were required for higher current densities. However, lower current densities should be preferred for an economically feasible process. Therefore, 10 A/m² to 30 A/m² were appropriate as the optimum current densities.

4. Conclusion

From this study, the highest result of removal efficiency for turbidity is 90.3%. However, for the following optimum parameter, which is color, its highest percentage removal is 88.12%. Then, for the optimum parameter of Suspended Solids, it can achieve up to 94.27%. All the highest removals have been achieved at the optimum conditions when pH is

8, the current density is 27 A/m^2, and the electrolysis time is adjusted at 110 minutes. From the results obtained, the car wash wastewater is quite good quality after being treated with the electrocoagulation process. The wide range of these experiments could provide evidence of electrocoagulation treatment. Therefore, the quality of the treated car wash wastewater could be improved and might be suitable for reuse in the washing process. In this study, the potential of the electrocoagulation method in treating car wash wastewater has been investigated and can be applied to future wastewater technology after optimization of the process was discovered. Moreover, to get a better result for further research, several suggestions can be employed, such as using a more flexible DC power supply to cover a more current scale. However, it will probably consume more cost to buy types of equipment, reduce the spacing between electrodes, and increase the total working area of electrodes to give more effect on the removal efficiencies.

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Appendix A: Initial Characteristics of Car Wash Wastewater

Table A - Initial characteristics of car wash wastewater

Characteristic \ Readings	9/2/2020	16/2/2020	24/2/2020	8/3/2020	Average
pH	8.06	10.13	9.73	9.48	9.35
Turbidity (NTU)	231	113	311	216	218
Colour (PtCo)	897	588	1273	808	897
Suspended solid (mg/L)	293	199	445	250	297
Chemical oxygen demand (mg/L)	390	388	407	No data	395

Appendix B: Raw Data of Optimisation Studies

Table B1 - Optimisation of current density for turbidity removal

Time taken (min)	Current density (A/m^2)	pH	Initial Reading	Turbidity (NTU)				Removal Efficiency %				SD
				R1	R2	R3	Average	R1	R2	R3	Average	
20	0	7.04	231	231	231	231	231.00	0.00%	0.00%	0.00%	0.00%	0.0000
20	27	7.04	231	108	107	106	107.00	53.25%	53.68%	54.11%	53.68%	0.0043
20	45	7.03	231	115	115	114	114.67	50.22%	50.22%	50.65%	50.36%	0.0025
20	64	7.05	231	154	153	152	153.00	33.33%	33.77%	34.20%	33.77%	0.0043
20	82	7.04	231	161	158	157	158.67	30.30%	31.60%	32.03%	31.31%	0.0090

Table B2 - Optimisation of current density for colour removal

Time taken (min)	Current density (A/m^2)	pH	Initial Reading	Colour (PtCo)				Removal Efficiency %				SD
				R1	R2	R3	Average	R1	R2	R3	Average	
20	0	7.04	896.67	896.67	896.67	896.67	896.67	0.00%	0.00%	0.00%	0.00%	0.0000
20	27	7.04	896.67	515	517	514	515.33	42.57%	42.34%	42.68%	42.53%	0.0017
20	45	7.03	896.67	531	532	529	530.67	40.78%	40.67%	41.00%	40.82%	0.0017
20	64	7.05	896.67	630	627	624	627	29.74%	30.07%	30.41%	30.07%	0.0033
20	82	7.04	896.67	683	675	676	678	23.83%	24.72%	24.61%	24.39%	0.0049

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)				Removal Efficiency %				SD
				R1	R2	R3	Average	R1	R2	R3	Average	
20	0	7.04	293	293	293	293	293.00	0.00%	0.00%	0.00%	0.00%	0.0000
20	27	7.04	293	124	122	123	123.00	57.68%	58.36%	58.02%	58.02%	0.0034
20	45	7.03	293	129	128	126	127.67	55.97%	56.31%	57.00%	56.43%	0.0052
20	64	7.05	293	147	148	146	147.00	49.83%	49.49%	50.17%	49.83%	0.0034
20	82	7.04	293	NA	168	166	167.00	NA	42.66%	43.34%	43.00%	0.0048

NA= Not available data

Table B4 - Optimisation of pH for turbidity removal

Time taken (min)	Current density (A/m^2)	pH	Initial Reading	Turbidity (NTU)				Removal Efficiency %				SD
				R1	R2	R3	Average	R1	R2	R3	Average	
20	27	7.03	231	108	107	106	107.00	53.25%	53.68%	54.11%	53.68%	0.0043
20	27	8.02	311.33	122	119	119	120.00	60.81%	61.78%	61.78%	61.46%	0.0056
20	27	9.01	112.67	101	100	99	100.00	10.36%	11.25%	12.13%	11.25%	0.0089
20	27	10.06	311.33	298	297	297	297.33	4.28%	4.60%	4.60%	4.50%	0.0019

Table B5 - Optimisation of pH for colour removal

Time taken (min)	Current density (A/m^2)	pH	Initial Reading	Colour (PtCo)				Removal Efficiency %				SD
				R1	R2	R3	Average	R1	R2	R3	Average	
20	27	7.03	896.67	515	517	514	515.33	42.57%	42.34%	42.68%	42.53%	0.002
20	27	8.02	1273.67	644	643	643	643.33	49.44%	49.52%	49.52%	49.49%	0.000
20	27	9.01	588.33	541	540	541	540.67	8.04%	8.21%	8.04%	8.10%	0.001
20	27	10.06	1273.67	1219	1217	1218	1218.00	4.29%	4.45%	4.37%	4.37%	0.001

Table B6 - Optimisation of pH for suspended solids removal

Time taken (min)	Current density (A/m^2)	pH	Initial Reading	Suspended Solids (mg/L)				Removal Efficiency %				SD
				R1	R2	R3	Average	R1	R2	R3	Average	
20	27	7.03	293	124	122	123	123.00	57.68%	58.36%	58.02%	58.02%	0.003
20	27	8.02	445.33	142	144	140	142.00	68.11%	67.66%	68.56%	68.11%	0.004
20	27	9.01	199.33	125	126	125	125.33	37.29%	36.79%	37.29%	37.12%	0.003
20	27	10.06	445.33	382	383	385	383.33	14.22%	14.00%	13.55%	13.92%	0.003

Table B7 - Optimisation of electrolysis time for turbidity removal

Time taken (min)	Current density (A/m^2)	pH	Initial Reading	Turbidity (NTU)				Removal Efficiency %				SD
				R1	R2	R3	Average	R1	R2	R3	Average	
10	27	8.03	311.33	277	278	263	272.667	11.03%	10.71%	15.52%	12.42%	0.027
20	27	8.07	311.33	251	252	252	251.667	19.38%	19.06%	19.06%	19.16%	0.002
30	27	8.02	311.33	252	246	241	246.333	19.06%	20.98%	22.59%	20.88%	0.018
40	27	8.07	311.33	213	211	213	212.333	31.58%	32.23%	31.58%	31.80%	0.004
50	27	8.00	311.33	182	180	179	180.333	41.54%	42.18%	42.50%	42.08%	0.005
60	27	8.03	311.33	180	179	179	179.333	42.18%	42.50%	42.50%	42.40%	0.002
70	27	8.03	311.33	158	155	158	157.000	49.25%	50.21%	49.25%	49.57%	0.006
80	27	8.01	311.33	109	110	110	109.667	64.99%	64.67%	64.67%	64.77%	0.002
90	27	8.01	216	29.45	28.95	28.65	29.017	86.37%	86.60%	86.74%	86.57%	0.002
100	27	8.01	216	27.1	26.14	25.84	26.360	87.45%	87.90%	88.04%	87.80%	0.003
110	27	8.01	216	21.3	20.81	20.72	20.943	90.14%	90.37%	90.41%	90.30%	0.001
120	27	8.05	216	25.21	24.53	24.48	24.740	88.33%	88.64%	88.67%	88.55%	0.002

Table B8 - Optimisation of electrolysis time for colour removal

Time taken (min)	Current density (A/m^2)	pH	Initial Reading	Colour (PtCo)				Removal Efficiency %				SD
				R1	R2	R3	Average	R1	R2	R3	Average	
10	27	8.03	1273.6	1171	1168	1166	1168.333	8.06%	8.29%	8.45%	8.27%	0.002
20	27	8.07	1273.6	1125	1129	1127	1127.000	11.67%	11.35%	11.51%	11.51%	0.002
30	27	8.02	1273.6	1093	1091	1090	1091.333	14.18%	14.34%	14.42%	14.31%	0.001
40	27	8.07	1273.6	981	981	978	980.000	22.97%	22.97%	23.21%	23.05%	0.001
50	27	8.00	1273.6	855	855	853	854.333	32.87%	32.87%	33.02%	32.92%	0.001
60	27	8.03	1273.6	856	851	853	853.333	32.79%	33.18%	33.02%	33.00%	0.002
70	27	8.03	1273.6	760	763	763	762.000	40.33%	40.09%	40.09%	40.17%	0.001
80	27	8.01	1273.6	604	607	602	604.333	52.58%	52.34%	52.73%	52.55%	0.002
90	27	8.01	808	129	132	129	130.000	84.03%	83.66%	84.03%	83.91%	0.002
100	27	8.01	808	125	123	123	123.667	84.53%	84.78%	84.78%	84.69%	0.001
110	27	8.01	808	96	96	96	96.000	88.12%	88.12%	88.12%	88.12%	0.000
120	27	8.05	808	107	106	105	106.000	86.76%	86.88%	87.00%	86.88%	0.001

Table B9 - Optimisation of electrolysis time for suspended solids removal

Time taken (min)	Current density (A/m^2)	pH	Initial Reading	Suspended Solids (mg/L)				Removal Efficiency %				SD
				R1	R2	R3	Average	R1	R2	R3	Average	
10	27	8.03	445.33	353	352	352	352.333	20.73%	20.96%	20.96%	20.88%	0.001
20	27	8.07	445.33	314	311	311	312.000	29.49%	30.16%	30.16%	29.94%	0.004
30	27	8.02	445.33	296	296	299	297.000	33.53%	33.53%	32.86%	33.31%	0.004
40	27	8.07	445.33	262	259	259	260.000	41.17%	41.84%	41.84%	41.62%	0.004
50	27	8	445.33	202	201	203	202.000	54.64%	54.86%	54.42%	54.64%	0.002
60	27	8.03	445.33	199	200	198	199.000	55.31%	55.09%	55.54%	55.31%	0.002
70	27	8.03	445.33	167	167	167	167.000	62.50%	62.50%	62.50%	62.50%	0.000
80	27	8.01	445.33	124	124	124	124.000	72.16%	72.16%	72.16%	72.16%	0.000
90	27	8.01	250.33	22	22	22	22.000	91.21%	91.21%	91.21%	91.21%	0.000
100	27	8.01	250.33	20	19	20	19.667	92.01%	92.41%	92.01%	92.14%	0.002
110	27	8.01	250.33	15	14	14	14.333	94.01%	94.41%	94.41%	94.27%	0.002
120	27	8.05	250.33	17	17	17	17.000	93.21%	93.21%	93.21%	93.21%	0.000

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