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Study on Ammonia and Suspended Solids Removal from Leachate using Aerated Electrocoagulation (Aluminium Electrodes) Under the Influence of Aeration Rate, Current Density and pH

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Abstract: This study was conducted to review the performance of aluminium electrodes in the aerated electrocoagulation process to remove chemical oxygen demand (COD), biochemical oxygen demand (BOD), colour, pH, suspended solids, turbidity and ammonia from Simpang Renggam Landfill under the influence of aeration rate, current density, and pH from previous studies. Through a reviewed study, the most effective range for the electrocoagulation process for optimisation of current density in removal ammonia was expected at a range between 30 A/m^2 to 600 A/m^2 which give the highest percentage of removal ammonia by using aerated electrocoagulation (AEC) process from range 19.8% up to 71.01%. For suspended solids it was expected at a range between 30 A/m^2 to 500 A/m^2 which give the highest percentage of removal suspended solids by using AEC process from range 25% to 96%. Then, the optimum pH for ammonia removal based on previous studies was expected to range from pH 5 to pH 9.6, giving the highest percentage of removal ammonia by the AEC process from 16.0% to 85.5%. Besides, the optimum pH for suspended solids was expected to range from pH 4 to pH 7, giving the highest percentage removal of suspended solids by the AEC process from 73% to 89%. Based on previous studies, the optimum aeration rate in removal ammonia was expected at a range from 0.25 L/min to 6 L/min with the percentage of removal ammonia using the AEC process at a range of 10% to 95.7%. This indicated that the aerated electrocoagulation treatment process would be able to reduce the level of pollutants in the waste.

Keywords: Leachate, Aerated Electrocoagulation, Ammonia, Suspended Solids

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1. Introduction

The municipal and industrial solid waste generation was increasing due to rapid industrial and economic progress worldwide. The processing of municipal solid waste resulted in a significant increase in industrial waste due to population growth, different technologies, the use of industrial and material use around the world [1]. In general, landfills are the place of solid waste disposal in Malaysia with economically satisfactory management. Garbage or trash, which comes from households, institutions, industry, agriculture, and sewerage producing non-hazardous waste, was known as Municipal Solid Waste (MSW). According to Zin [2], more sanitary landfills might be open due to the increment of solid waste, and landfill methods have the ability in terms of economic aspect and simple disposal.

Landfill leachate can be categorised as high-strength wastewater that can affect human health [3]. Furthermore, leachate generation from solid waste without appropriate storage facilities can cause soil and groundwater pollution [4]. Therefore, a healthy environment needs to control and minimise the removal of NH_3-N and suspended solids from its source or treatment plant. Nowadays, many treatment methods can be used to treat leachate. However, every treatment has its ability according to the leachate composition. According to Aziz et al. [5], the effectiveness of the leachate treatment method can be compromised due to the variation of leachate composition. Hence, proper treatment of industrial and municipal solid waste should be considered to protect the environment. According to Li et al. [6], various landfill leachate management methods include aerated electrocoagulation, electrocoagulation, the biological method, and aerobic treatment. In this study, the method used was an aerated electrocoagulation process. According to Li et al. [6], this method effectively removed contaminants that passed the electrical current through water. Electrocoagulation was an electrochemical process that uses electric current, allowing wastewater to oxidise electrochemically or reduce organic pollution of harmless inorganic matter. It was determined by the use of simple equipment, compatibility environment, and safety.

According to Kobya et al. [7], electrocoagulation was widely used as one of the best alternatives for leachate treatment. The purification of water and wastewater in the electrocoagulation process was a simple procedure requiring effective and efficient electrochemical. One of the important factors considered in the electrocoagulation method was the type of electrode used in the electrochemical process [8]. According to Harun et al. [8], aluminium electrodes were widely used as the main electrode in the electrocoagulation method because they were readily available and cheap. In this study, the purpose of this study was to characterise leachate from Simpang Renggam landfill (SRL) by measuring COD, BOD, colour, pH, suspended solids, turbidity and ammonia. Then, to review ammonia and suspended solids in leachate at Simpang Renggam landfill using aerated electrocoagulation (aluminium electrodes) under the influence of aeration rate, current density, and pH from previous research papers. The findings of this research gave information to society on how aerated electrocoagulation was one of the solutions in the treatment of leachate. Furthermore, this study helps students in civil engineering acquire knowledge, and it might be a reference for students and researchers conducting aerated electrocoagulation method research in the future.

2. Materials and Methods

2.1 Study Area

The leachate sample was obtained from SRL site. SRL site is located at Simpang Renggam, Kluang, Johor. According to Zaini et al. [9], SRL coordinates are 1°53'41 "N, 103°22'35 "E, as shown in Figure 1, while Figure 2 shows the view of the SRL site.

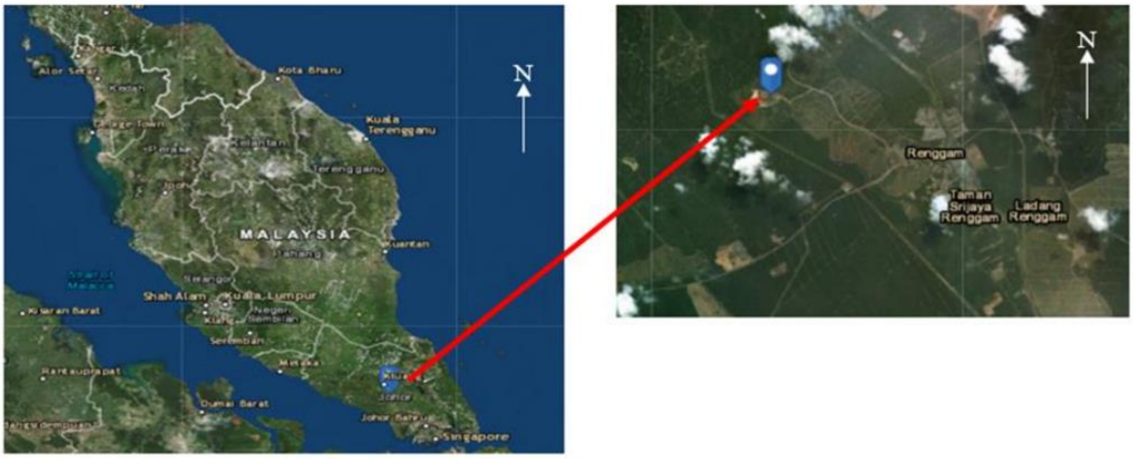

Figure 1: Location of Simpang Renggam Landfill Site (Source: Google Image)

Figure 2: View of Simpang Renggam Landfill Site (Source: Google Image)

2.2 Sampling

The grab sampling method was used in this study by referring to the American Public Health Association (APHA, 2008) Standard Method. High-density polyethylene (HDPE) containers were used to collect raw leachate samples from the SRL site, and the guideline of APHA (2008) Standard Method was used to analyse the procedure of all the experiments were conducted [10]. Table 1 shows the standard methods used to characterise leachate according to the APHA 2008 [10].

Table 1: Standard method in the characterisation of leachate

Parameter	Standard Method
pH	APHA Method: (4500-HB)
Color	HACH Method: 8025
BOD	Standard Method 5210(B)
COD	HACH Method: 8000
Turbidity	APHA Method: 2130
Ammonia	HACH Method: 8038
Suspended Solid	APHA Method: 2540D

2.3 Review Method

Research of various sources, such as Sci-Hub, Google Scholar, Science Direct, IOP Publishing, and Chemosphere, 91 papers related to electrocoagulation, aluminium electrodes, and leachate were reviewed. The previous study used the year range from 2008 to 2020 and the optimum value for the parameters of current density, pH, and aeration rate for removing ammonia and suspended materials in landfill leachate, allowing to meet the objectives of the study.

3. Results and Discussion

3.1 Leachate characteristics

Table 2 shows the characteristics of raw leachate from the SRL site. The parameters are pH, BOD_5, COD, turbidity, suspended solids, colour, and ammonia. Based on table 2, the concentration values for COD and BOD_5 show high concentrations at 996 mg/L and 83 mg/L, respectively. According to Baiju et al. [1], the obtained COD value is in the old leachate type because the value was less than <4,000 mg/L. According to a study by Rui [11], the leaching characteristic exceeds the maximum level, which the value of BOD_5 and COD concentration will begin to decrease or experience a rate of decline after two or three years of site age. Apart from that, the leachate characteristics were also influenced by the age of the landfill and the length of time the solid waste was disposed of. It can be proven because the SRL site aged more than 10 years.

Furthermore, Baiju et al. [1] stated that the content of leachate characteristics of young landfills has higher concentration rates for COD and BOD_5 and will experience a further decline at landfills over 10 years. Based on Table 2, the concentration values for suspended solids and ammonia show that the readings of the recorded values are 282 mg/L and 1,238.14 mg/L, respectively. According to Zailani [12], landfills produce leachates with high concentration rates in organic content and inorganic content, including heavy metals. According to Fatehah [13], it can be observed that the colour value was increasing by 3,710 (Pt-Co) from 3,500 (Pt-Co), and the turbidity value decreases by 55 NTU from 220 NTU. The increasing colour concentration was due to the solid waste itself comprising the debris and food waste [13].

Table 2: Characteristic of raw leachate from Simpang Renggam Landfill site

Parameter	Average
pH	8.6
Color (Pt-Co)	3710
BOD (mg/L)	83
COD (mg/L)	996
Turbidity (NTU)	55
Ammonia	1238.14
Suspended Solids (mg/L)	282

According to Zailani [12], the pH range recorded was 7.9 to 8.3. Based on Table 2, the pH value of raw leachate at SRL was 8.6. Therefore, this type of leachate was old leachate because, according to Baiju et al. [1], old leachate has a pH greater than 7.5. According to Rui [11], the concentration of heavy metals whose chemical properties change was influenced by the pH rate in the leachate at the landfill. Therefore, the aerated electrocoagulation process was appropriate for this type of leachate. It involves specific electrolytic reactions on electrode surfaces, forming aqueous coagulants, and the adsorption of soluble or colloidal contaminants on coagulants, which are then removed by sedimentation or flotation [14]. Furthermore, the purpose of the aeration process was to provide oxygen for leachate treatment, which may increase the consumption of dissolved oxygen and allocate components in the leachate to microorganisms, organic and inorganic elements [15]. Therefore, the selection of leachate treatment was important because it depends on the composition of the leachate. Aerated electrocoagulation treatment with aluminium electrodes can be one of the alternative treatments to treat leachate.

3.1.1 Optimisation of current density for ammonia removal

Figure 3 shows the findings from previous studies [12][16][17][18][19] to illustrate the percentage elimination of ammonia for determining the optimum current density using electrodes (Al/Al). Based on a previous study by Zailani [12], the experiment was conducted to determine the effectiveness of electrocoagulation by treating the samples with poly aluminium chloride and cassava flour. Zailani [12] study was reviewed because her study used electrocoagulation without aeration for landfill leachate samples. Thus, the current density studied by Zailani [12] can be used as a guideline in determining the expected range of current density in removing ammonia. By adding aeration to the electrocoagulation, the removal of ammonia is expected to be increased. According to Zailani [12], the optimum value of current density is 200 A/m^2, with the highest removal percentage value of ammonia being 9%. The reaction occurred after 30 minutes reaction with pH 5 as an initial pH. The sample used in this previous study was a leachate sample from SRL. According to Rusdianasari et al. [16], the highest NH_3-N content reduction in leachate was achieved in 60 minutes at 30 A/m^2 with a percentage removal of 57.92%. The levels of NH_3-N in the filtrate were 1.01 mg/L in this condition, compared to 2.4 mg/L in the preliminary analysis. According to Hamid et al. [17], the results of NH_3-N removal from leachate was 71.01%. Therefore, this study achieved the optimum current density at 600 A/m^2 with an electrolysis duration of 60 minutes and a pH of 8.20.

According to Zailani et al. [18], the highest ammonia removal was at 200 A/m^2, where ammonia removal efficiency was 37% at pH 4. On the other hand, according to Li et al. [19], the current density at 50 A/m^2 increases from 19.8 % to 32% for NH_3-N removal. Based on the study conducted by Li et al. [19], an electrocoagulation method stated that an increased current density gives the percentage of removals as much as 37% for ammonia nitrogen. From the results obtained in the study, all the samples were taken from landfill leachate, and it was found that the electrocoagulation treatment used for the removal of landfill leachate has a current density capability of up to 600 A/m^2. Therefore, it can be expected that the optimum current density was at the range between 30 A/m^2 to 600 A/m^2 which probably, gives better more than 19.8% removal of ammonia because of the addition of aeration in the system.

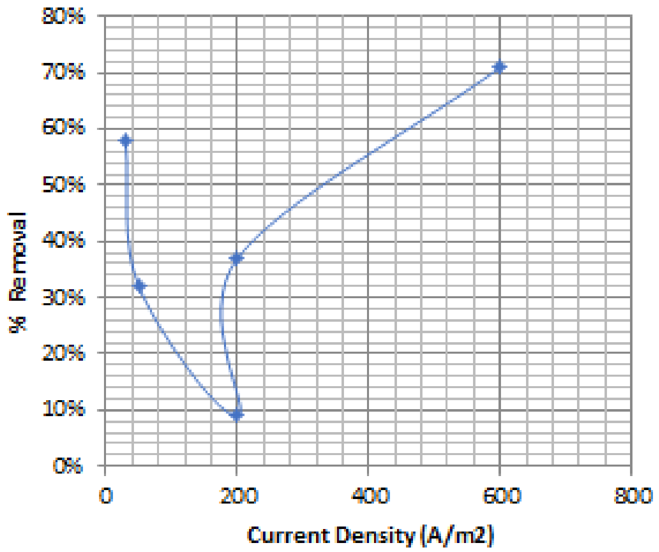

Figure 3: Percentage removal of ammonia by electrocoagulation [12][16][17][18][19]

3.1.2 Optimisation of current density for suspended solids removal

Figure 4 shows the findings from previous studies [12][16][18][20] to illustrate the percentage elimination of suspended solids for determining the optimum current density using electrodes (Al/Al). Based on a previous study by Zailani [18], this experiment was performed to determine the removal efficiency of electrocoagulation treatment by using an aluminium electrode for stabilised leachate. Zailani [18] study was chosen because it used similar electrodes in the leachate sample but without the addition of aeration. Therefore, it was expected that the current study would produce better results by using an aerated electrocoagulation process. According to Zailani [18], the increase in current density from 50 A/m^2 to 300 A/m^2 resulted in the increase of suspended solids from 25% to 81%. According to Zailani [18], current density was adjusted from 50, 100, 150, 200, 250 and 300 A/m^2. Therefore, this study shows optimum current density at 200 A/m^2 with the removal suspended solids at 87%. The sample used in this study was a leachate sample from SRL. According to Rusdianasari et al. [16], the best result in suspended solids deficiency was 60 minutes with a current density of 30 A/m^2. The initial suspended solids value of 112.6 mg/L decreasing to 59.9 mg/L with the percentage removal of 46.80%. Besides, the results of the study found that the highest removal percentage obtained for the electrode (Al/Al) was at the value of electric current density of 200 A/m^2 which the removal suspended achieved up to 90% [12]. According to Alena [20], the study obtained optimum current density at 450 A/m^2 with 96% removal of suspended solids and at the current density of 500 A/m^2, the suspended solids removal achieved 95%. Based on a study conducted by Nidheesh et al. [21], increasing the rate of current density will increase the effective rate of suspended solids removal. From the results obtained in the study, all the samples were taken from landfill leachate. It can be expected that the optimum current density was at the range between 30 A/m^2 to 500 A/m^2, which give the highest removal of suspended solids by using aerated electrocoagulation process, i.e., expected from range 25% to 96% or more.

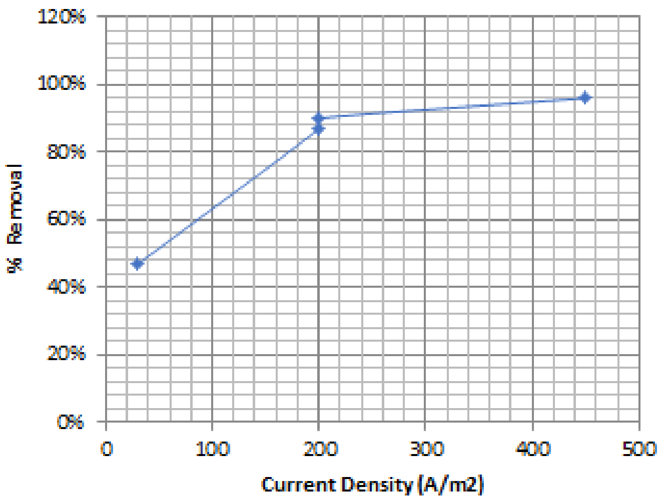

Figure 4: Percentage removal of suspended solids by electrocoagulation [12][16][18][20]

3.1.3 Optimisation of pH for ammonia removal

Figure 5 indicates the findings from previous studies [12][16][18][22][23] to illustrate the percentage removal of ammonia to determine the optimum pH using electrodes (Al/Al). According to Zailani [12], the pH value was set between the range of 3 to 9. In addition, a constant current density has been set at 200 A/m^2, with a reaction time of 20 min and a sedimentation time of 30 min. However, at pH 5, the highest removal percentage for ammonia, 16%, was recorded. The sample used in this study is a leachate sample from SRL. According to Rusdianasari et al. [16], the pH tended to rise, with the best results in the increase in pH of 8.5 occurring at a current density of 50 A/m^2 in 60 minutes, with a 20% of ammonia removal. According to Hamid et al. [17], the actual removal of ammonia was very close to the predicted result in the verification experiment, i.e., 71.01% and 72.51%, respectively, with an electrolysis time of 60 minutes and a pH of 8.20. According to Izadi et al. [22], pH 7 was selected as the optimum value with an ammonia removal rate of 85.5%. The initial pH of raw wastewater was 7.2 for Izadi et al. [22] study, indicating that no chemicals were required in the EC process. The removal efficiency of colour and total suspended solids has reduced at pH values greater than 10 because the dominant species in high pH solutions is $Al(OH)^-$, which does not coagulate the pollutants [21]. According to Ilhan et al. [23], the increase in value pH is highly dependent on the composition and influence of the activity occurring at the cathode. In addition, 6N

NaOH was used to improve the pH increase, and the pH was raised to 9.6. This method achieved a 24% ammonia removal efficiency in the first 30 minutes. From the results obtained in the study, the samples were taken from landfill leachate, and it can be expected that the optimum pH in ammonia removal was at range from pH 5 to pH 9.6. The highest ammonia removal using aerated electrocoagulation process was expected to range from 16.0% to 85.5% or more. This gives an excellent effect to be practised at the landfill in the future.

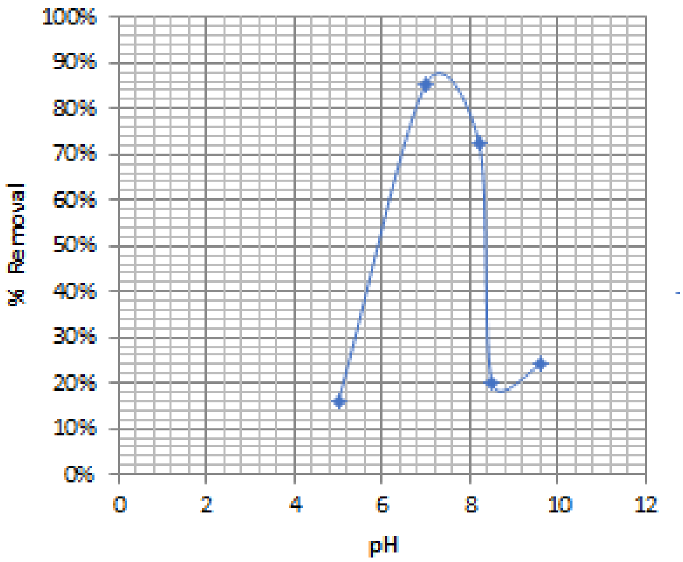

Figure 5: Percentage removal of ammonia by electrocoagulation [12][16][18][22][23]

3.1.4 Optimisation of pH for suspended solids removal

Figure 6 indicates the finding from previous studies [12][18][22][23] to illustrate the percentage removal of suspended solids to determine the optimum pH using electrodes (Al/Al). Based on Zailani [18] study, to identify the effects of pH in the treatment process, pH was adjusted from 3, 4, 5, 6, 7, 8, 9, 10, 11, and 12. According to Zailani [18], the removal efficiency of suspended solids at pH 4 is 73%. Zailani [12] stated that pH 5 has the highest removal percentage for the parameter of suspended solids at 8%. According to Izadi et al. [22], the removal efficiencies of total suspended solids were 83.4% at the optimum conditions of 10 V, initial pH of 7, and operating time of 60 minutes. In fact, according to the study of previous researchers of Hamid et al. [17], usually, the pH value will fluctuate during the aerated electrocoagulation process. By comparing to Ilhan et al. [23], pH toward acidic value give a better result, and it can be summarised that the best optimum pH value for the study was at pH 5. From the results obtained in the study, all of the samples were taken from landfill leachate. The optimum pH in removing suspended solids was expected in the range of pH 4 to 7, with the highest percentage of suspended solids removal using an aerated electrocoagulation process expected ranging from 73% to 89%, or more.

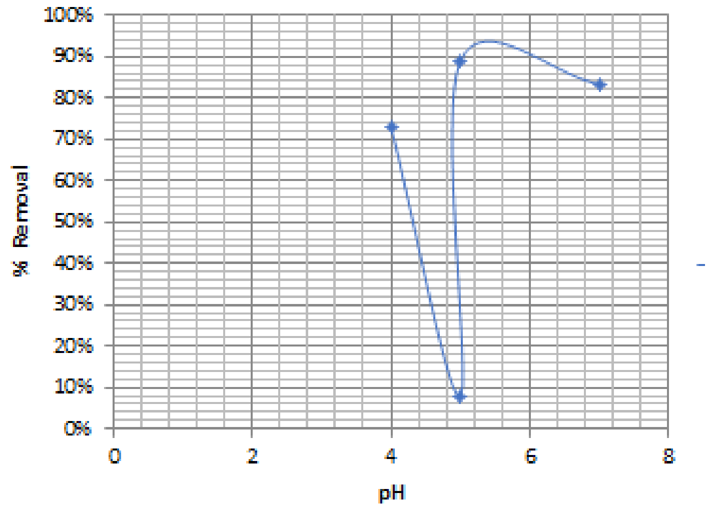

Figure 6: Percentage removal of suspended solids by electrocoagulation [12][18][22][23]

3.1.5 Optimisation of aeration rate for ammonia removal

The optimum aeration rate can be determined by the value of pH and current density at a constant parameter. According to Goren et al. [24], increasing the airflow rate will increase the removal efficiency. For example, the arsenic removal was 92.3% with the flow rate of 2 L/min while the flow rate of 6 L/min the efficiency was 95.7% [24]. The arsenic sample used in the study came from groundwater. According to Goren et al. [24], 0.25 L/min aeration was performed using an aquarium type porous material (with a pore size of 5 m) to study the effect of aeration on ammonia removal after EC treatment. After a one-hour settling period, the sludge volume was determined. According to Ilhan et al. [23], the presence of ammonia in the leachate was observed. A 10% to 15% reduction in ammonia was achieved depending on the current density and contact time. Although this seems to be a small amount, 250–350 mg/L of ammonia was removed to achieve this efficiency. A diffused aeration system with a 0.5 µm pore size and 1 L/min air flow rate was applied in this study to increase ammonia removal efficiency, resulting in the percentage of ammonia removal was 20% [23]. According to Wang et al. [25], the results of ammonia removal were 23.89%. The sample used was dyeing wastewater. Wang et al. [25] stated that the electric current used was between 0-20 A for 15 minutes, and the initial pH was around 6. The ammonia nitrogen removal rate was the highest at 12 minutes, with only a slight fluctuation in the subsequent reaction. Therefore, the optimum aeration rate in removal ammonia was expected to be between 0.25 L/min to 6 L/min with the percentage of ammonia removal using aerated electrocoagulation process at an expected range of 10% to 95.7%, or more.

3.1.6 Optimisation of aeration rate for suspended solids removal

Based on a previous study by Rusdianasari et al. [26], the experiment was performed to combine electrocoagulation and aeration process by NaCl for leachate treatment. This study was selected because it was used the same types of samples and the same method as the current study. Therefore, it was expected that the current study would produce better results by using an aerated electrocoagulation process. According to Rusdianasari et al. [26], the result of leachate analysis using an electrocoagulation method with a combination of aeration processes for suspended solids is 53 mg/L with a 65% efficiency when 1.5 g/L of NaCl is added. Based on the study, the higher the NaCl addition, the higher the efficiency in suspended solids removal with a combination of aeration rate processes. The wastewater pH ranges from pH 7.5-8, showing the wastewater still contains acidification [16]. The best leachate characteristics are found in a variation of the aeration process with the addition of 2.0 g/L NaCl, which results in suspended solids removal of 28 mg/L with an efficiency of 81.46% after treatment. This indicates that leachate quality after being processed by the aerated electrocoagulation method was below the environmental quality standard. The optimum aeration rate is not easy to be determined due to limited research from previous reports. According to

Kumar et al. [3], continuous aeration during the electrocoagulation process significantly improved COD removal efficiency. After 1 hour of electrolysis, the maximum COD removal efficiency of the electrocoagulation process performed without aeration was only 29%. At the same time, aeration improved its performance to 42%. The collision between ferric hydroxides and pollutants present in the wastewater contributes to the improved performance of the electrocoagulation process by continuous aeration [3]. Therefore, the higher the aeration rate in the aerated electrocoagulation process, the better the suspended solids removal efficiency.

4. Conclusion

The leachate sample was collected from Simpang Renggam Landfill (SRL), Johor, Malaysia, and samples were analysed to characterise leachate from SRL. It can be concluded that the characterisation of leachate at Simpang Renggam Landfill by measuring COD, BOD_5, colour, pH, suspended solids, turbidity, and ammonia was 996 mg/L, 83 mg/L, 3,710 (Pt-Co), pH 8.6, 282 mg/L, 55 NTU and 1,238.14 mg/L, respectively. Therefore, this type of leachate is classified as old leachate. The data was obtained from previous research papers for the optimum current density, pH, and aeration rate in this study. In this reviewed study, the optimum current density for ammonia removal using the aerated electrocoagulation process was expected to be between 30 A/m^2 to 600 A/m^2, while suspended solids removal was expected to be between 30 A/m^2 and 500 A/m^2. This resulted in the highest percentages of ammonia and suspended solids removal for optimum current density, ranging from 19.8% to 71.1% and 25% to 96%, respectively. Then, the optimum pH for ammonia removal was predicted to be in the range of pH 5 to 9.6, while the optimum pH for suspended solids removal was predicted to be in the range of pH 4 to 7. As a result of the aerated electrocoagulation process, the optimum pH for removing ammonia and suspended solids ranged from 16.0% to 85.5% and 73% to 89%, respectively. According to previous studies, the optimum aeration rate for ammonia removal was expected to be in the range of 0.25 L/min to 6 L/min, with a percentage of ammonia removal using the aerated electrocoagulation process from 10% to 95.7%. Since this method is easy to operate, low cost and no chemical used, this method can be implemented to treat leachate in the future.

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