Journal of Water Resources Management, Vol. 3 No. 2 (2025) p. 1-5

JOWRM

Journal of Water Resources Management

Journal homepage: https://journal.water.gov.my

e-ISSN: 2811-3578

Ammoniacal Nitrogen (AN) Degradation Via Coagulation Using Polyaluminum Chloride (PAC) for Matured Leachate

M.I.H.M Hazmee[2], N.S.M Zin[1,2*], N.A.N.A Rasid[2], L.W.M Zailani[2], M.F Rashim[3]

[1] Micropollutant Research Centre (MPRC), Institute for Integrated Engineering (I^2E), Universiti Tun Hussein Onn Malaysia (UTHM), 86400 Parit Raja, Batu Pahat, Johor, MALAYSIA

[2] Universiti Tun Hussein Onn Malaysia (UTHM), 86400 Parit Raja, Batu Pahat, Johor, MALAYSIA

[3] Worldwide Holdings Berhad, Mercu Worldwide, Persiaran Sukan Laman Seri Bussiness Park, Seksyen 13, 40100 Shah Alam, Selangor, MALAYSIA

*Corresponding Author

Email: nursha@uthm.edu.my

Received 04 March 2025; Accepted 21 Nov 2025; Available online 27 December 2025

Abstract: Coagulation-flocculation is a commonly used treatment in matured leachate (ML). This study aimed to remove ammoniacal nitrogen (AN) in ML from the Simpang Renggam Landfill Site (SRLS), Johor, by using Polyaluminum Chloride (PAC) as the coagulant. The performance of PAC was evaluated by optimizing the optimal dosage (500 – 4000 mg/L), pH (2 – 8), and settling time (10 – 60 min). The optimal conditions for coagulation-flocculation by using PAC were determined to be at the dosage of 2000 mg/L, pH 7, and a settling time of 20 minutes, achieving 29% AN removal. A Sludge Volume Index (SVI) test was conducted, resulting in 98.66 mL/g, which falls within the good range of SVI values (80-150 mL/g). Compliance with the regulations was not achieved under Malaysia's Environmental Quality Act (EQA) 1974 since the AN concentration for the coagulant remained above 5 mg/L. However, the findings demonstrated that PAC could potentially be effective as a primary mature leachate treatment, as it managed to remove 29% of AN. Thus, this study highlighted the relevance of this method in the treatment of matured leachate.

Keywords: Landfill, Wastewater, Ammoniacal Nitrogen, SVI, Polyaluminum Chloride

1. Introduction

The speedy rise in population and urbanization has led to waste management issues in many developing nations, such as Malaysia. Landfilling is the most popular waste disposal approach due to its low cost, but it contributes significantly to environmental contamination, particularly the release of ammoniacal nitrogen (AN) into water bodies [1]. Landfill leachate, a highly contaminated liquid created by decomposing trash and precipitation infiltration, has major implications for soil and groundwater quality [2]. This problem tends to be serious in matured leachate (ML), which contains significant levels of persistent contaminants that must be effectively treated [2].

Leachate properties vary according to dump age, with ML (from landfills beyond 10 years) showing decreased biodegradability and greater pollutant loading [3]. Traditional biological treatment approaches are frequently insufficient for ML due to the presence of refractory chemical components and high AN concentration [4]. Coagulation is commonly used for ML treatment because it effectively eliminates suspended particles, organic matter, and heavy metals. Polyaluminum Chloride (PAC), a pre-hydrolyzed coagulant, has shown more effective effects because it works efficiently in a larger pH range and forms more stable flocs, allowing for better pollutant removal [5][6]. Chemical coagulation with PAC has emerged as an effective approach for decreasing AN due to its low dosage, high removal efficiency, and low sludge generation [7].

Malaysia addresses substantial environmental issues because of poor landfill management and weak enforcement of waste disposal laws [8]. Open landfills, combined with heavy rainfall in tropical climates, contribute to excessive leachate production [8][9]. The presence of AN in leachate speeds up eutrophication in water bodies, impairs biological treatment processes, and generates harmful conditions for aquatic life [10]. Effective AN removal is critical to addressing these contaminants. Research has shown that regulating the pH between 7.6 and 8.3 throughout the coagulation phase can improve AN removal performance by up to 75% [11]. PAC has been recognized as a potential coagulant because of its capacity to minimize chemical oxygen demand (COD) and total suspended solids (TSS) while using a lower dosage [12][13].

Coagulation treatment with PAC consists of three important steps: rapid mixing, which ensures even coagulant

**Corresponding author: nursha@uthm.edu.my*

spread; slow mixing to encourage floc formation; and sedimentation, which lets pollutant-laden flocs settle [14]. This technique produces cleaner effluent with a much lower AN level. Furthermore, PAC produces less sludge than other coagulants, such as Alum, which reduces disposal costs and environmental concerns [15]. Considering the limitations of ML treatment, regular evaluation and optimization of coagulation parameters, such as dose, pH, and settling time, are required to maximize efficiency and maintain compliance with Malaysia's Environmental Quality Act (EQA) 1974.

This study attempted to optimize PAC dosage, pH, and settling time for successful AN removal while also evaluating the sludge volume index (SVI) for operational success. This research provides sustainable leachate treatment by enhancing coagulation performance, which benefits both the environment and public health.

2. Methodology

2.1 Leachate Sampling and Characterization

Leachate sampling was conducted at the Simpang Renggam Landfill Site (SRLS) in Johor, Malaysia, to assess the leachate treatment method. Sampling was carried out at a designated pond, as in Fig. 1, before chemical treatment, with samples taken from the effluent of the preliminary treatment pond. The process was repeated monthly for three months. On-site measurements of pH, temperature, and dissolved oxygen (DO) were recorded using calibrated instruments following APHA standard methods. A pH meter was calibrated with sodium hydroxide and sulphuric acid (APHA 4500), temperature was measured with a thermometer (APHA 2550), and DO levels were assessed using a DO meter. Collected leachate samples were transported to the Micropollutant Research Centre (MPRC) laboratory for further analysis.

Leachate characterization involves assessing physical and chemical properties to determine contaminant levels. The analysis followed the 2017 APHA standard methods for water and wastewater examination. AN concentration was determined using the Nessler reagent and HACH Method 8038. Chemical Oxygen Demand (COD) was analyzed using HACH Method 8000 with potassium dichromate, sulphuric acid, and a spectrophotometer (DR6000). Biochemical Oxygen Demand (BOD) was measured using HACH Method 8215, incorporating an incubator, BOD bottles, and nutrient buffer pillows. Suspended solids were quantified using a DR6000 spectrophotometer (APHA 2540). Turbidity was assessed with a turbidity meter (APHA 2130), and the Sludge Volume Index (SVI) was measured using a cylinder and stirrer (APHA 2710).

Additional analyses included salinity, conductivity, and color intensity. Salinity was measured using a salinity meter (APHA 2520), and conductivity was assessed with a conductivity meter and deionized water (APHA 2510). These procedures provided insights into the leachate composition, supporting the development of optimized treatment strategies.

Fig. 1 - Leachate sampling pond at SRLS

2.2 Treatment Optimization

The study optimized the coagulation-flocculation process for matured leachate treatment using PAC as the primary coagulant, which consists of varied and fixed operating parameters. The optimization parameters included pH, coagulant dosage, and settling time, which were determined through jar tests. The experimental procedure involved the varied operating parameters as in Table 1, which are pH (2.0 to 8.0), PAC dosage (500 to 4000 mg/L), and settling time (10 to 60 minutes) [16].

While the fixed operating parameters, jar tests followed a standard procedure as presented in Table 2: rapid mixing at 200 rpm for 4 minutes, followed by slow mixing at 30 rpm for 15 minutes, conducted at 20°C [16].

Table 1 - Varied operating parameters [16]

Parameter	Unit	Value
Coagulant dosage	mg/L	500 – 4000
pH	-	2.0 – 8.0
Settling time	Minutes	10 – 60

Table 2 - Fixed operating parameters [16]

Parameter	Unit	Value
Speed of rapid mixing	rpm	200
Speed of slow mixing	rpm	30
Duration of rapid mixing	Minutes	4
Duration of slow mixing	Minutes	15
Temperature	°C	20

2.3 SVI

SVI was used to analyze sludge formation and assess the success of the leachate treatment process [17]. The SVI produced by PAC is evaluated under this treatment. The optimal range of SVI value is within (80-150 mL/g) [18][19]. Thus, it indicates good settling ability.

The SVI method was carried out according to Feria-Díaz *et al*. [20]. Matured leachate samples were placed in 1.0 L beakers, 3 beakers that were treated by PAC with its optimum dose and optimum pH, as determined by 4000 mg/L PAC at pH 7 [16]. As the jar test neared completion, samples ranging from 20 ml to 30 ml were extracted directly from the beakers to measure their suspended solid (SS) value. These samples were then filtered through filter paper no. 40 to retain SS, followed by a 24-hour drying period in the oven to obtain the dried sample weight and determine SS in mg/L [16]. After the jar test was completed, the sample was poured into a 1.0 L cylinder without disrupting the formed flocs. The samples were left to settle for 30 minutes in the cylinder, after which the settled sludge volume (SSV) was measured to obtain the SSV value in ml/L. Thus, the SVI value could be calculated from the obtained SSV and SS values.

3. Result and Discussion

The laboratory findings on SRLS leachate parameters were thoroughly reviewed and analyzed. The conventional jar test was performed to fulfill the study's objectives. This method is conducted to assess the PAC's efficiency in removing AN from ML under optimal conditions.

3.1 Leachate Characteristic

Characterization was crucial to understanding its composition and concentration [21][22]. Six raw leachate samples were collected between March and May 2024 without dilution. The pH measured at 8.41 indicated old leachate, surpassing the 7.5 threshold. Similarly, the COD value of 1900 mg/L confirmed its classification as old leachate (<4000 mg/L) [23]. The BOD_5/COD ratio, essential for biodegradability assessment, was 0.02, further supporting this classification as old leachate [23]. Although the ammoniacal nitrogen concentration (466.78 mg/L) was lower than previous findings, it still indicated old leachate (>400 mg/L) [23]. These parameters collectively classified the leachate as old due to its high pH, low COD, low BOD_5/COD ratio and elevated ammoniacal nitrogen content. Additionally, temperature, TSS, color, turbidity, and BOD_5 levels exceeded the Malaysia Environmental Quality Act 1974 discharge limit, underlining the urgency of effective treatment methods [24]. Table 3 presents the results of the SRLS's leachate characterization parameters, emphasizing the need for immediate action to mitigate environmental risks.

Table 3 – Leachate characteristics from SRLS

Parameter	Unit	Result
Duration	Months	March-May 2024
pH	-	8.41 – 8.42
Ammoniacal Nitrogen	mg/L	461.96 – 472.61
COD	mg/L	1900 – 2000
Colour	ADMI	5400 – 5500
Turbidity	NTU	198 – 203
TSS	mg/L	170 – 180
Temperature	°C	23 – 31
BOD_5	mg/L	30 – 45
BOD_5/COD Ratio	-	0.01 – 0.02

3.2 PAC Optimization

Table 4, Fig. 2, 3, and 4 showed the optimal parameters for PAC treatment to achieve maximum AN removal, which were determined based on dosage concentration, pH, and settling time. The optimum PAC dosage was 2000 mg/L, achieving a 26% AN removal. Beyond this concentration, the removal efficiency declined, which is consistent with findings from previous studies where excessive coagulant dosages led to charge reversal and floc destabilization, ultimately reducing treatment efficiency [25]. The influence of pH on AN removal efficiency was significant, with pH 7 yielding the highest removal rate of 28%. This optimal pH aligns with other research indicating that a neutral pH facilitates the formation of larger, more stable flocs, enhancing contaminant removal [21][22]. Deviations from this neutral pH resulted in lower efficiencies, with pH 4 and 5 showing the least effectiveness at 14% and 12%, respectively, due to increased solubility of PAC and inefficient floc formation. Additionally, the optimal settling time was identified at 20 minutes, resulting in a 29% AN removal, with longer times leading to decreased efficiency due to particle re-suspension or floc densification [26] [27].

PAC performed better in terms of AN removal efficiency, dose needs, and compatibility with the SRLS's existing leachate pH. PAC had a greater AN removal effectiveness (29%) at neutral pH (7) and required a lower dosage (2000 mg/L) with a 20-minute settling time. This reduced the need for extensive chemical changes, making it a more cost-effective and practical approach for leachate treatment [27]. Although PAC treatment did not satisfy the EQA 1974 criteria (<5 mg/L AN removal) in the provided conditions, it still showed good AN removal efficiency (26-29%) than other treatment approaches [28][29]. PAC is the recommended coagulant for optimizing matured leachate treatment because of its ability to perform well at the leachate's natural pH, as well as its lower chemical consumption and operational expense.

Table 4 - Optimization of PAC under the influence of dosage, pH, and settling time for AN removal

Parameter	Value	AN removal (%)	Optimum AN removal (%)
PAC dosage (mg/L)	500	2	26 (2000 mg/L)
	1000	22	
	1500	22	
	2000	26	
	2500	23	
	3000	24	
	3500	23	
	4000	22	
pH	2	23	28 (pH 7)
	3	24	
	4	14	
	5	12	
	6	17	
	7	28	
	8	21	
Settling time (Min.)	10	18	29 (20 Min.)
	20	29	
	30	28	
	40	13	
	50	10	
	60	11	

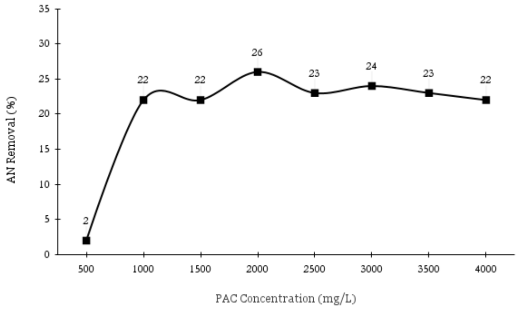

Fig. 2 – Optimum dose at 2000 mg/L and 26% AN removal

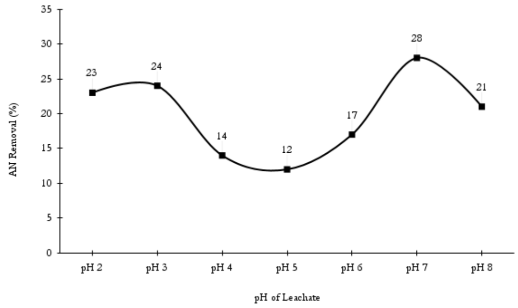

Fig. 3 – Optimum at pH 7 and 28% AN removal

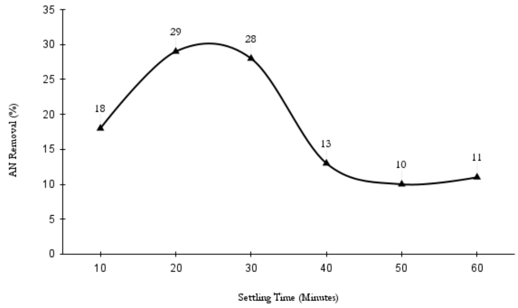

Fig. 4 – Optimum at settling time 20 Min. and 29% AN removal

3.3 Sludge Volume Index (SVI) by PAC

The obtained SVI value is shown in Table 5, with an average value of 98.66 mL/g, which falls within the optimal range (80–150 mL/g). This result indicates stable and adequate settling performance, aligned with findings from previous studies [30][31]. The slight variation in SVI value suggests a marginally higher settling volume, which remains within the acceptable limit for effective sludge settling.

Table 5 – SVI result produced by PAC

SVI	Unit	Average
97.40		
98.93	mL/g	98.66
99.67		

4. Conclusion

In conclusion, this study proved the ability of PAC to remove AN from ML. The experimental results showed that PAC had a high AN removal efficiency of 29%, confirming its effectiveness in treating ML. The SVI reading of 98.66 mL/g indicated that sludge settled well within the optimum range of SVI (80-150 mL/g). Despite the slightly higher SVI, PAC's greater AN removal efficiency and low pH adjustment requirements make it the preferred coagulant for leachate treatment. These findings give insight into the coagulation-flocculation process, perhaps leading to better leachate treatment methods and increased environmental protection.

Acknowledgment

This research was supported by the Ministry of Higher Education (MOHE) through the Fundamental Research Grant Scheme (FRGS/1/2023/WAB02/UTHM/02/3).

References

[1] Tey, J. S., Goh, K. C., & Ern Ang, P. S. (2017, October). Sustainable Impact of Landfill Siting Towards Urban Planning in Malaysia. *IOP Conference Series: Materials Science and Engineering, 245*, 052052. https://doi.org/10.1088/1757-899x/245/5/052052.

[2] Jaradat, A. Q., Telfah, D. B., & Ismail, R. (2021, November 12). Heavy metals removal from landfill leachate by coagulation/flocculation process combined with continuous adsorption using eggshell waste materials. *Water Science and Technology*, *84*(12), 3817–3832. https://doi.org/10.2166/wst.2021.493.

[3] Shamsudin, F., Moktar, A. M., & Abdullah, S. B. (2019, June 10). Managing solid waste using chloride-based ionic liquids. International Journal of Environmental Analytical Chemistry, 99(14), 1484–1493. https://doi.org/10.1080/03067319.2019.1625340.

[4] Nik Ab Rahim, N. N. R., Othman, J., Hanim Mohd Salleh, N., & Chamhuri, N. (2021, July 10). A Non-Market Valuation Approach to Environmental Cost-Benefit Analysis for Sanitary Landfill Project Appraisal. *Sustainability*, *13*(14), 7718. https://doi.org/10.3390/su13147718.

[5] Madon, I., Drev, D., & Likar, J. (2020). Long-term groundwater protection efficiency of different types of sanitary landfills: Model description. *MethodsX*, *7*, 100810. https://doi.org/10.1016/j.mex.2020.100810.

[6] Shaylinda, M. Z. N., Taruunen, R., Hazreek, Z. A. M., & Afnizan, W. M. W. (2019). Coagulation-flocculation of leachate by using single coagulant made from chemical coagulant (Polyaluminium Chloride) and natural coagulant (Tapioca Flour). *International Journal of Integrated Engineering*, *11*(6), 236–243. https://doi.org/10.30880/ijie.2019.11.06.025.

[7] Liu, S., Sinharoy, A., Lee, G. Y., Lee, M. J., Lee, B. C., & Chung, C. M. (2023, October 18). Synergistic Effects of Ionizing Radiation Process in the Integrated Coagulation–Sedimentation, Fenton Oxidation, and Biological Process for Treatment of Leachate Wastewater. *Catalysts, 13*(10), 1376. https://doi.org/10.3390/catal13101376.

[8] Abiriga, D., Vestgarden, L. S., & Klempe, H. (2020, October). Groundwater contamination from a municipal landfill: Effect of age, landfill closure, and season on groundwater chemistry. *Science of the Total*

Environment, *737*, 140307. https://doi.org/10.1016/j.scitotenv.2020.140307.

[9] Fellner, J., Döberl, G., & Brunner, P. H. (2019, June 27). Impacts of leachate flow conditions on the duration of the aftercare period. *Linnaeus Eco-Tech*, 295–305. https://doi.org/10.15626/eco-tech.2003.035.

[10] Akmal, T., & Jamil, F. (2021, March 3). Assessing Health Damages from Improper Disposal of Solid Waste in Metropolitan Islamabad–Rawalpindi, Pakistan. *Sustainability*, *13*(5), 2717. https://doi.org/10.3390/su13052717.

[11] Zeiss, C., & Uguccioni, M. (1997, May). for leachate generation. *Water Environment Research*, *69*(3), 276–285. https://doi.org/10.2175/106143097x125452.

[12] Johnson, M. B., & Mehrvar, M. (2021, December 24). Treatment of Actual Winery Wastewater by Fenton-like Process: Optimization to Improve Organic Removal, Reduce Inorganic Sludge Production and Enhance Co-Treatment at Municipal Wastewater Treatment Facilities. *Water*, *14*(1), 39. https://doi.org/10.3390/w14010039.

[13] Öman, C., & Junestedt, C. (2019, May 16). Assessing landfill leachate quality and leachate treatment efficiency using good sampling practices. *Linnaeus Eco-Tech*, 183–194. https://doi.org/10.15626/eco-tech.2003.020.

[14] Mihailovski, S., Mircovski, V., & Ilijovski, Z. (2021). Pollution with Cr6+ of groundwater and surface waters from the industrial dump Jugohrom - Jegunovce – Republic of North Macedonia. *Rudarsko-Geološko-Naftni Zbornik*, *36*(5), 121–129. https://doi.org/10.17794/rgn.2021.5.11.

[15] Iravanian, A., & Ravari, S. O. (2020, December 1). Types of Contamination in Landfills and Effects on The Environment: A Review Study. *IOP Conference Series: Earth and Environmental Science*, *614*(1), 012083. https://doi.org/10.1088/1755-1315/614/1/012083.

[16] Mohamad Zailani, L. W., & Zin, N. S. M. (2018, July). Characterization of Leachate at Simpang Renggam Landfill Site, Johor Malaysia. *Journal of Physics: Conference Series*, *1049*, 012040. https://doi.org/10.1088/1742-6596/1049/1/012040.

[17] Naji, L. A., Faisal, A. A., Rashid, H. M., Naushad, M., & Ahamad, T. (2020, May). Environmental remediation of synthetic leachate produced from sanitary landfills using low-cost composite sorbent. *Environmental Technology & Innovation*, *18*, 100680. https://doi.org/10.1016/j.eti.2020.100680.

[18] Azizan, M. O., Shaylinda, M. Z. N., Mohd-Salleh, S. N. A., Amdan, N. S. M., Yashni, G., Fitryaliah, M. S., & Afnizan, W. M. W. (2020, January 1). Treatment of leachate by coagulation-flocculation process using polyaluminum chloride (PAC) and tapioca starch (TS). *IOP Conference Series: Materials Science and Engineering*, *736*(2), 022029. https://doi.org/10.1088/1757-899x/736/2/022029.

[19] Kooch, Y., Nouraei, A., Haghverdi, K., Kolb, S., & Francaviglia, R. (2023, October). Landfill leachate has multiple negative impacts on soil health indicators in Hyrcanian forest, northern Iran. *Science of the Total Environment*, *896*, 166341. https://doi.org/10.1016/j.scitotenv.2023.166341.

[20] J. Jairo Feria-Díaz, J. Ramírez-Montoya, and G. Ballut-Dajut, "Comparison of the Sludge Volume Index (SVI) between a natural coagulant and aluminum sulfate," Artic. Int. J. ChemTech Res., vol. 10, no. 2, pp. 1037–1043, 2017, [Online]. Available: https://www.researchgate.net/publication/322061809.

[21] Bisht, T. S., Kumar, D., & Alappat, B. J. (2022, December). Revised leachate pollution index (r-LPI): A tool to quantify the contamination potential of landfill leachate. *Process Safety and Environmental Protection*, *168*, 1142–1154. https://doi.org/10.1016/j.psep.2022.10.052.

[22] Mihai, F. C., & Grozavu, A. (2019, December 2). Role of Waste Collection Efficiency in Providing a Cleaner Rural Environment. *Sustainability*, *11*(23), 6855. https://doi.org/10.3390/su11236855.

[23] Kamaruddin, M. A., Yusoff, M. S., Aziz, H. A., & Hung, Y. T. (2014, March 21). Sustainable treatment of landfill leachate. *Applied Water Science*, *5*(2), 113–126. https://doi.org/10.1007/s13201-014-0177-7.

[24] Wu, K. C., Yau, Y. H., & Sze, E. T. P. (2020, April). Application of anaerobic bacterial ammonification pretreatment to microalgal food waste leachate cultivation and biofuel production. *Marine Pollution Bulletin*, *153*, 111007. https://doi.org/10.1016/j.marpolbul.2020.111007.

[25] Haslina, H., NorRuwaida, J., Dewika, M., Rashid, M., Md Ali, A. H., Khairunnisa, M. P., & Afiq Daniel Azmi, M. (2021, February 1). Landfill Leachate Treatment Methods and Its Potential for Ammonia Removal and Recovery - A Review. *IOP Conference Series: Materials Science and Engineering*, *1051*(1), 012064. https://doi.org/10.1088/1757-899x/1051/1/012064.

[26] Zainun, M. Y., & Simarani, K. (2018, March). Metagenomics profiling for assessing microbial diversity in both active and closed landfills. *Science of the Total Environment*, *616–617*, 269–278. https://doi.org/10.1016/j.scitotenv.2017.10.266.

[27] Mohd-Salleh, S. N. A., Mohd-Zin, N. S., Othman, N., Gopalakrishnan, Y., & Abu-Bakar, N. (2021, July 31). Treatability of Manihot esculenta Peel Extract as Coagulant Aid for Stabilised Leachate. *Pertanika Journal of Science and Technology*, *29*(3). https://doi.org/10.47836/pjst.29.3.36.

[28] Anuar, N. K., Zin, N. S. M., Zailani, L. W., Salleh, S. N. A., & Akbar, N. A. (2022, May 1). Study on Ammonia and Colour Removal from Leachate via Aerated Electrocoagulation (Ferum and Aluminium Electrode). *IOP Conference Series: Earth and Environmental Science*, *1022*(1), 012067. https://doi.org/10.1088/1755-1315/1022/1/012067.

[29] Ahmad, A. L., Ismail, S., & Bhatia, S. (2005). Optimization of coagulation-flocculation process for palm oil mill effluent using response surface methodology. Journal of Environmental Science and Health, Part A, 40(1), 159-174.

[30] Wang, J., & Wang, S. (2019). Coagulation/flocculation process for dye removal using water treatment residuals: Modeling through artificial neural networks. Journal of Environmental Chemical Engineering, 7(4), 103223.

[31] Amuda, O. S., Amoo, I. A., & Ajayi, O. O. (2006). Performance optimization of some coagulation agents in the treatment of industrial wastewater. Journal of Hazardous Materials, 129(1-3), 92-97.