Journal of Emerging Technologies and Industrial Applications
Vol. 4 No. 1 (2025) pp. 1-8
e-ISSN: 2948-507X

Journal homepage: https://jetia.mbot.org.my/index.php/jetia/index

Performance Evaluation and Optimization of a Single-Tank Anaerobic/Anoxic/Oxic Membrane Bioreactor for Landfill Leachate Treatment

Ya Mohammad Nazir Syah Ismail[1,2], New Bei Qi [1], Norzita Ngadi[1], Muhammad Arif Ab Aziz[1*], Mohamed Hizam Mohamed Noor[1], Nurul Balqis Mohamed[1], Fatin Amirah Razmi[1], Mahadhir Mohamed[1]

[1]Department of Chemical Engineering, Faculty of Chemical and Energy Engineering, Universiti Teknologi Malaysia, 81310 Skudai, Johor, MALAYSIA

[2]Environment Institute of Malaysia (EiMAS), Department of Environment, Kampus Universiti Kebangsaan Malaysia, 43600 UKM, Bangi, Selangor Darul Ehsan, MALAYSIA

Email: [a]mnazir@doe.gov.my, [b]m.arif@utm.my

Abstract: Landfill leachate, characterised by high levels of COD, BOD_5, NH_3-N, TSS, and colour, poses significant environmental risks and requires stringent treatment to comply with discharge regulations. This study evaluates the performance of a prototype single-tank anaerobic/anoxic/oxic membrane bioreactor (A2O-MBR) for landfill leachate treatment, focusing on the effects of hydraulic retention time (HRT) and dissolved oxygen (DO) levels. The A2O-MBR, integrating biological and membrane filtration processes within a compact configuration, was assessed under varying HRTs (12, 15, 18 hours) and DO levels (2.6, 3.1, 3.5 mg/L). Effluent parameters were analysed for COD, BOD_5, NH_3-N, TSS, and colour, and compared against Malaysian regulatory standards. Results revealed that an HRT of 15 hours and a DO level of 3.1 mg/L provided optimum performance, achieving COD and BOD_5 removal efficiencies exceeding 90%, while TSS consistently met discharge standards. NH_3-N removal was moderate, with the lowest effluent concentration of 430 mg/L observed at DO 3.5 mg/L. However, colour removal remained limited, highlighting the persistence of refractory compounds. The findings underscore the critical role of optimising HRT and DO to balance microbial activity and pollutant removal efficiency. Notably, prolonged HRTs showed diminishing returns on performance improvement and increased operational costs. This study demonstrates the feasibility of a single-tank A2O-MBR for cost-effective leachate treatment, with potential enhancements through advanced oxidation or adsorption for improved ammonia and colour removal. The insights provided contribute to the design and optimisation of sustainable leachate management systems.

Received 10 February 2025; Accepted 20 May 2025; Available online 30 June 2025

Keywords: Landfill leachate, Anaerobic/anoxic/oxic membrane bioreactor, Hydraulic retention time, Dissolved oxygen, Pollutant removal efficiency, Advanced treatment processes

*Corresponding Author:

Muhammad Arif Ab Aziz,
Department of Chemical Engineering,
Faculty of Chemical and Energy Engineering,
Universiti Teknologi Malaysia, 81310 Skudai, Johor, MALAYSIA
Email: m.arif@utm.my

1. Introduction

Landfill leachate is a by-product of the decomposition of solid waste and the percolation of water through landfill material. This highly polluted liquid typically contains a complex mixture of organic and inorganic matter, ammoniacal nitrogen (NH_3–N), heavy metals, colour-causing compounds, and other contaminants [1],[2]. Its composition varies based on factors such as landfill age, waste composition, and weather conditions [3]–[5] Generally, leachate exhibits high chemical oxygen demand (COD), biochemical oxygen demand (BOD), total suspended solids (TSS), and extreme pH levels, making it one of the most challenging forms of wastewater to treat [6]. If improperly managed, leachate can pollute surface and groundwater, leading to reduced dissolved oxygen levels, harm to aquatic life, and risks to human health through waterborne toxic substances [1],[2],[4],[6] To mitigate these impacts, stringent discharge regulations such as the Malaysian Environmental Quality (Control of Pollution from Solid Waste Transfer Station and Landfill) Regulations (PU(A) 433/2009) enforce strict compliance for leachate treatment before disposal [7].

Conventional methods for leachate treatment, including activated sludge systems and multi-tank membrane bioreactors (MBRs), have shown varying degrees of success in removing pollutants. MBRs combine biological treatment with membrane filtration, achieving superior effluent quality and higher pollutant removal rates than traditional systems [2]. However, multi-tank configurations require significant capital investment, operational expenditure, and spatial resources, making them less feasible for many applications. These challenges have driven interest in single-tank anaerobic/anoxic/oxic membrane bioreactor (A2O-MBR) systems, which integrate anaerobic, anoxic, and aerobic processes into a single unit [8]. By eliminating the need for separate tanks, this design reduces infrastructure costs, operational complexity, and space requirements while maintaining treatment efficiency, positioning it as a promising alternative for leachate management.

Despite these advantages, single-tank A2O-MBR systems require careful optimization of operational parameters to achieve maximum efficiency [1],[9] Hydraulic retention time (HRT) and dissolved oxygen (DO) levels are key factors influencing the biological and physical processes in the reactor. HRT governs the interaction time between pollutants and microorganisms, affecting the extent of organic matter degradation and ammonia removal. Meanwhile, DO levels directly impact microbial respiration and the effectiveness of aerobic and anoxic zones. Low DO levels can limit aerobic degradation, while excessive DO can disrupt anoxic processes such as denitrification, leading to reduced ammonia removal efficiency. Optimizing these parameters is crucial for achieving compliance with stringent discharge standards while maintaining cost-effectiveness.

This study evaluates the performance of a single-tank A2O-MBR system for treating landfill leachate from the Seelong sanitary landfill in Johor, Malaysia. The primary objectives include assessing the feasibility of integrating anaerobic, anoxic, and aerobic zones within a single reactor, determining the optimal microbial concentration, and investigating the effects of varying HRT and DO levels on treatment efficiency. By systematically analysing these factors, the study seeks to address current limitations in leachate treatment technologies. The findings are expected to provide valuable insights into the design and operation of cost-effective, compact, and high-performance systems for landfill leachate management, contributing to sustainable environmental practices.

2. Methodology

This study employed a prototype-scale single-tank A2O-MBR with a total capacity of 1000 L to treat leachate from the Seelong sanitary landfill. The reactor comprised three zones: anaerobic (250 L), anoxic (250 L), and aerobic (500 L), operating in sequence from the bottom to the top. High-density polyethylene hollow fiber membranes with a pore size of 0.4 μm and a flux of 0.6 m^3/m^2/day were used for filtration. Aeration was supplied by a ring blower and three air pumps with flow rates of 900 L/min and 125 L/min. Effluent was pumped using a peristaltic pump.

The system was seeded using cow manure to promote rapid biomass growth, following established protocols. The seeding process was monitored over 14 days to ensure the establishment of a stable microbial community. Key parameters, including mixed liquor suspended solids (MLSS), mixed liquor volatile suspended solids (MLVSS), MLVSS/MLSS ratio, dissolved oxygen (DO), pH, and temperature, were recorded daily. The growth rate constant (μ) was calculated during the seeding process using the following equation [10]:

$$\mu = \frac{\Delta X}{\Delta t}$$

Where μ is the growth rate constant (mg/L.day), X is concentration of biomass, MLVSS, (mg/L) and t is time (day). This specific growth rate constant was used to evaluate the microbial biomass development and ensure the reactor's readiness for leachate treatment.

Hydraulic retention time (HRT) was adjusted to 12, 15, and 18 hours by varying inlet flow rates using a ball valve. After determining the optimal HRT, DO levels in the aerobic zone were varied between 2.5, 3.0, and 3.5 mg/L by regulating airflow to assess its impact on treatment efficiency. Effluent was analysed and compared against the discharge limits set by Malaysian Environmental Quality (Control of Pollution from Solid Waste Transfer Station and Landfill) Regulations (PU(A) 433/2009).

The choice of the A2O-MBR system was justified by its ability to integrate biological and membrane filtration processes within a single tank, reducing capital and operational costs compared to conventional multi-tank systems. The sequential anaerobic, anoxic, and aerobic processes ensured efficient removal of organic and inorganic pollutants, while the membrane filtration provided superior effluent quality. This configuration also minimised space requirements and energy consumption, addressing common limitations of traditional leachate treatment methods.

Published by MBOT Publishing
https://jetia.mbot.org.my/index.php/jetia/index

3. Results and Discussions

3.1 Study of Microorganism Growth Rate

Fig. 1 shows the variation of MLSS, MLVSS, and DO levels during the seeding process in the single-tank A2O-MBR system. The MLSS and MLVSS increased steadily from Day 1 to Day 10, peaking at 13,307 mg/L and 10,240 mg/L, respectively. However, the data indicates that the optimum biomass growth occurred when DO levels were approximately 2.0 mg/L, reflecting MLSS and MLVSS values of approximately 6,300 mg/L and 4,700 mg/L, respectively. These conditions represent the balance between sufficient oxygen availability and active biomass growth. The initial increase in MLSS and MLVSS up to Day 10 can be attributed to the favourable conditions during the seeding process, including adequate substrate and DO levels. The drop in DO to below 2 mg/L by Day 10 led to oxygen limitations, resulting in slower microbial activity and subsequent biomass decline by Day 14. This finding underscores the importance of maintaining DO above 2 mg/L to ensure effective microbial respiration and organic matter removal, as indicated by past studies [6],[10]–[12]. The identified optimum MLSS and MLVSS values at approximately 6,300 mg/L and 4,700 mg/L, respectively, will serve as target concentrations for subsequent experiments. Maintaining these values during the operational phase is critical for achieving consistent pollutant removal efficiency in the reactor.

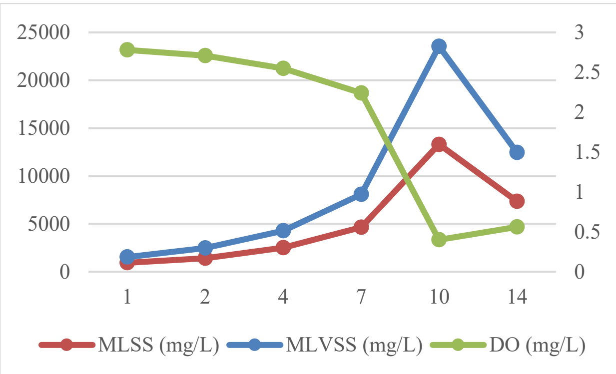

Fig. 1 - Variation of MLSS, MLVSS, and DO during the seeding process in the single-tank A2O-MBR system.

Fig. 2 illustrates the MLVSS/MLSS ratio over the seeding period, highlighting the proportion of active biomass relative to the total biomass. The ratio remained relatively stable, ranging between 0.63 and 0.77, with a peak value observed on Day 10. This indicates a consistent and healthy microbial community during the exponential growth phase of the seeding process. A slight decline in the ratio on Day 14 suggests the onset of biomass decay or a shift in microbial viability, corresponding to observed reductions in MLSS and MLVSS. The stable ratio during Days 1–10 reflects favourable environmental conditions, such as adequate substrate availability and sufficient DO levels, supporting active biomass growth. The decline on Day 14 can be attributed to substrate depletion and reduced oxygen levels during the earlier phase, leading to endogenous respiration and an accumulation of inert biomass. Maintaining this ratio close to the peak value is critical for optimising the microbial activity required for effective pollutant removal. Similar trends have been observed in studies by previous studies who reported that a stable MLVSS/MLSS ratio indicates optimal microbial health and reactor acclimatisation in aerobic systems [11],[13],[14] Additionally, Xu et al. [15] highlighted the role of DO levels in sustaining active biomass, with declines in DO resulting in reduced microbial viability, as seen in this study. The stability of the MLVSS/MLSS ratio up to Day 10 demonstrates the robustness of the seeding process under controlled conditions.

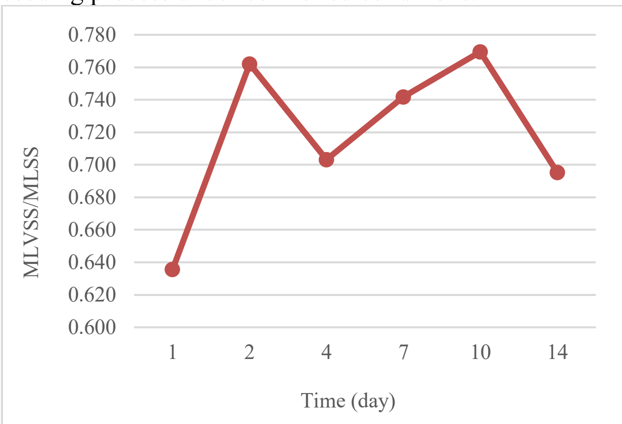

Fig. 2 - MLVSS/MLVSS over time during the seeding process in the single-tank A2O-MBR system.

Fig. 3 depicts the growth rate constant (μ) during the seeding period, providing insights into the dynamics of microbial proliferation. The growth rate increased steadily, peaking at 2268 mg/L.day on Day 10, which corresponds to the maximum biomass productivity observed in MLSS and MLVSS trends. After Day 10, the growth rate turned negative, reaching −1282 mg/L.day on Day 14, reflecting biomass decay. The peak growth rate on Day 10 indicates that substrate availability, DO levels above 2 mg/L, and stable environmental conditions supported optimal microbial growth. The negative growth rate on Day 14 suggests that oxygen limitations and substrate exhaustion during the earlier phases led to reduced microbial activity and biomass decay. This decline emphasises the importance of timely nutrient supplementation and maintaining adequate oxygen supply to sustain biomass productivity. Similar findings are supported by previous study, who found that peak microbial growth in bioreactors occurred under well-regulated aeration and nutrient availability, with growth rates declining when resources became limiting [16]. Additionally, previous study emphasised the importance of maintaining positive growth rates to ensure consistent biomass productivity and reactor stability [11]. These findings underline the need for operational strategies to mitigate resource depletion, ensuring long-term system efficiency.

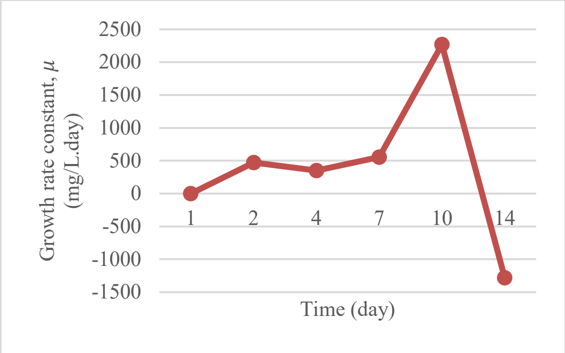

Fig. 3 - Growth rate constant, μ (mg/L.day) over time during the seeding process in the single-tank A2O-MBR system.

3.2 Optimization of HRT

Fig. 4 shows the removal efficiency of COD, BOD_5, NH_3-N, TSS, and Colour across three hydraulic retention times (HRT12, HRT15, and HRT18). COD and BOD_5 removal efficiencies were consistently high, exceeding 85% for all HRTs and improving slightly with longer HRTs. NH_3-N removal showed moderate efficiencies, with the highest removal at HRT18 (67.27%). The experiments were conducted by operating parameters as shown in Table 1. TSS removal was excellent, maintaining efficiencies above 93% across all HRTs. However, Colour removal efficiencies were the lowest, ranging from 22.61% at HRT12 to 32.80% at HRT18, indicating limited treatment for colour-related pollutants. The high removal efficiencies for COD and BOD_5 can be attributed to effective microbial degradation of organic matter, enhanced by longer HRTs, which allow more contact time for biochemical reactions [17]. TSS removal reflects efficient settling and filtration within the system. NH_3-N removal improved with longer HRTs, likely due to enhanced nitrification processes that require time for microbial conversion of ammonia to nitrate [18],[19] The low efficiency in Colour removal can be linked to the persistence of dye compounds, which are less biodegradable and often require advanced oxidation processes for effective treatment. These trends align with findings by previous study, who observed that increasing HRT enhances biological treatment performance for organic and particulate pollutants [17],[20].

Table 1 - Operating parameters of the single-tank A2O-MBR system grouped by hydraulic retention time (HRT) at 12, 15, and 18 hours.

HRT (hours)	Volume of Aeration Zone (L)	Inlet Flow Rate (mL/s)	Inlet Flow Rate (L/day)	MLSS (mg/L)	MLVSS (mg/L)	F/M Ratio	DO Level of Aeration Zone (mg/L)	DO Level of Anaerobic Zone (mg/L)
12 (HRT12)	400	9.26	800	5807	4297	0.072	3.1	0.9
15 (HRT15)	400	7.41	640	5931	4626	0.067	3.2	1
18 (HRT18)	400	6.17	533.33	5321	3892	0.065	2.9	0.7

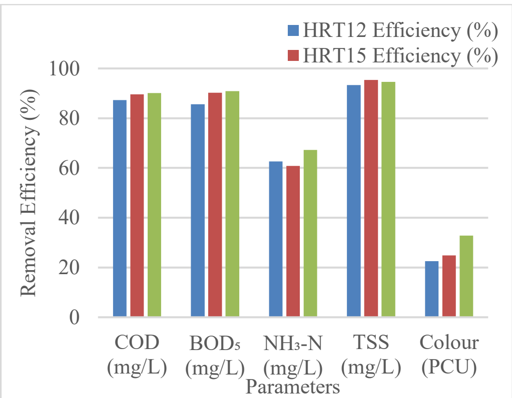

Fig. 4 - Removal efficiency of COD, BOD_5, NH_3-N, TSS, and colour across different hydraulic retention times (HRT12, HRT15, and HRT18).

Table 2 compares the influent and effluent concentrations of COD, BOD_5, NH_3-N, TSS, and Colour for HRT12, HRT15, and HRT18, along with regulatory standards. Effluent concentrations of COD, BOD_5, and TSS decreased significantly with increasing HRT. COD concentrations dropped from 1,170 mg/L at HRT12 to 845 mg/L at HRT18 but remained above the regulatory standard of 400 mg/L. BOD_5 concentrations were reduced below the standard of 50 mg/L for all HRTs, with the lowest concentration observed at HRT18 (17.1 mg/L). NH_3-N concentrations showed moderate reductions, with HRT15 achieving the lowest concentration (432 mg/L). TSS consistently met the standard of 50 mg/L, while colour in the effluent remained high across all HRTs. The observed reductions in COD and BOD_5 are attributed to effective microbial degradation of organic matter, enhanced by the increased retention time. TSS compliance with standards reflects the system's ability to effectively settle and capture suspended solids. NH_3-N reduction was moderate, as ammonia removal requires sufficient oxygen and

Published by MBOT Publishing
https://jetia.mbot.org.my/index.php/jetia/index

microbial activity, which might have been limited during the treatment process. The limited reduction in colour likely results from the persistence of complex organic compounds and dye molecules resistant to biological degradation [21],[22].

Studies on membrane bioreactors (MBRs) have consistently demonstrated high removal efficiencies for organic matter and suspended solids, but challenges remain in effectively removing ammonia and colour without additional treatment. For instance, Jagaba et al. (2021) reported COD removal efficiencies of 90% to 95% with increasing HRTs in an MBR treating oily wastewater, while ammonia removal remained less effective due to the need for further nitrification processes [22]. Similarly, Gao et al. (2022) observed that longer retention times in MBRs enhanced organic pollutant degradation, but ammonia and colour removal required supplementary methods [23]. Furthermore, Nguyen et al. (2021) noted limited Colour removal in sponge-submerged anaerobic reactors, emphasizing the persistence of non-biodegradable compounds [24]. To achieve better compliance with regulatory standards, particularly for ammonia and colour, integrating advanced treatment methods such as chemical oxidation, adsorption, or hybrid processes may be necessary. Dubey et al. (2021) demonstrated that electro-peroxone processes effectively enhanced colour and ammonia removal, with up to 91.3% efficiency for dyes and COD reductions below regulatory standards [25]. Similarly, Rathorea et al. (2021) highlighted the potential of chemical coagulation to improve TSS and colour reductions in textile wastewater [26]. These findings underscore the limitations of biological treatment systems in addressing certain persistent pollutants and highlight the effectiveness of supplementary treatments in improving overall effluent quality. Combining biological processes with advanced treatment methods may offer a robust solution for achieving compliance with stringent environmental standards.

To achieve better compliance with regulatory standards, especially for ammonia and colour, integrating advanced treatment methods such as chemical oxidation or adsorption could be beneficial. The longer the HRT, the more sufficient the time for microorganisms to decompose biodegradable organic matter. However, excessively high HRT may lead to larger capacity MBR systems and potentially cause microorganisms to enter the endogenous respiration phase. Additionally, increasing HRT has limited impact on colour removal, making it challenging to meet the effluent discharge limits. Based on Fig. 4, an HRT of 15 hours demonstrated higher treatment performance compared to 12 hours and comparable performance to 18 hours. Considering the balance between treatment efficiency and capital and operational costs, 15 hours is identified as the optimum HRT for proceeding with subsequent experiments.

Table 2 - Comparison of influent and effluent concentrations for COD, BOD_5, NH_3-N, TSS, colour, and pH across different hydraulic retention times (HRT12, HRT15, and HRT18) with corresponding regulatory standards.

Parameters	Influent	HRT12 Effluent	HRT15 Effluent	HRT18 Effluent	Standard
COD (mg/L)	9230	1170	970	845	400
BOD_5 (mg/L)	153.65	22	18.9	17.1	50
NH_3-N (mg/L)	1396	521	432	576	10
TSS (mg/L)	234.3	15.6	19	21.45	50
Colour (PCU)	11500	8900	11200	8400	-
pH	10.97	8.26	8.83	8.43	6–9

3.3 **Optimization of DO**

Fig. 5 illustrates the removal efficiencies of COD, BOD_5, NH_3-N, TSS, and colour under different dissolved oxygen (DO) levels (2.6, 3.1, and 3.5 mg/L), corresponding to the operating parameters outlined in Table 3. COD and BOD_5 removal efficiencies remained consistently high across all DO levels, exceeding 85%, indicating that aerobic conditions were sufficient for organic matter degradation. TSS removal was also highly efficient (>90%), reflecting effective solids separation in the system. NH_3-N removal was optimal at DO 3.5 mg/L, achieving the highest efficiency of 70.78%, suggesting enhanced nitrification due to sufficient oxygen availability. However, colour removal showed limited improvement, with efficiencies ranging from 21.57% at DO 2.6 mg/L to 24.96% at DO 3.5 mg/L, indicating the persistence of colour-causing compounds that require advanced treatment. These findings highlight the critical role of DO in optimising microbial activity, particularly for nitrogen removal, as nitrifying bacteria are oxygen-sensitive. While increasing DO levels improved NH_3-N removal, the marginal benefits observed at DO 3.5 mg/L suggest diminishing returns and potential cost inefficiencies. Studies by previous studies have similarly demonstrated that moderate DO levels optimise organic and nitrogen removal while minimising energy consumption [11],[12],[27]. The limited impact on colour removal aligns with previous research that highlights the resistance of dye compounds to biological degradation. This indicates a need for supplementary processes, such as advanced oxidation, to address colour-related pollutants effectively.

Published by MBOT Publishing
https://jetia.mbot.org.my/index.php/jetia/index

Table 3 - Operating parameters of the single-tank A2O-MBR system grouped by dissolved oxygen (DO) at 2.6, 3.1, and 3.5 mg/L.

DO Level	Volume of Aeration Zone (L)	HRT (hours)	Inlet Flow Rate (mL/s)	Inlet Flow Rate (L/day)	MLSS (mg/L)	MLVSS (mg/L)	F/M Ratio	DO Level of Anaerobic Zone (mg/L)
2.6 mg/L (DO2.6)	400	15	7.41	640	5579	3960	0.075	0.6
3.1 mg/L (DO3.1)	400	15	7.41	640	6001	4294	0.061	0.8
3.5 mg/L (DO3.5)	400	15	7.41	640	5537	4473	0.065	1.2

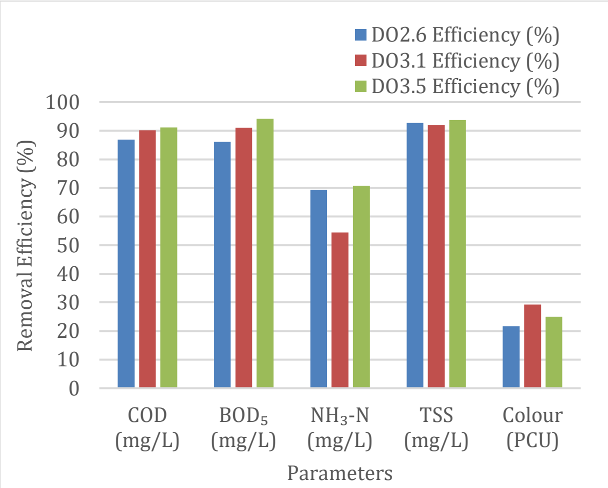

Fig. 5 - Removal efficiency of COD, BOD₅, NH₃-N, TSS, and colour across different dissolved oxygen (DO2.6, DO3.1, and DO3.5).

Table 4 compares influent and effluent concentrations of COD, BOD_5, NH_3-N, TSS, colour, and pH across different dissolved oxygen (DO) levels (DO2.6, DO3.1, and DO3.5), alongside regulatory standards. COD concentrations in the effluent consistently decreased with higher DO levels, from 818 mg/L at DO2.6 to 550 mg/L at DO3.5, but only the latter approached the standard of 400 mg/L. BOD_5 concentrations were reduced significantly across all conditions, with DO3.5 achieving the lowest concentration (10.95 mg/L), well below the standard of 50 mg/L. NH_3-N concentrations were highest at DO3.1 (671 mg/L), but the lowest concentration was observed at DO3.5 (430 mg/L), indicating improved nitrification at higher DO levels though still above the standard of 5 mg/L. TSS effluent concentrations consistently met the standard of 50 mg/L, with DO3.5 showing the best performance (21.8 mg/L). Colour concentrations exhibited limited reductions, remaining high across all DO levels, with the lowest value observed at DO3.5 (8900 PCU), reflecting the difficulty of removing colour-causing compounds biologically. The pH values of the effluent ranged between 8.05 and 8.62, remaining within the standard range of 6–9. These results highlight that higher DO levels improve organic matter and TSS removal, with DO3.5 being the most effective overall. However, the persistence of NH_3-N and colour indicates limitations in biological processes for these pollutants, requiring advanced treatment methods for compliance. The findings align with previous research, which demonstrated the importance of optimising DO levels to enhance nitrification and solid removal while recognising the need for supplementary processes to address refractory pollutants like colour and ammonia [11],[12],[27].

Table 4 - Comparison of influent and effluent concentrations for COD, BOD_5, NH_3-N, TSS, colour, and pH across different dissolved oxygen (DO2.6, DO3.1 and DO3.5) with corresponding regulatory standards.

Parameters	Influent	DO2.6 Effluent	DO3.1 Effluent	DO3.5 Effluent	Standard
COD (mg/L)	6240	818	634	550	400
BOD_5 (mg/L)	186.5	25.86	15.7	10.95	50
NH_3-N (mg/L)	1472	452	671	430	5
TSS (mg/L)	347.63	25.2	35.3	21.8	50
Colour (PCU)	12700	9960	8990	8900	-
pH	10.96	8.05	8.3	8.62	6–9

4. Conclusion

This study demonstrated the feasibility of a single-tank A2O-MBR for the treatment of landfill leachate, effectively integrating anaerobic, anoxic, and aerobic zones within a compact configuration. The system achieved high removal efficiencies for COD and BOD_5 (>90%) and consistently met regulatory standards for TSS across varying HRT and DO levels. Optimal performance was observed at an HRT of 15 hours and a DO level of 3.1 mg/L, balancing pollutant removal efficiency and operational feasibility. However, NH_3-N removal remained moderate, with effluent concentrations still above regulatory limits, and colour removal showed limited improvement, highlighting the need for advanced treatment methods to address persistent pollutants. The findings emphasise the critical role of optimising HRT and DO levels in enhancing microbial activity and pollutant removal. Future work should focus on integrating supplementary processes, such as advanced oxidation or adsorption, to achieve compliance with stringent discharge standards for ammonia and colour. This study provides a foundation for further development and optimisation of sustainable and cost-effective landfill leachate management systems.

Acknowledgement

This work was supported by the Universiti Teknologi Malaysia (UTM) Fundamental Research Grant (Grant No. Q.J130000.3846.22H85).

References

[1] Wang, J., & Qiao, Z. (2024). A comprehensive review of landfill leachate treatment technologies. Frontiers in Environmental Science, 12.

[2] Babaei, S., Sabour, M.R., & Moftakhari Anasori Movahed, S. (2021). Combined Landfill Leachate Treatment Methods: An Overview. Environmental Science and Pollution Research.

[3] Aziz, H.A., Ramli, S.F., & Hung, Y.T. (2023). Physicochemical Technique in Municipal Solid Waste (MSW) Landfill Leachate Remediation: A Review. Water 2023, Vol. 15, Page 1249, 15(6), 1249.

[4] Wijekoon, P., Koliyabandara, P.A., Cooray, A.T., et al. (2022). Progress and prospects in mitigation of landfill leachate pollution: Risk, pollution potential, treatment and challenges. Journal of Hazardous Materials, 421, 126627.

[5] Teng, C., Zhou, K., Peng, C., et al. (2021). Characterization and treatment of landfill leachate: A review. Water Research, 203, 117525.

[6] Remmas, N., Manfe, N., Zerva, I., et al. (2023). A Critical Review on the Microbial Ecology of Landfill Leachate Treatment Systems. Sustainability (Switzerland).

[7] Department of Environment Malaysia. (2009). Environmental Quality Regulations (Control of Pollution from Solid Waste Transfer Station and Landfill) 2009.

[8] Jamrah, A., AL-Zghoul, T.M., & Al-Qodah, Z. (2024). An Extensive Analysis of Combined Processes for Landfill Leachate Treatment. Water, 16(12), 1640.

[9] Khoramipour, S., Mehralipour, J., & Hosseini, M. (2023). Optimisation of ultrasonic-electrocoagulation process efficiency in the landfill leachate treatment: a novel advanced oxidation process. International Journal of Environmental Analytical Chemistry.

[10] Metcalf, & Eddy. (2014). Wastewater Engineering: Treatment and Resource Recovery. 5th ed. McGraw Hill Education.

[11] Banti, D.C., Mitrakas, M., & Samaras, P. (2021). Membrane fouling controlled by adjustment of biological treatment parameters in step-aerating MBR. Membranes.

[12] Wang, D., Tao, J., Fan, F., et al. (2021). A novel pilot-scale IFAS-MBR system with low aeration for municipal wastewater treatment: Linkages between nutrient removal and core functional microbiota. Science of the Total Environment.

[13] Zhang, Y., Meng, C., He, Y., et al. (2021). Influence of cell lysis by Fenton oxidation on cryptic growth in sequencing batch reactor (SBR): Implication of reducing sludge source discharge. Science of the Total Environment.

[14] Li, J., Dong, K., Bai, S., et al. (2023). Efficacy of Nitrogen and Phosphorus Removal and Microbial Characterization of Combined A2O-MBBR Constructed Wetlands. Water (Switzerland).

[15] Xu, R., Fan, F., Lin, Q., et al. (2021). Overlooked Ecological Roles of Influent Wastewater Microflora in Improving Biological Phosphorus Removal in an Anoxic/Aerobic MBR Process. Environmental Science and Technology.

[16] Ma, Q., Han, F., Lyu, F., et al. (2023). Municipal Sewage Treatment Technology: A2/O-VMBR Integrated Technology for Municipal Treatment and Improved Pollutant Removal. Water (Switzerland).

[17] Eid, A., El-Sayed, A.E., Ayoub, M., et al. (2024). Optimizing the MBBR System and Integrating Nanoparticles to Improve Wastewater Treatment Efficiency. Ecological Engineering and Environmental Technology.

[18] Anuar, N.K., Zin, N.S.M., Zailani, L.W., et al. (2022). Study on Ammonia and Colour Removal from Leachate via Aerated Electrocoagulation (Ferum and Aluminium Electrode). In: IOP Conference Series: Earth and Environmental Science.

[19] Yin, T., Zheng, Y., Liu, T., et al. (2022). Study on Water Purification Effect and Operation Parameters of Various Units of Wastewater Circulation. Water (Switzerland).

[20] Zazouli, M.A., Yousefi, Z., Babanezhad, E., et al. (2024). Landfill leachate treatment using a combined method of coagulation, flocculation,

Published by MBOT Publishing
https://jetia.mbot.org.my/index.php/jetia/index

advanced oxidation, and extended aeration. Environmental Health Engineering and Management, 11(2), 177–190.

[21] Srivast, G., Rajpal, A., Khursheed, A., et al. (2021). Influence of Variations in Wastewater on Simultaneous Nutrient Removal in a Pre-anoxic Selector Attached Full-scale Sewage Treating SBR.

[22] Jagaba, A.H., Kutty, S.R.M., Baloo, L., et al. (2021). Effect of Hydraulic Retention Time on the Treatment of Pulp and Paper Industry Wastewater by Extended Aeration Activated Sludge System. In: 2021 3rd International Sustainability and Resilience Conference: Climate Change.

[23] Gao, J., Yue, Z., Yan, Y., et al. (2022). Application of the membrane bioreactor process in upgrading a norfloxacin pharmaceutical wastewater treatment system. Desalination and Water Treatment.

[24] Nguyen, T.H., Watari, T., Hatamoto, M., et al. (2021). Enhanced decolorization of dyeing wastewater in a sponges-submerged anaerobic reactor. Chemosphere.

[25] Dubey, S., Joshi, A., Trivedi, R., et al. (2021). Electro-peroxone treatment of rice grain based distillery biodigester effluent: COD and color removal. Water Resources and Industry.

[26] Rathore, J., Sharma, A., Sharma, R., et al. (2012). Studies on reduction of colour, COD and TSS in textile dyeing and printing wastewater by coagulation and adsorption method. Journal of the Indian Chemical Society.

[27] Qin, L., Wang, D., Zhang, Z., et al. (2023). Impact of Dissolved Oxygen on the Performance and Microbial Dynamics in Side-Stream Activated Sludge Hydrolysis Process. Water (Switzerland).

Published by MBOT Publishing
https://jetia.mbot.org.my/index.php/jetia/index