Journal of Emerging Technologies and Industrial Applications
Vol. 4 No. 1 (2025) pp. 1-5
e-ISSN: 2948-507X

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

Constructed Wetland Vegetated with Different Plants for Leachate Treatment

Nurul Balqis Mohamed[1], Nuurfatihah Nazihah Sakhon[1], Norzita Ngadi[1], Muhammad Arif Ab Aziz[1*], Mohamed Hizam Mohamed Noor[1], Ya Mohammad Nazir Syah Ismail[1,2], Fatin Amirah Razmi[1], Saharudin Haron[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: *m.arif@utm.my

Abstract: Landfill leachate, a byproduct of waste decomposition, contains harmful pollutants that pose serious risks to the environment and public health. This study explored the use of a vertical subsurface flow constructed wetland system to treat landfill leachate, focusing on the effectiveness of three plant species: Napier Grass (Pennisetum purpureum), Golden Beak Sedge (Rhynchospora corymbosa), and Tube Sedge (Lepirona articulata). Napier Grass emerged as the most effective, achieving removal rates of 24.99% for turbidity, 29.97% for color, 85.01% for chemical oxygen demand (COD), and 78.39% for ammonia nitrogen (NH3-N). The study also identified four days as the optimal retention time for maximum pollutant removal, beyond which improvements leveled off. These findings highlight Napier Grass as a promising option for improving the efficiency of constructed wetlands, providing a sustainable and cost-effective solution for landfill leachate treatment.

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

Keywords: Constructed wetland, landfill leachate, vegetation, efficiency, optimum retention time

*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

Landfills are essential for managing municipal solid waste, yet they also create a hidden but pressing environmental problem: landfill leachate. This liquid, formed as rainwater filters through layers of decomposing waste, contains a hazardous cocktail of pollutants, including high concentrations of ammonia nitrogen (NH3-N), organic matter, heavy metals, and other toxic substances. Left untreated, leachate can seep into groundwater, pollute nearby water bodies, and disrupt ecosystems, posing significant threats to public health and the environment [1],[2].

In Malaysia, where tropical rainfall is abundant, the leachate production is estimated to exceed 3 million litres per day, a figure that underscores the scale of this challenge. Traditional treatment methods, such as chemical and physical processes, are often expensive, energy-intensive, and difficult to implement on a large scale. As a result, there is a growing interest in exploring more sustainable and cost-effective alternatives [3],[4].

Constructed wetlands (CWs) have emerged as a promising solution. These engineered ecosystems replicate natural wetland processes to treat wastewater through a combination of biological, chemical, and physical mechanisms. They offer a practical, low-maintenance, and environmentally friendly approach to managing leachate, particularly in regions where resources for advanced treatment technologies may be limited. Among the various types of CWs, vertical subsurface flow systems stand out for their efficiency in nitrogen removal, making them particularly suitable for treating landfill leachate [5]. One critical factor in the success of constructed wetlands is the choice of vegetation. Plants play a central role in these systems, acting as natural filters by absorbing nutrients, enhancing microbial activity, and providing oxygen to support the degradation of pollutants. While the benefits of CWs are well-documented, the specific contributions of different plant species, especially in tropical environments like Malaysia's, remain less explored [3],[6].

This study seeks to address this knowledge gap by investigating the performance of three plant species—Napier Grass (*Pennisetum purpureum*), Golden Beak Sedge (*Rhynchospora corymbosa*), and Tube Sedge (*Lepirona articulata*)—in a vertical subsurface flow constructed wetland system designed for landfill leachate treatment. The analysis focuses on key parameters, including turbidity, pH, colour, ammonia nitrogen (NH_3-N), and chemical oxygen demand (COD), which are critical indicators of water quality. By comparing the pollutant removal efficiencies of these plant species, the study aims to identify the most effective option for enhancing leachate treatment in tropical regions [6],[7]. Beyond its scientific contribution, this research has practical implications. Identifying the right vegetation for CWs can significantly improve the efficiency and sustainability of leachate treatment systems, reducing the environmental impact of landfills while offering a cost-effective solution for water pollution control. Moreover, the findings could serve as a blueprint for adapting CW designs to other regions with similar environmental conditions, advancing global efforts toward more sustainable waste management practices.

2. Methodology

In order to run the experiment for treating the landfill leachate, vertical flow type constructed wetland is used for the experiment. The overall methodology consists of several stages which are preparation of leachate samples, preparation of vegetations, preparation of constructed wetlands and data analysis.

2.1 Leachate Sample

Two different batches of landfill leachate that collected from Seelong Sanitary Landfill, Johor. The treated leachate from the landfill that discharged to aerated lagoon undergoes filtration and sedimentation was collected as the sample for the experiment. After collecting the leachate from the landfill, 10 L of the leachate will manually transfer into the 32L volume of constructed wetland. The all three units of the constructed wetland are planted with different species of vegetation.

2.2 Vegetation

Three species of vegetation were used for this experiment which are shown in Figure 1 a) Napier grass (Pennisetum purpureum), b) Golden Beak Sedge (*Rhynchospora corymbosa*) and c) Tube Sedge (*Lepironia articulata*). All the plants were taken from the natural wetland at Kampung Parit Rambai, Pontian, Johor. Ten to twelve healthy adult plants with same height were selected from each wetland to be placed in the constructed wetland. As a preparation stage for the vegetation before planting into the lab scale constructed wetland, all the vegetation species were placed in the large container filled with soil and water as shown in Fig. 1(d). The goal is also to standardize the nutritional content of all species before they are planted in the newly built wetland.

2.3 Constructed Wetlands

The vertical flow type of constructed wetland was chosen as it gives higher efficiency of nitrogen removal (Fig. 2 (a) and (b)). The wetlands were constructed from 32L semi-transparent plastic containers with dimension of 57cm length x 35cm width x 23cm height. Gravel is chosen as the medium because it has a wide surface area that is ideal for biochemical processes. It provides the high conductivity required to stabilise the hydraulic retention time of a constructed wetland. The bottom of the bed includes a modest slope that allows for collecting the treated water and drainage out of the unit. Gravel at bottom layer with 9 cm height, and the soil at top layer with a 9 cm height as well.

2.4 Experimental Method

After the preparation of the leachate sample, the water analysis of the initial leachate sample was determined for turbidity, pH, colour, Ammonia Nitrogen (NH_3-N), and Chemical Oxygen Demand (COD). After five days, the leachate sample was collected through the pipe valve pipe for analysis. Percentage removal efficiency was calculated using the equation:

$$Removal\ (\%) = (\frac{C_o - C_t)}{C_o} \times 100\% \qquad (1)$$

Fig. 1 - a) *Pennisetum purpureum*, b) *Rhynchospora corymbosa*, c) *Lepironia articulate* and d) Standardize Nutritional Content in Vegetation.

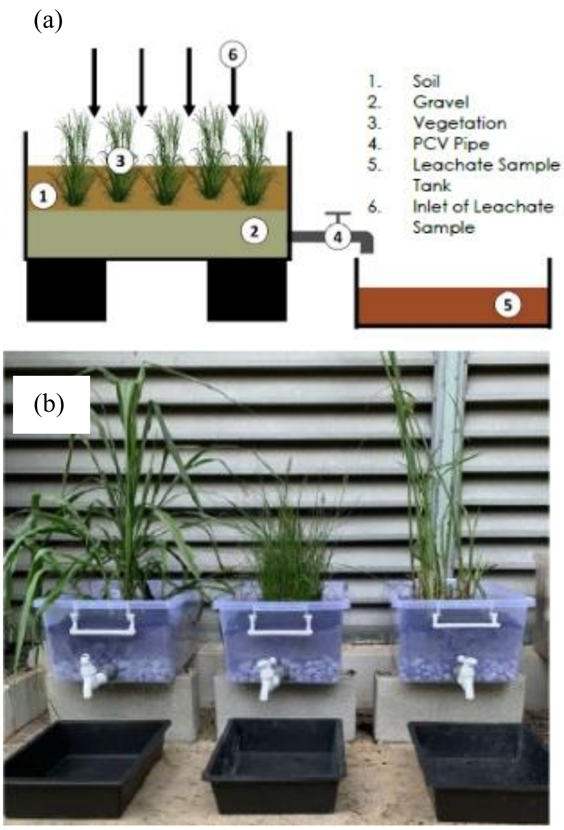

Fig. 2 - a) Schematic Diagram of Vertical Flow Constructed Wetland and b) Lab Scale Constructed Wetlands.

3. Results and Discussions

3.1 Effective Species of Vegetation

The effectiveness of three plant species Napier Grass (*Pennisetum purpureum*), Golden Beak Sedge (*Rhynchospora corymbosa*), and Tube Sedge (*Lepirona articulata*) in treating landfill leachate was evaluated using a vertical subsurface flow constructed wetland system was shown in Fig. 3. The performance of these species was assessed based on their ability to remove turbidity, colour, chemical oxygen demand (COD), and ammonia nitrogen (NH_3-N) from the leachate. Among the three, Napier Grass emerged as the most effective species, achieving removal efficiencies of 24.99% for turbidity, 29.97% for colour, 85.01% for COD, and 78.39% for NH_3-N. Golden Beak Sedge showed moderate performance with removal efficiencies of 15.05%, 25.21%, 69.67%, and 75.12% for turbidity, colour, COD, and NH_3-N, respectively, while Tube Sedge exhibited the lowest removal efficiencies across all parameters [5],[8].

The superior performance of Napier Grass can be attributed to its robust root system and high biomass, which enhance its ability to remove pollutants through multiple mechanisms. Its dense root network facilitates sedimentation and filtration, effectively trapping suspended particles and improving turbidity removal. The roots also provide a substrate for microbial activity, which is essential for breaking down organic pollutants, thereby enhancing COD removal. Additionally, Napier Grass absorbs significant amounts of nutrients such as nitrogen and phosphorus, reducing their concentrations in the leachate. Oxygen transfer from its roots into the surrounding soil further supports aerobic microbial processes, aiding in the conversion of ammonia into less harmful compounds. In contrast, the relatively lower removal efficiencies observed for Golden Beak Sedge and Tube Sedge may be due to their less extensive root systems and lower nutrient uptake capacities [9],[10].

These findings emphasize the critical role of vegetation selection in the design and performance of constructed wetlands. Napier Grass, with its superior pollutant removal efficiencies and adaptability, is the most effective species for landfill leachate treatment in this study. Incorporating such vegetation into constructed wetland systems can significantly enhance their treatment performance while maintaining cost-effectiveness. This insight is particularly valuable for tropical climates like Malaysia's, where environmental conditions may favour plant species with similar characteristics.

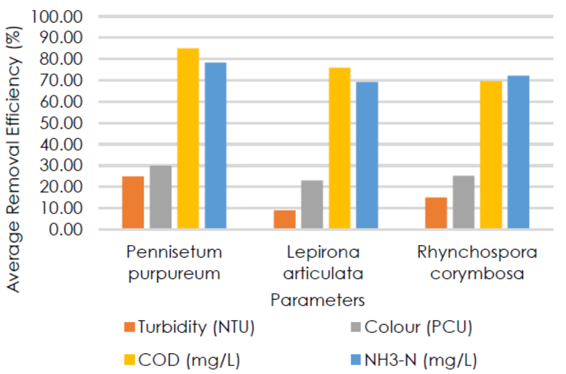

Fig. 3 - Average Removal Efficiency for Every Vegetation

3.2 Optimum Retention Time

The optimum retention time for Napier Grass (*Pennisetum purpureum*) in the constructed wetland system was determined through a seven-day observation of its performance in treating landfill leachate in Fig. 4 (a) and (b). The results showed that pollutant removal efficiencies increased steadily from day one to day four, after which the improvements plateaued, indicating the optimal duration for treatment. For turbidity, removal efficiency rose from an initial 1.96% on day one to 24.71% on day four, eventually stabilizing around 25.77% by day seven. Similarly, the colour removal efficiency increased from 3.15% on day one to 29.93% by day four, reaching a marginally higher value of 30.65% by day seven. These trends suggest that while some removal processes continue beyond day four, the rate of improvement diminishes, making a four-day retention period the most efficient for practical applications [11],[12].

The physical appearance of the leachate further corroborated these findings, as samples treated with Napier Grass showed noticeable clarity by the fourth day. This retention period aligns with the plant's capacity to optimize sedimentation, filtration, and nutrient uptake processes within the constructed wetland system. The stabilization of pollutant removal efficiencies after day four indicates that extending the retention time beyond this point yields minimal additional benefits, thereby optimizing both treatment efficacy and operational efficiency [13],[14]. These results are significant for scaling up constructed wetland systems, particularly in settings where resource efficiency is paramount. By adopting a four-day retention time, it is possible to achieve effective treatment while minimizing the space and time requirements for leachate management [14],[15]. This finding highlights the practical advantages of using Napier Grass in wetland systems, especially in tropical regions where rapid and efficient pollutant removal is essential for sustainable waste management practices.

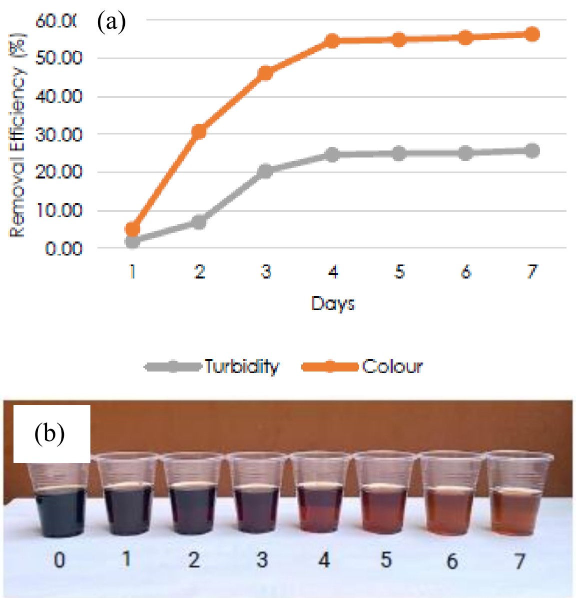

Fig. 4 (a) Optimization of Retention Time for Napier Grass (*Pennisetum purpureum*) and (b) Sample of Pennisetum Purpureum Leachate for 7 Days

4. Conclusion

This study demonstrated the potential of vertical subsurface flow constructed wetlands for addressing the environmental challenges posed by landfill leachate. Among the plants tested, Napier Grass (Pennisetum purpureum) stood out as the most effective species, showing superior removal rates for key pollutants like turbidity, colour, COD, and NH3-N. The findings also revealed that a retention time of four days is optimal for achieving high treatment efficiency while maintaining practicality. These results emphasize the importance of

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

selecting suitable vegetation for enhancing the performance of constructed wetlands. Incorporating Napier Grass into wetland designs offers a low-cost, environmentally friendly approach to managing leachate, especially in tropical climates like Malaysia. Beyond its immediate application, this research provides valuable insights for scaling up constructed wetland systems and adapting them to treat other types of wastewaters. Future work could further explore the long-term viability of such systems and their effectiveness under varying environmental conditions.

Acknowledgement

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

References

[1] Bakhshoodeh, R., Alavi, N., Oldham, C., et al. (2020). Constructed Wetlands for Landfill Leachate Treatment: A Review. Ecological Engineering.

[2] Joseph, S.M.R., Wijekoon, P., Dilsharan, B., et al. (2020). Anammox, biochar column and subsurface constructed wetland as an integrated system for treating municipal solid waste derived landfill leachate from an open dumpsite. Environmental Research.

[3] Ogata, Y., Ishigaki, T., Ebie, Y., et al. (2018). Design considerations of constructed wetlands to reduce landfill leachate contamination in tropical regions. Journal of Material Cycles and Waste Management.

[4] Wojciechowska, E. (2017). Potential and limits of landfill leachate treatment in a multi-stage subsurface flow constructed wetland – Evaluation of organics and nitrogen removal. Bioresource Technology.

[5] Silvestrini, N.E.C., Hadad, H.R., Maine, M.A., et al. (2019). Vertical flow wetlands and hybrid systems for the treatment of landfill leachate. Environmental Science and Pollution Research.

[6] Madera Parra, C.A. (2016). Treatment of landfill leachate by polyculture constructed wetlands planted with native plants. INGENIERÍA Y COMPETITIVIDAD.

[7] Alam, M.K., Islam, M.A.S., Saeed, T., et al. (2023). Life Cycle Analysis of Lab-Scale Constructed Wetlands for the Treatment of Industrial Wastewater and Landfill Leachate from Municipal Solid Waste: A Comparative Assessment. Water (Switzerland).

[8] Taufikurahman, T., Melani, L., Sianturi, N.L.H., et al. (2023). Effective removal of chromium from contaminated water using horizontal subsurface flow constructed wetland with Napier grass (Pennisetum purpureum). Current Research on Biosciences and Biotechnology.

[9] Klomjek, P. (2016). Swine wastewater treatment using vertical subsurface flow constructed wetland planted with Napier grass. Sustainable Environment Research.

[10] Saeed, T., Miah, M.J., Majed, N., et al. (2021). Effect of effluent recirculation on nutrients and organics removal performance of hybrid constructed wetlands: Landfill leachate treatment. Journal of Cleaner Production.

[11] Akinbile, C.O., Yusoff, M.S., & Ahmad Zuki, A.Z. (2012). Landfill leachate treatment using sub-surface flow constructed wetland by Cyperus haspan. Waste Management.

[12] Akinbile, C.O., Yusoff, M.S., & Ahmad Zuki, A.Z. (2012). Landfill leachate treatment using sub-surface flow constructed wetland by Cyperus haspan. Waste Management, 32(7), 1387–1393.

[13] Galindo Montero, A.A., Pimienta Serrano, E. V., & Montiel, J.I.P. (2019). Sanitary Landfill Leachate Treatment with Double Chamber Anaerobic Reactor in Series with Constructed Wetland. Environmental Processes.

[14] Pillai, J.S., & Brijesh Nair, A.N. (2021). Performance of vertical flow constructed wetlands planted with indigenous species for decentralized wastewater treatment and biomass production in Kerala, India. Nature Environment and Pollution Technology.

[15] Yalçuk, A., & Ugurlu, A. (2020). Treatment of landfill leachate with laboratory scale vertical flow constructed wetlands: plant growth modeling. International Journal of Phytoremediation.