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RESEARCH ARTICLE

Design of a Moving Bed Biofilm Reactor (MBBR) to Address Problems of the Leachate Treatment Plant (LTP) at Banyuroto Landfill

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Abstract
The Leachate Treatment Plant (LTP) at Banyuroto Landfill was constructed as an effort to control environmental pollution; however, its performance has not yet fully complied with the applicable effluent standards. This study aims to evaluate the performance of the existing LTP and to formulate an alternative development of a leachate treatment system based on a Moving Bed Biofilm Reactor (MBBR). The leachate flow rate was estimated using the Thornthwaite method based on climatic water balance, while leachate quality was evaluated by comparing laboratory analysis results with the effluent standards stipulated in Regulation of the Ministry of Environment and Forestry of the Republic of Indonesia No. 59 of 2016.
The evaluation results indicate that several key pollutant parameters, particularly organic matter and nitrogen compounds, still exceeded the effluent standards at the outlet of the LTP. Technical evaluation shows that limitations in capacity and process configuration of the existing treatment units hinder effective system optimization. Based on the analysis of leachate flow rate and pollutant loading, an MBBR-based treatment system is recommended as a replacement unit due to its higher process stability under fluctuating loads and better technical efficiency.
Keywords: leachate; leachate treatment plant; MBBR; effluent standard; Banyuroto landfill

1. Introduction

Leachate is a liquid formed from the percolation of rainfall through solid waste deposits in landfills and may carry various contaminants at high concentrations. If not properly managed, leachate can pollute surface water bodies and groundwater, leading to serious environmental impacts. Therefore, leachate management and treatment are essential components of sustainable landfill operation.

Leachate characteristics are generally marked by high concentrations of organic matter and nitrogen, as well as significant variability influenced by waste composition, landfill age, and climatic conditions. High ammonia concentrations and variable COD/N ratios make biological treatment of leachate more complex than that of domestic wastewater. These conditions require treatment systems that can adapt to fluctuations in flow rate and pollutant loading to ensure compliance with effluent quality standards.

Leachate Treatment Plants (LTPs) are designed to reduce pollutant loads before discharge into the environment. However, in practice, many LTPs do not operate optimally due to design limitations, mismatches between unit capacity and actual leachate flow and loading, and changes in leachate characteristics over time. As a result, the effluent quality often fails to meet regulatory standards and poses potential environmental risks.

Such conditions are also observed at the LTP of Banyuroto Landfill, where the treated leachate still shows several parameters exceeding the applicable discharge standards. This situation indicates the need for a comprehensive evaluation of the existing LTP performance, particularly in terms of effluent quality and the suitability of treatment units relative to the actual leachate flow rate and pollutant loading.

In addition to treatment system performance, leachate generation and migration are influenced by local geological and hydrogeological conditions. The permeability of soil and underlying geological materials plays an important role in controlling rainfall infiltration and the potential movement of leachate into the subsurface. Consequently, ineffective leachate treatment systems not only affect effluent quality but also increase the risk of soil and groundwater contamination in the surrounding landfill area.

Based on these considerations, it is necessary to conduct a study that not only evaluates the performance of the existing LTP but also incorporates leachate flow rate and pollutant load analysis as the basis for developing a more effective treatment system. The Moving Bed Biofilm Reactor (MBBR) technology is considered a promising alternative due to its ability to maintain high biomass concentration, withstand load fluctuations, and effectively remove organic matter and nitrogen.

Therefore, this study aims to evaluate the performance of the Banyuroto Landfill LTP based on effluent quality and unit suitability, analyze leachate flow rate using the Thornthwaite method, and propose an alternative leachate treatment system based on an aerobic–post-anoxic MBBR configuration. The results of this study are expected to provide technical contributions to improving leachate treatment performance and supporting environmental protection efforts, particularly in mitigating the risk of soil and groundwater contamination around the landfill.

Characteristics of Landfill Leachate

Leachate is a liquid generated by rainwater percolating through waste layers in a landfill, resulting in the dissolution and transport of organic and inorganic compounds from the waste materials (Kjeldsen et al., 2002; Renou et al., 2008). Leachate characteristics are strongly influenced by landfill age, waste composition, and local hydrological and climatic conditions.

In general, leachate is characterized by high concentrations of organic matter expressed as BOD and COD, high nitrogen content predominantly in the form of ammonia, and the presence of suspended solids and inorganic compounds (Kurniawan et al., 2010). In relatively old landfills, leachate pH tends to be neutral to alkaline, while BOD decreases but COD and nitrogen concentrations remain relatively high (Renou et al., 2008). These conditions require treatment systems capable of handling high and fluctuating pollutant loads.

Principles of Biological Leachate Treatment

Biological treatment is the primary method for reducing organic matter and nitrogen compounds in leachate. This process utilizes microbial activity to degrade organic compounds into more stable forms and to convert nitrogen through nitrification and denitrification processes (Metcalf & Eddy, 2014).

Nitrification occurs under aerobic conditions, where ammonia is oxidized to nitrite and nitrate by autotrophic nitrifying bacteria. Denitrification subsequently takes place under anoxic conditions, reducing nitrate to nitrogen gas by heterotrophic microorganisms (Gerardi, 2002). The effectiveness of biological treatment is strongly influenced by hydraulic retention time, dissolved oxygen availability, and biomass stability within the reactor.

Concept of Leachate Treatment Plant (LTP)

A Leachate Treatment Plant (LTP) is designed to treat leachate prior to discharge into the environment so that effluent quality complies with applicable standards. In general, an LTP consists of a series of physical, chemical, and biological treatment units arranged according to the characteristics of the leachate being treated (Tchobanoglous et al., 2014).

Mismatch between leachate characteristics and the function or capacity of treatment units may result in low system efficiency and failure to meet effluent standards (Renou et al., 2008). Therefore, evaluation of the performance and configuration of existing LTP units is a crucial step in determining the need for system improvement.

Analysis of Leachate Generation and Flow Rate

Leachate generation at landfills results from rainwater infiltration into waste layers that exceeds storage capacity and is affected by evapotranspiration losses and surface runoff (Kjeldsen et al., 2002; Renou et al., 2008). Climatic factors, particularly rainfall and air temperature, play a major role in determining leachate flow rates.

The climatic water balance approach is commonly used to estimate leachate generation, particularly during the evaluation and planning stages of leachate treatment systems. In this approach, leachate flow is estimated as the difference between effective rainfall and evapotranspiration losses, considering waste storage capacity (Fatta et al., 1999).

The Thornthwaite method is an empirical method used to calculate potential evapotranspiration based on average monthly air temperature and an annual heat index (Thornthwaite, 1948). Due to its simplicity and minimal data requirements, this method is widely applied in leachate management studies, especially in areas with limited meteorological data (Xu & Singh, 2001).

Leachate Flow Rate Determination Formula :

PERC = P – (RO) – (AET) – (ΔST)
RO = P x Cr
AET = PET if I ≥ Adj.PET; and I – ΔST if I < Adj.PET
PET = $c\ x \left(\frac{10\text{T}}{\text{Ip}}\right)^{a}$
Ip = $\sum_{T=1}^{12} i^{1,514}$
i = $\left(\frac{T}{5}\right)^{1,514}$
a = $(0{,}000000675 \times Ip^3) - (0{,}0000771 \times Ip^2) + (0{,}01792 \times Ip) - 0{,}49239$
Adjusted PET(Adj.PET) = r x PET
I = P – RO
Ka = I - Adj.PET
APWL = P – PET
ΔST = $(\theta_2 - \theta_1) \times Z$

Where:
PERC = Percolation of rainfall entering the landfill (mm)
P = Monthly precipitation (mm)
RO = Runoff (mm)
AET = Actual evapotranspiration (mm)
ΔST = Annual change in soil moisture storage (mm)
Cr = Runoff coefficient of the specific land cover
I = Infiltration (mm)
PET = Potential evapotranspiration (mm)
Adjusted PET (Adj. PET) = Potential evapotranspiration adjusted for solar radiation index (mm)
c = Constant value of 1.62 for PET calculation (mm)
T = Monthly average temperature (°C)
R = Solar radiation or sunshine duration factor based on geographic location
Ip = Heat index

In leachate management studies, the Thornthwaite method is widely applied as a basis for estimating leachate flow rates at landfills, particularly in evaluations of leachate treatment plant performance and the planning of treatment unit capacities (Fatta et al., 1999; Renou et al., 2008). Although this method does not explicitly account for variations in the physical properties of the waste mass, the Thornthwaite approach is considered adequate for preliminary leachate flow analysis when applied consistently and combined with available field data (Metcalf & Eddy, 2014).

Principles of Moving Bed Biofilm Reactor (MBBR)

The Moving Bed Biofilm Reactor (MBBR) is a biological treatment technology that utilizes mobile carrier media as a surface for biofilm attachment. The media move continuously within the reactor due to aeration or mixing, thereby enhancing contact between microorganisms and substrates (Ødegaard et al., 2000).

According to Metcalf & Eddy (2014), MBBR systems are capable of maintaining high biomass concentrations without sludge recirculation, as required in conventional activated sludge systems. MBBR also provides greater process stability under fluctuating hydraulic and organic loads and allows higher biological reaction rates within relatively compact reactor volumes.

The determination of treatment unit requirements and design calculations were based on Metcalf & Eddy (2014) in their book *Wastewater Engineering: Treatment and Resource Recovery*. The required treatment units and design criteria were determined as follows:

1. Daily flow rate (Q)
2. Influent quality (Inf)
3. Required treatment efficiency
4. Type of treatment unit applied
5. Surface Area Loading Rate (SALR)
6. Specific Surface Area (SSA) and type of biofilm media
7. Media fill ratio (%)

Based on the above design criteria, the dimensions of the treatment units were determined, including:

1. Required removal capacity

$$\text{Required removal efficiency} = \frac{Q\ x\ Inf}{1000}$$

Where:
Q = Daily flow rate (m^3/day)
Inf = Influent concentration (mg/L)

2. Biofilm media surface area (A)

$$A = \frac{\text{Required removal efficiency}}{SALR} x1000$$

Where:
A = Biofilm media surface area (m^2)
SALR = Surface Area Loading Rate (g Inf/m^2 ·day)

3. Media volume (V)

$$V = \frac{\text{A}}{SSA\ x\ (\%) fill\ ratio} x100$$

Where:
V = Media volume (m^3)
A = Biofilm media surface area (m^2)
SSA = Specific Surface Area (m^2/m^3)
Fill ratio (%) = Ratio of biofilm media (Kaldnes K1) to reactor volume (%)

4. Hydraulic Retention Time (HRT)

$$HRT = \frac{V}{Q} x24$$

Where:
HRT = Hydraulic Retention Time (hours)
V = Media volume (m^3)
Q = Daily flow rate (m^3/day)

The division of the reactor into several compartments, such as anoxic and aerobic zones, aims to optimize the nitrification and denitrification processes. The determination of MBBR compartment volume and configuration must be adjusted to leachate characteristics to ensure that the treatment system achieves the expected removal efficiency (Ødegaard et al., 2000).

2. Research Method

The methodology of this study includes the research location, data sources, and research design. The study was conducted at the Leachate Treatment Plant (LTP) of Banyuroto Landfill, focusing on the evaluation of the existing leachate treatment system. The data used consist of leachate quality data, rainfall data, and technical information on existing treatment units obtained from the landfill management authority and supporting documents. The research design was developed to evaluate LTP performance based on compliance with effluent standards and design criteria, analyze leachate flow rate using the Thornthwaite method, and propose an improved leachate treatment system based on Moving Bed Biofilm Reactor (MBBR) technology. Local geological and hydrogeological conditions were qualitatively considered to support the assessment of leachate migration potential and environmental contamination risks.

This study employed a descriptive–analytical method with a case study approach. The descriptive method was used to characterize the existing condition of the Leachate Treatment Plant (LTP) based on leachate quality data and treatment unit characteristics. The analytical method was applied to evaluate LTP performance through leachate flow rate estimation using the Thornthwaite method, pollutant load analysis, and assessment of treatment unit suitability against design criteria and effluent standards. A case study approach was adopted as the analysis focused on the Banyuroto Landfill LTP.

RESULT AND DISCUSSION

Leachate Quality And Compliance With Effluent Standards

The results of leachate quality analysis indicate that several key pollutant parameters still exceeded the applicable effluent standards at both the inlet and outlet of the LTP. The highest exceedances were generally observed in organic and nitrogen-related parameters, indicating that biological treatment processes in the existing system have not been operating optimally.

Table 1 Leachate quality at the inlet and outlet, effluent standards, and required treatment efficiency

Parameter	Effluent Standard (mg/l)	Test Result (mg/l)		Inlet-Outlet Comparison (%)	Required Treatment Efficiency (%)
		inlet	outlet		
BOD	150	596	538	9,732	74,83
COD	300	1450	1037,5	28,448	79,31
TSS	100	109	143	-31,193	8,26
N-total	60	495,4	612,8	-23,698	87,89
pH	6-9	8	8,4	-5,00	-
Cd	0,1	<0,0018	<0,0018	-	-

: Exceeds effluent standard

The leachate characteristics observed in this study are closely influenced by the geological and hydrogeological conditions of the landfill site. Rainwater infiltration into the waste mass and interactions between leachate and soil and rock materials can affect the physicochemical properties of leachate, such as pH and dissolved constituent concentrations. Under conditions where the leachate treatment plant is not operating optimally, leachate may infiltrate the subsurface and interact with the groundwater system, thereby increasing the risk of geological and environmental contamination in the surrounding landfill area. Therefore, the implementation of a more reliable MBBR-based leachate treatment system is intended not only to achieve effluent quality standards but also to mitigate the risk of soil and groundwater contamination.

Evaluation of the Existing Leachate Treatment System

Technical evaluation of the existing leachate treatment system indicates that the configuration of the treatment units does not adequately support advanced biological processes, particularly for nitrogen removal. Limitations in unit capacity and hydraulic retention time result in low overall treatment efficiency.

To clarify the configuration of the leachate treatment system prior to system development, a process flow diagram of the existing leachate treatment plant is presented.

Furthermore, field observations reveal that the limitations of the existing system hinder performance improvement through unit optimization. These conditions indicate that system replacement or redevelopment is a more rational approach than maintaining the existing treatment system.

Leachate Flow Rate and Pollutant Load Analysis

The leachate flow rate calculated using the Thornthwaite method was used as the basis for determining the pollutant loads entering the treatment system. Pollutant load analysis was conducted by multiplying the leachate flow rate by the concentrations of the main pollutant parameters.

Table 2 Average monthly rainfall in Kapanewon Nanggulan during the period 2014–2023

Month	Average Rainfall (mm)
January	384,381
February	399,211
March	311,754
April	280,755
May	227,168
June	166,105
July	104,445
August	56,862
September	116,928
October	212,035
November	351,838
December	396,487

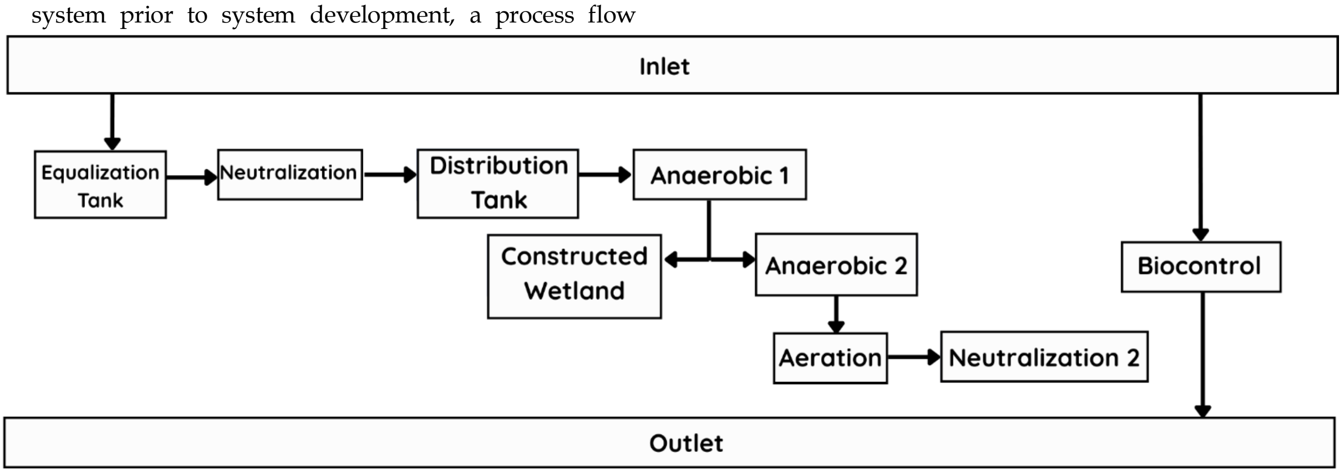

Fig. 1 Process Flow Diagram of the Existing Leachate Treatment Plant

Table 3 Average monthly air temperature in Kapanewon Nanggulan during the period 2014–2023

Month	Average Temperature(°C)
January	27,169
February	27,174
March	27,462
April	27,648
May	27,276
June	26,409
July	25,362
August	24,98
September	25,341
October	26,214
November	26,92
December	27,09

Leachate flow rate calculation was performed using the Thornthwaite method, with February selected as the representative month due to having the highest average monthly rainfall.

Determination :

PERC = P – (RO) – (AET) – (ΔST)

P = 399,211 mm

Cr = 0,2 (Cr=0,2 The study area is characterized by open land with heavy soil and gently sloping terrain (2%–7%) =0,18 – 0,22)

T = 27,174°C

c = I,62

r = 0,96

ΔST = 0 (The landfill cover is incomplete and still exposes waste that should have been properly covered, resulting in minimal water storage within the landfill body. Therefore, the change in water storage was assumed to be negligible in the percolation calculation)

Determination of percolation value :

RO = P x Cr
= 399,211 x 0,2
= 79,8422

i = $(\frac{27{,}174}{5})^{1{,}514}$
= 12,97

Ip = $\sum_{T=1}^{12} i^{1{,}514}$
= 150,69

A =(0,000000675x150,69³)−(0,0000771 x 150,69²) + (0,01792 x 150,69) − 0,49239
= 3,76

PET = 1,62 x $\left(\frac{10 \text{ x } 27{,}169}{150{,}69}\right)^{3{,}76}$)
= 147,98 mm

Adj.PET = 0,96 x 147,88
= 142,06 mm

I = 399,211 - 79,84
= 319,37

Ka = 319,37 - 142,06
= 177,3 mm

APWL = 399,211 – 142,06
= 251,23 mm

AET = PET (I ≥ Adj.PET) = 147,898 mm

PERC = 399,211 – 79,84– 147,98 – 0
= 171,39 mm

Based on the calculation results, the highest percolation value was obtained in February, amounting to 171.39 mm/month. Therefore, the leachate flow rate generated can be determined using the following equation:

$$\text{Percolation value} \left(\frac{\text{mm}}{\text{day}}\right) = \left(\frac{171{,}39}{28}\right)$$

$$\text{Percolation value} \left(\frac{\text{mm}}{\text{day}}\right) = 6{,}12 \text{ mm/day}$$

Accordingly, the leachate flow rate was calculated as follows:

$$\text{Leachate flow rate} = \frac{6{,}12 \text{ mm/day x } 10.800\ m^2}{1000}$$

= 66,11 m³/day

Furthermore, the pollutant load was calculated by multiplying the laboratory analysis results at the inlet by the daily leachate flow rate, as presented in the following table:

Table 4 Daily pollutant loads generated by Banyuroto Landfill

Parameter	Pollutant Load (kg/day)	Required Treatment Efficiency (kg/day)
BOD	39,399	29,483
COD	42,750	33,906
TSS	8,157	0,673
Total-N	2,651	2,330

Table 5 Design criteria of the existing leachate treatment plant

No	Units	Parameter	Guideline Criteria	Unit Design Criteria	Compliance with Criteria
1	Equalization Tank	Hydraulic Retention Time(HRT)	2-8 hour	27,77 hour	Not Compliant
		Depth(h)	3-5 meter	1,7 meter	Not Compliant
		Overflow rate(OR)	30–40 m³/m² ·day	1,47 m³/m² ·day	Not Compliant
2	Neutralization	Hydraulic Retention Time(HRT)	20-30 minutes	1,4 hour	Not Compliant
3	Distribution Tank	-	-	-	-

No	Units	Parameter	Guideline Criteria	Unit Design Criteria	Compliance with Criteria
4	Anaerobic 1	Hydraulic Retention Time(HRT)	12–48 hour	20,37 hour	Compliant
		Depth(h)	3–6 meter	1,5 meter	Not Compliant
		Organic loading rate(OLR)	1–4 kg COD/m³·day	1,69 kg COD/m³·day	Compliant
5	Anaerobic 1	Hydraulic Retention Time(HRT)	24–72 hour	20,37 hour	Not Compliant
		Depth(h)	3–6 m	1,5 meter	Not Compliant
		Organic loading rate(OLR)	0.5–2 kg COD/m³·day	1,69 kg COD/m³·day	Compliant
6	Constructed Wetland	Hydraulic Retention Time(HRT)	3–7 day	17,97 hour	Not Compliant
7	Aeration	Hydraulic Retention Time(HRT)	6–12 hour	1,63 hour	Not Compliant
		Depth(h)	3–5 m	0,5 meter	Not Compliant
8	Neutralization 2	Hydraulic Retention Time(HRT)	10–20 minutes	13,07 minutes	Compliant
9	Biocontrol	Depth(h)	1.5–3 meter	0,7 meter	Not Compliant

The analysis results indicate that the pollutant loads entering the leachate treatment plant (LTP) are relatively high and subject to significant fluctuations. Therefore, a treatment system capable of adapting to variations in flow rate and pollutant concentrations is required.

Justification for the Development of an MBBR-Based System

Based on the performance evaluation and technical condition of the existing LTP, optimization of the current treatment units was considered ineffective in achieving significant performance improvement. Limitations in unit capacity and process configuration represent the main factors constraining treatment efficiency.

The failure of existing leachate treatment systems to meet effluent standards is commonly attributed to insufficient unit capacity and process configurations that are not designed to handle high organic and nitrogen loads (Renou et al., 2008). This condition is consistent with the evaluation results of the Banyuroto Landfill LTP, where optimization of the existing units was deemed ineffective for substantially improving treatment performance.

Moving Bed Biofilm Reactor (MBBR) technology is therefore recommended as an alternative leachate treatment system due to its ability to retain biomass in the form of biofilm attached to moving carrier media. According to Metcalf & Eddy (2014), MBBR systems enable higher biological reaction rates without requiring large reactor volumes and provide greater process stability under fluctuating loading conditions. In addition, the combination of anoxic and aerobic zones within an MBBR system effectively supports continuous denitrification and nitrification processes.

Table 6 Pollutant Parameters Requiring MBBR Treatment Units

Parameter	Removal Process	Required MBBR Unit
BOD	Aerob	Aerobic
COD	Aerob	Aerobic
TSS	Sedimentation	Clarifier
Total-N	Nitrification–Denitrification	Aerobic & Anoxic

Table 7 Design Criteria of MBBR Units

Criteria	Unit			
	Aerobic I	Aerobic II	Clarifier	Post-Anoxic
Daily Flow Rate	66,11 m³/day	66,11 m³/day	66,11 m³/day	66,11 m³/day
Required removal capacity	74,83(%)	87,89(%)	8,26 (%)	87,89(%)
Removal Load	29,48 kg/day	28,78 kg/day	0,59 kg/day	28,78 kg/day
SALR	10 g BOD/m².day (5–15 g BOD/m²·day)	1 g NH4-N /m².day (0,4–1,0 g NH_4-N /m²·day)	SOR/OLR = 25 m³/m²·day (20–30m³/m²·day)	1,5 g NO_3-N/m².day (0,5–1,5 g NO_3-N/m²·day)
SSA	500 m²/m³ (Kaldnes K-1)	500 m²/m³ (Kaldnes K-1)	WOR = 150 m³/m·day (125–250 m³/m·day)	500 m²/m³ (Kaldnes K-1)
%fill ratio	40% (40-70%)	60% (40-70%)	-	50% (40-70%)
Media Specific Surface Area	2.948,31 m²	28.782,33 m²	2,64 m²	19.188,22 m²
Unit Volume	14,74 m³	95,94 m³	6,89 m³	47,97 m³
HRT	5,352 hour ~ ±5 hour, 25 minutes	34,832 hour ~ ±1 day, 10 hour, 50 minutes	2,5 hour (2–3 hour)	17,42 hour ~ ±17 hour, 30 minutes
Unit Dimensions	Width 5 m; Height 1,5 m; Length 1,97 m; freeboard 0,2 m	Width 5 m; Height 1,5 m; Length 12,79 m; freeboard 0,2 m	Surface Area 4,6 m2; Height 1,5 m; Diameter 1,84 m; freeboard 0,2 m	Width 5 m; Height 1,5 m; Length 6,4 m; freeboard 0,2 m.

The MBBR system configuration proposed in this study consists of an aerobic unit followed by a post-anoxic unit, designed to optimize the removal of organic matter and nitrogen from leachate. The aerobic unit serves as the primary stage for BOD and COD oxidation as well as nitrification of total nitrogen into nitrate. Application of the MBBR system under aerobic conditions promotes the formation of biofilm with high biomass concentration, thereby enhancing process stability and resistance to fluctuations in flow rate and pollutant loading commonly observed in landfill leachate (Ødegaard et al., 2000; Metcalf & Eddy, 2014).

The post-anoxic unit is implemented downstream of the aerobic unit to remove nitrate produced during the nitrification process. In this configuration, the effluent from the aerobic unit typically contains high nitrate concentrations but relatively low organic carbon content, necessitating a dedicated denitrification stage as a nitrogen polishing process. Compared to pre-anoxic configurations, post-anoxic treatment is more suitable under these conditions because pre-anoxic systems require a high influent COD/N ratio, which is no longer available in the Banyuroto Landfill leachate after aerobic treatment (Metcalf & Eddy, 2014; Renou et al., 2008).

Denitrification in the post-anoxic unit requires an external organic carbon source as an electron donor. Due to the low dissolved organic carbon content in the aerobic effluent, external carbon addition is necessary to ensure optimal denitrification performance. In this study, methanol was selected as the external carbon source because of its high efficiency, ease of control, and widespread application in post-nitrification denitrification systems (Gerardi, 2002; Metcalf & Eddy, 2014).

Limitations in the capacity and configuration of the existing treatment units hinder effective system optimization. Based on the analysis of leachate flow rate and pollutant loading, a Moving Bed Biofilm Reactor (MBBR)-based treatment system is recommended as a more adaptive and technically efficient alternative to improve leachate treatment performance.

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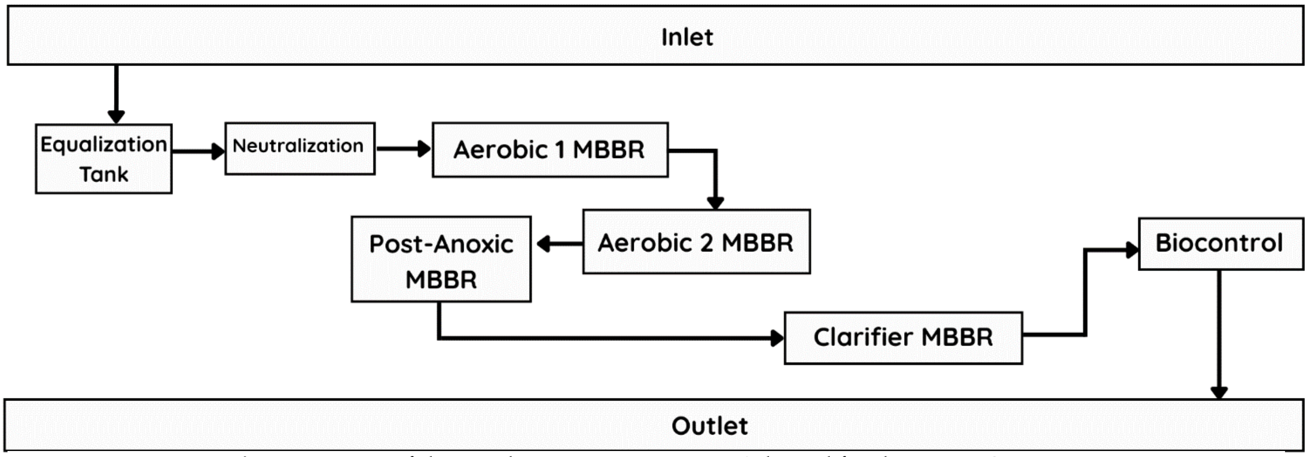

Fig. 2 Diagram of the Leachate Treatment Units Adapted for the MBBR System

A clarifier unit is placed downstream of the MBBR system to separate suspended solids and detached biomass from the effluent. The clarifier functions to reduce effluent total suspended solids (TSS) and to ensure more stable effluent quality prior to discharge into receiving water bodies, thereby supporting overall compliance with effluent standards.

The development of an MBBR-based system was selected as an alternative replacement because this technology has been proven to be more adaptable to fluctuations in flow rate and pollutant loading and to provide greater process stability compared to conventional biological treatment systems (Ødegaard et al., 2000; Di Trapani et al., 2011).

CONCLUSION

The evaluation results demonstrate that the Banyuroto Landfill Leachate Treatment Plant has not yet complied with the applicable leachate effluent standards, particularly for organic and nitrogen-related parameters.

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