Journal Home Page:
https://e-journal.unair.ac.id/JKL

Jurnal Kesehatan Lingkungan
Journal of Environmental Health
Vol. 15 No. 2
DOI: 10.20473/jkl.v15i2.2023.143-151
ISSN: 1829 - 7285 | E-ISSN: 2040 - 881X

ORIGINAL RESEARCH Open Access

POTENTIAL SEQUENCING BATCH REACTOR IN LEACHATE TREATMENT FOR ORGANIC AND NITROGEN REMOVAL EFFICIENCY

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Article Info

Submitted	: 1 February 2023
In reviewed	: 8 March 2023
Accepted	: 5 April 2023
Available Online	: 30 April 2023

Keywords : *Leachate, Sequencing batch reactor, Wastewater treatment*

Published by *Faculty of Public Health Universitas Airlangga*

Abstract

Introduction: *Landfill wastewater or leachate has unique characteristics. Several conventional methods need a few treatment tanks to cover the treatment process. A Sequencing Batch Reactor (SBR) is a biological treatment method that uses a single tank with few-cycle phases. This study aims to determine the potential of a Sequencing Batch Reactor (SBR) that can be used to treat landfill leachate.* ***Methods:*** *A Sequencing Batch Reactor (SBR) was used in this study. The characteristics of leachate served as the basis for the design of the SBR reactor. The synthetic leachate was used to create the reactor feed based on the actual landfill leachate compositions. The reactor's influent and effluent were analyzed based on a few parameter changes, such as Suspended Solid (SS), Chemical Oxygen Demand (COD), ammonia nitrogen (NH_3-N), and Total Kjeldahl Nitrogen (TKN).* ***Results and Discussion:*** *While the experiment was running, 84% of SS were removed, 88% of COD were removed, a -28% efficiency rate for NH_3-N removal, and a -172% efficiency rate for TKN removal. After the withdrawal phase, the supernatant showed promising results with 99% COD removal, 97% SS removal, and 65% TKN removal. Unfortunately, the removal of NH_3-N reaches -130%. It indicates insufficient concentrations of MLSS and SRT, as well as the presence of a eutrophication process.* ***Conclusion:*** *SBR shows a promising result for leachate treatment. Few changes in the cycling process were needed for further study, so the treatment process becomes optimal to reach its full potential.*

INTRODUCTION

Economic growth, industrial activities, production-consumption activities, and human activities contribute to the increase in waste produced each year. Waste originating from residential, industrial, commercial, and some construction areas usually use the backfilling method or landfill. However, there are still some problems related to the landfill, such as the problem of leachate and the problem of methane gas formed from biological reactions between living organisms in the soil with types of garbage that organisms can biologically decompose.

Leachate is produced when water seeps through any permeable material containing solution, suspended material, or both (1). Leachate has different characteristics from other wastewater. The leachate characteristic depends on the permeable material the water passes. The more organic, inorganics, and heavy metals contained in the material, the more dangerous the pollution produced for the environment. Some factors that affect the composition of leachate are particle size, degree of compaction, waste characteristics, hydrology, climate, site age, and level of waste stabilization (2).

In some countries with dry weather and high humidity, the landfill leachate generates higher COD and BOD concentrations. Meanwhile, countries with wet weather have the lowest COD and BOD content in their leachate. A country's economic income also significantly contributes to landfill leachate composition. High-income countries have leachate content less vulnerable to the environment due to lower COD and BOD concentration

Cite this as :
Viareco H, Adriansyah E, Sufra R. Potential Sequencing Batch Reactor in Leachate Treatment for Organic and Nitrogen Removal Efficiency. *Jurnal Kesehatan Lingkungan*. 2023;15(2):143–151. https://doi.org/10.20473/jkl.v15i2.2023.143-151

than middle-income and lower-income countries (3). High-income countries have implemented good waste management programs to dispose of less waste in landfills.

Regarding landfill waste fraction, organic fractions such as food waste significantly contributed to the organic matter in leachate generation (4). The organic matter in leachate consists of most humic-like organic compounds, some protein-based, degraded through the evaporation process (5). The inorganic fraction in leachate includes a rich content of ammonia and salinity. Several studies have shown the involvement of the anaerobic ammonium oxidation process (anammox) as an alternative to biological nitrogen removal in leachate treatment, with a removal performance of up to 65% in 13 days (6). Besides organic, inorganic, and heavy metals compounds, leachate has microplastic content due to plastic waste degradation in landfills and becomes a source of microplastic dispersion through groundwater (7).

An Index is being used to measure the potential contamination of landfill leachate, Leachate Pollution Index (LPI), which ranges from 0 to 100. Based on the Leachate Pollution Index (LPI), a landfill with an LPI value of more than 35 indicates high negative impacts on the surrounding environment (8). Therefore, it is necessary to periodically observe the quality of the leachate produced by landfills (9).

In the selection treatment, the content factor significantly affects the results obtained. Furthermore, the leachate content depends on the landfill age (10), so much so that the content and age of the site factor influence the selection of the appropriate treatment process.

Landfill under five years of operation time has higher BOD and COD concentrations in their leachate. In this condition, an acidogenic phase occurs where organic compounds begin to ferment rapidly with the help of microorganisms. Within the increment of landfill age, the BOD and COD concentration decreases until it reaches stable condition, called the maturation process through the methanogenic phase (11). It indicates that landfill leachate contains high organic matter from organic waste during the first year's operation. Nevertheless, due to biological decomposition by microorganisms, the organic fraction slowly decreases.

Contrary to organic fraction, the inorganic component in leachate does not decrease with increasing landfill age. It is crucial to sort inorganic waste before disposal in landfills to avoid high inorganic content in leachate. All the different characteristics of landfill leachate due to the age of the landfill are defined in Table 1.

Table 1. Leachate Characteristic based on Age

Characteristics	Young	Mature	Old
Age (years)	<5	5 - 10	>10
pH	6.21 – 7.7	6.5 – 7.5	>7.5
COD (mg/l)	>10,000	4,000 – 10,000	<4,000
BOD (mg/l)	10,000 – 25,000	1,000 – 4,000	<1,000
BOD/COD ratio	>0.5	0.1 – 0.5	<0.1
Heavy metals	Medium	Low	Low
Biodegradable	High	Medium	Low
Organic matter	80% Volatile fatty acids	5 – 30% Volatile fatty acids, fulvic, and humic acid	Fulvic and humic acid

As for leachate treatment, there are several methods, such as conventional treatment methods (water transfer leaching, biodegradation, and chemical and physical methods) and some new methods, such as microfiltration, ultrafiltration, reverse osmosis, and advanced oxidation technics (12). Some landfill leachate treatment designs use several-stage processes to achieve minimum requirement standard quality, such as equalization tanks, anaerobic ponds, facultative ponds, maturation ponds, and anaerobic baffled reactors (ABR). Specific landfill leachate treatment design requires a large land area to cover the entire stage (13). Biological leachate treatment has the advantage of being cost-effective, such as using fungi as a biological method, showing promising results (14). In addition, biological methods categorized as green treatment have significant efficiency removal, such as the use of constructed wetlands and solar Photo-Fenton in leachate treatment which reaches 75%-95% efficiency for organic and inorganic compounds (15).

Few studies modify the chemical leachate treatment process by using electro-coagulant methods as the intermediary, and it shows a magnificent result for high organics and ammonia content by simultaneous removal (16). The use of membranes in leachate treatment has been widely trialed in recent years, especially as an additional reverse osmosis method. Nanofiltration membranes with antifouling and antibacterial properties can help improve the process of separating organic content and divalent/monovalent ions (17). Several studies have shown promising results for membrane technology used for leachate treatment with mature and old landfills age ranges (18–20).

Sequencing Batch Reactor (SBR) is one of the technology treatments most suitable for landfill leachate within the age range from young to intermediate (21). SBR treatment includes biological nutrient removal, nitrification, denitrification, and phosphorus. SBR combines several tanks, such as filling tanks, tank reaction, and sedimentation tanks, in one container or tank. Respond biological, aeration, sedimentation, and clarification processes occur in one tank but at different times (22).

SBR uses activated sludge to perform biological treatment in one container with few cycling processes. The cycling process in SBR includes the idle phase, static phase, mixing phase, aeration phase, reaction phase, settling phase, and draw phase, then comes back again to the idle phase. The idle phase is the biomass seeding process to become mature activated sludge. The organic compound removal gradually occurs from the static to the aeration phase. Activated sludge reacts with leachate to perform biological processes, and SBR organic removal efficiency rate depends on it (23–24).

After the aeration phase comes the reaction phase, which starts the nitrification and denitrification process, appropriate time exposure to the reaction process, and nitrification leads to a complete transition to nitritation and increased nitrogen removal efficiency (25–26). The settling phase will show how much the organic removal reaches the peak point by separation by gravity between sedimented biomass and supernatant. In the draw phase, supernatant will be removed from the reactor, leaving the biomass as activated sludge for the following cycling process. As for energy consumption, SBR operated at a low energy consumption level. The power consumption used mixing and aeration phases, which contribute to removing organic matter (27).

In the last few decades, SBR modifications, such as adding biofilters, have improved SBR's performance in removing leachate content, not only organic content but also microplastic content and endocrine-disrupting chemicals (28). SBR is promising in leachate treatment and can be used for other types of wastewater, such as agricultural wastewater (29). Using palm oil clinker waste as a bio-carrier in the SBR reactor provides promising results in removing COD from wastewater (30).

This study designed a single-stage SBR to investigate its potential in the synthetic leachate treatment process that resembles actual leachate from the landfill. Where the study was done on the changes like the leachate before treated and after treated until the treated effluent can fill existing standards based on a few parameter changes, such as Suspended Solid (SS), Chemical Oxygen Demand (COD), ammonia nitrogen (NH_3-N), and Total Kjeldahl Nitrogen (TKN). The objective was: (i) evaluate organic removal efficiency with indicator SS and COD, (ii) identify nitrogen removal efficiency with indicator NH_3-N and TKN.

METHODS

Leachate Synthetic Influent

The influent used synthetic leachate from a mixture of certain types of chemicals. Synthetic leachate has characteristics that almost match the properties of actual leachate. A list of chemicals used is in Table 2.

Table 2. List of Chemicals for the Preparation of Synthetic Wastewater

Component	Concentration (g/l)	Source
Glucose	0.5	Carbon and Energy
Ammonium Chloride (NH_4-Cl)	0.32	Nitrogen and Sulfur
Magnesium Sulphate ($MGSO_4$-$7H_2O$)	0.6	Magnesium and Sulfur
Calcium Chloride ($CaCl_2$-$2H_2O$)	0.007	pH Buffer
Kalium Hydrogen Phosphate (K_2HPO_4)	0.09	pH Buffer, Kalium, and Phosphate
Kalium Dihydrogen Phosphate (KH_2PO_4)	0.05	pH Buffer, Kalium, and Phosphate
Ferric Chloride ($FECl_3$-$6H_2O$)	0.005	Iron

The chemicals are weighed based on the concentration of the solution required. The Organic Load Rate (OLR) required affects the solution's concentration. The Organic Load Rate determines the daily flow rate and quantity used. The Organic Load Rate can be calculated using equation 1.

$$OLR = \frac{M \ x \ V_{in}}{V_{tot}} OLR = \frac{M \ x \ V_{in}}{V_{tot}} \quad (1)$$

M represents the COD concentration of leachate synthetic in g/l, Vin for the volume influent in a liter, and Vtot for the volume reactor in m^3. OLR values will be calculated for each run to determine the effect on detention time. For the first run, the OLR rate is set at 0.2 kg COD/m^3.day, the volume of leachate synthetic used of 6 liters per day, and the volume of the reactor used is 10 liters. The required COD concentration value was obtained to determine the amount of solution that should be prepared for each component of the synthetic leachate. The COD concentration value obtained through equation 1 is 333.33 mg/l. Then by comparing the concentration rate of COD, N (Ammonium Chloride), and P (Potassium Hydrogen Phosphate and Potassium Dihydrogen Phosphate), which is 100:5:1, the concentration of Ammonium Chloride (NH_4-Cl) is 16.65 mg/l, and for Potassium Hydrogen Phosphate and Potassium Dihydrogen Phosphate is

3.33 mg/l. Then each component is weighed to match the concentration estimated. Due to the lack of storage flasks, the concentration was increased sufficiently for ten days process.

Table 3. List of Chemical Feed Rates used in 6 Liters of Influent

Component	Concentration (g/l)	Influent Concentration (ml)
Glucose	0.5	10
Ammonium Chloride (NH_4-Cl)	0.32	20
Magnesium Sulphate ($MGSO_4$-$7H_2O$)	0.6	40
Calcium Chloride ($CaCl_2$-$2H_2O$)	0.007	10
Kalium Hydrogen Phosphate (K_2HPO_4)	0.09	10 (mixed KH_2PO_4)
Kalium Dihydrogen Phosphate (KH_2PO_4)	0.05	10 (mixed KH_2PO_4)
Ferric Chloride ($FECl_3$-$6H_2O$)	0.005	2.5

Each component in Table 3 is mixed based on the solution rate into a container, and then water is added until it reaches a volume of 6 liters. The mixed solution is added to the SBR reactor as an influent.

Activated Sludge

A system based on activated sludge microalgae-bacteria collection derived from sewage can be used as a high-impact component in the SBR reactor cycle process (31). As an initial feeder, activated sludge from the domestic septic tank is used for the reactor seeding of microorganisms. In cultivating microorganisms in activated sludge, equation 2 determines the Mixed Liquor Suspended Solid (MLSS) value and the F:M ratio so that the activated sludge is sufficient to process biological treatments.

$$F:M = OLR\,\frac{1}{L} F:M = OLR\,\frac{1}{L} \qquad (2)$$

Where F:M is the food and microorganisms ratio of activated sludge, OLR value from equation 1, and L for the MLSS of activated sludge used in kg/m^3.

SBR Lab Scale Design

The study was conducted using a single-stage sequential batch reactor or SBR. The reactor was designed according to the suitability of the influent and based on research results from related journals and reference books (32). In the calculation of the design of the reactor in series, they were using the basic design calculations for activated sludge process aeration tanks. Information on the design parameters of the sequential batch reactor is listed in Table 4.

Table 4. Reactor Parameters Design

Parameter	SBR	This Experiment
SRT (day)	10 - 30	10
HRT (hours)	24	24
Volume (liter)	>100	10
F:M ratio	0.04 – 0.10	0.6
MLSS (mg/l)	2,000 – 5,000	4,000
Influent Flow rate (l/day)	>100	6
Activated Sludge (liter)	-	4
OLR (kg COD/m^3.day)	0.1 – 0.4	0.2
BOD loading (kg/ m^3.day)	0.1 – 0.3	4

The SBR lab scale in this study has an influent tube at the top of the reactor and two exit paths at the bottom and the side of the reactor. The bottom exit line is for sludge collection, and the sideline is for effluent. 2 exit paths for the separation process between suspended sludge and clarified effluent. The reactor is equipped with a medium blade stir for the mixing phase. The aeration process was through the influent tube by infusing air from the air pump within 2-5 mg/l.

SBR Cycling Process

The Sludge Retention Time (SRT) value used as the reactor's initial design could be measured using equation 3.

$$SRT = \frac{V_{tot}\ x\ L}{Q_w\ x\ L_w} SRT = \frac{V_{tot}\ x\ L}{Q_w\ x\ L_w} \qquad (3)$$

Q_w represents the flow rate of disposed of sludge in m^3/days, and L_w for the concentration of MLSS disposed of in mg/l. The experiment was run over ten days. The SBR operation method is used over the seeding process, which takes 15 minutes and 24 hours for one primary treatment cycle. The main treatment processes are the fill, reaction, settling, and draw phases—seeding in the idle phase, where activated sludge was prepared for microorganisms for the biological process. The activated sludge for this experiment was used domestic septic tank sludge.

After the idle phase, the primary cycle starts, with the first phase being the fill phase. Approximately 5 minutes of synthetic leachate was introduced into the reactor through the influent flow without mixing or aeration. After pouring, leachate synthetic and activated sludge was mixed for 5 minutes with a stirring speed of 5–10 rpm, and while the mixing process ran for the next

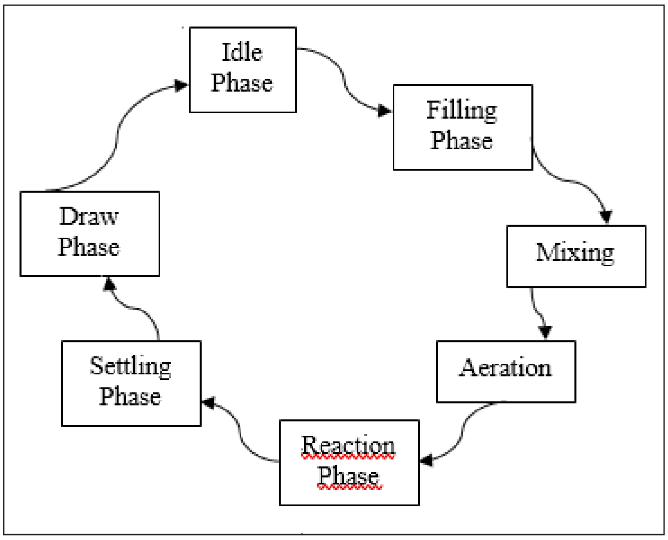

Figure 1. Schematic SBR Cycle Process (5)

5 minutes, oxygen was added approximately 2–4.5 mg/l. Once the volume of drain water has been fully fed into the tank, it starts the complete reaction phase. Although the reaction process started during the filling phase, the process is not complete. The reaction phase begins by maintaining the stirring and aeration process that has been done during the charging phase. The aeration feed is estimated at 2.5-4 mg/l. During the beginning reaction phase, the stirring speed increased to 36 rpm. In this phase, the ammoniation process will occur, and nitrification. This phase is estimated to take 12 hours.

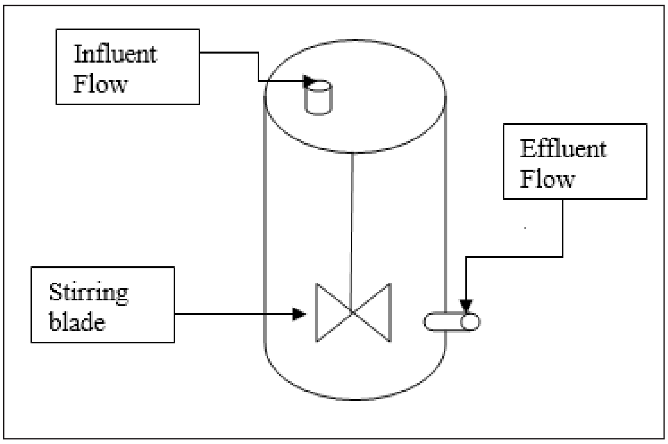

Figure 2. Schematic SBR Reactor

After the reaction phase is aerated, the reaction phase is continued with conditions anoxic and anaerobic, which is a mixed reaction phase, where in this phase, aeration is stopped, and stirring is maintained. Stirring speed maintained at 36 rpm. In this phase, the denitrification process will occur. This phase is estimated to take 12 hours. The cycle continues to the settling phase. In the settling phase, the reaction process of microorganisms may still be going on. In the sedimentation phase, the aeration and agitation processes are stopped. The process has naturally done that is using gravity. The specific weight of the sludge accumulates larger than the specific gravity of water until it settles in part under the tank. For the beginning of the study, this phase is estimated to require time for 60 minutes.

As a result of the settling phase, two layers accumulated: the supernatant layer at the top and the sludge layer at the bottom. During the draw phase, supernatant goes out through effluent flow and then sludges through the sludge line at the bottom. The drawing phase was estimated to take around 45 minutes. High drawing time due to unsettling sludge in the supernatant layer and reducing the amount of sludge is carried out through effluent flow.

Influent and Effluent Analysis

Influent and effluent samples were tested for the content of specific parameters in which the effectiveness of the reactor in treating can be measured. Influent and effluent were evaluated based on several parameters, including Chemical Oxygen Demand (COD) using the APHA (2000) 5220-B open reflux method and Suspended Solids (SS) using APHA (2000) 2540-D drying method. Besides that, it also includes Mixed Liquor Suspended Solid (MLSS) using APHA (2000) 2540-D drying method, ammonium nitrogen (NH_3-N) sing APHA (2000) 4500-NH_3-B distillation and titration method, and Total Kjeldahl Nitrogen (TKN) using APHA (2000) 4500-Norg-B Macro-Kjeldahl method. The parameters were tested daily as an overview treatment process.

RESULTS

Influent and Effluent Supernatant

The result data of influent and effluent supernatant analysis can be seen in table 5. From the COD/N/P ratio, which is 100/5/1, the data obtained for the effluent does not match the ratio. The influent COD value of 1000 mg/l, and the TKN value is 28.56 mg/l. The influent ratio is 100/2.85 (COD/N). From this result, it can be seen that the value of the nitrogen concentration contained in the leachate synthetic is less than the set value of 50 mg/l. Unsettle sludge causes the reading of several parameters such as COD, ammonia nitrogen, and TKN excess for the final value in the effluent, which is mixed with activated sludge carried away.

Table 5. Data and Results of Leachate Synthetic as Influent and Supernatant

Parameter	Leachate Synthetic	Supernatant
COD (mg/l)	1,000	10
MLSS (mg/l)	800	20

Parameter	Leachate Synthetic	Supernatant
Ammonia Nitrogen (NH_3-N) (mg/l)	17.36	40
Total Kjeldahl Nitrogen (TKN) (mg/l)	28.56	10

SBR Treatment Process

Based on Figure 3, the results are encouraging for Suspended Solids (SS). Where on the second day, the SS value decreased drastically. However, for the next several days, the pattern shows an up-and-down pattern. It may be due to sludge bulking, which filamentous microorganisms cause sludge to not settle well during the settling phase. The supernatant comes out with unsettled sludge residue.

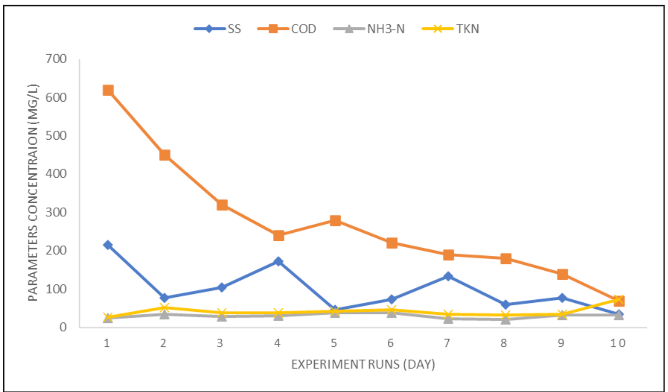

Figure 3. Parameter Removal in 10 Days Experiment Process

At the beginning of the experiment, the COD concentration started to show a declining pattern. There was a slight increment on the fifth day, but it decreased again. At the end of the study, the COD value showed satisfactory removal. For ammonia nitrogen and TKN analysis, the results show an irregular pattern. In the beginning, it can be seen that there is a decrease. However, for the range fifth to the eighth day, sudden peak up-down results trigger an increase of ammonia nitrogen and TKN at the end of experiments.

Table 6. Data and Results of Leachate Synthetic during the Treatment Process

Day	SS (mg/l)	COD (mg/l)	NH_3-N (mg/l)	TKN (mg/l)
1	216	620	25.2	26.88
2	78	450	35	52.36
3	105	320	28.36	39.2
4	172	240	29.68	38.64
5	46	280	39,2	41.44
6	74	220	38.64	45.64
7	133	190	21.84	34.16
8	59	180	20.72	31.92
9	77	140	32.48	35.28
10	34	70	32.48	73.19

DISCUSSION

From the results obtained, it can be concluded that the value of the F:M ratio and the OLR used (0.6 and 0.2 kg COD/m^3 day) is not the optimal value for treating the leachate synthetic used. The data obtained cannot state the effect of OLR and SRT on the effectiveness of SBR in leachate treatment. SRT value depends on the OLR value determined at the beginning of the study (33). If the OLR value is low, then the SRT value will increase, and If the OLR value is high, then the SRT value will be decreased. A high SRT value indicates a high MLSS concentration value. The OLR value significantly affects the Solid Retention Time (SRT) SBR (34). Further research must obtain appropriate data so that the effects of OLR and SRT can be seen clearly and get the optimal F:M ratio and OLR values.

During ten days of monitoring changes in parameters in the reactor, it was seen that there was a steady trend of decreasing parameter content such as SS and COD. The performance of removal of SS and COD content for ten days of the treatment process reached 84% and 88%. However, the elimination performance of the parameters NH_3-N and TKN give -28% and -172%. It shows that the role of microorganisms (Nitrosomonas and Nitrobacter) involved in nitrification and denitrification processes is very small.

The instability of the pattern shows that the nitrogen removal process is still happening by microorganisms, and at the end of the runs, the microorganism may have died so that nitrogen removal does not occur (35). Other factors, such as reactor conditions during the reaction phase and the process not being entirely anaerobic (influence of external conditions), also affect the removal process.

From the results of the increase in nitrogen content at the end of the study period, it can be concluded that eutrophication occurred during the processing process. Most nitrogen in the leachate at the start of the initial phase may be nitrate, thus triggering the eutrophication process. The parameters of the influent compounds need to be further measured at an early stage to ensure that the processing can be carried out according to plan.

The process of physically separating the draw phase is beneficial in reducing the value of the supernatant content parameter as the final effluent product. The final SBR effluent results showed that SS and COD removal performance reached 97% and 99%. The final assessment of SBR performance in eliminating NH_3-N and TKN content did not give the expected results but achieved values of -130% and 65%.

Several studies implied that the enrichment of nitrogen concentrations in the early phase of the SBR cycle could lead to the anammox process, which results in a nitrogen removal performance of up to 95% (36). The removal of the phosphorus content in the leachate itself goes hand in hand with the increase in the removal of the nitrogen content (37). Combining physical, chemical, and biological methods in the SBR cycle phase reduces nitrogen compounds and decolorizes landfill leachate (38).

ACKNOWLEDGMENTS

The authors appreciate significantly all members, staff, and lecturers of Universitas Jambi, Universitas Batanghari, Institut Teknologi Sumatera, Universitas Gadjah Mada, and Universiti Kebangsaan Malaysia for providing such excellent sharing information and discussion opportunity. Without their assistance and insights, the study's conclusion would not have been achievable.

CONCLUSION

Overall, the few results obtained a satisfactory removal, but the other hand showed unsuccessful removal. Percentage Suspended Solids (SS) removal reached 97%, COD removal reached 99%, ammonia nitrogen removal (NH_3-N) reached -130%, and the removal of total Kjeldahl nitrogen (TKN) reached 65%.

It can be concluded from the final results of the study that using SBR in leachate processing can remove organic content with an average removal rate above 96%, and for nitrogen content, it cannot provide results that are not as expected. The increase in nitrogen content in the supernatant indicates that the nitrification and denitrification processes are not going well, so the nitrogen content is higher than the previous one. It can also be concluded that a eutrophication process has occurred, which interferes with the removal of nitrogen content. Monitoring influent nitrogen content and adding nitrogen content during the seeding phase can assist in preparing nitrification and denitrification processes.

The MLSS value of 800 mg/l is insufficient, which should be between 2,000-4,000 mg/l. It shows that the value of Solid Retention Time (SRT) is less for microorganisms to multiply wholly, causing the value obtained to be unsatisfactory for nitration and denitrification. Further study and some changes are needed implementation of the study to provide better removal results. Reactor modification by utilizing carriers and using membranes as biofilters can be used as a basis for further research improvements.

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