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THE ENVIRONMENTAL IMPACT OF LEACHATE PROCESSING INSTALLATIONS: LIFE CYCLE ASSESSMENT (LCA) STUDY

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ABSTRACT
This study aims to analyze waste management in the face of population growth and increasing human activity. As the population continues to grow and human activities intensify, the proper management of waste becomes crucial to safeguarding the environment. In this context, leachate treatment through the Leachate Treatment Plant (LTP) emerges as a key element in protecting the environment from the negative impacts of leachate. The Life Cycle Assessment (LCA) method serves as a valuable tool for analyzing the environmental implications of LTPs and aiding in sustainable decision-making. The research process commences with gathering essential data and constructing an inventory related to energy use, greenhouse gas emissions, water pollution loads, and the utilization of natural resources. Through the gate-to-gate approach using the SimaPro application with the CML-IA Baseline method, the environmental impacts are quantified. The study reveals the significant impacts of Global warming (3.03E-08 Pt), Photochemical Oxidation (3.70E-09 Pt), Human toxicity (2.09E-09 Pt), and Eutrophication (1.87E-06 Pt). Eutrophication stands out as the most prominent impact of wastewater treatment. The resultant eutrophication impact predominantly originates from the Biological Oxygen Demand (BOD) pollutant component, mainly generated from the equalization tub unit and constructed wetland. Furthermore, the control tank emerges as the primary source of the dominant pollutant.
Keywords: Leachate Treatment Plant, Life Cycle Assessment, Impact Assessment, Eutrophication

INTRODUCTION

Rapid industrialization, urbanization, and improvement in living standards are expected to increase solid waste production (Yantrapalli, et al., 2018). Solid waste or garbage is the residue from activities or processes that are no longer needed or wanted (UU, 2008). To prevent adverse effects from waste disposal, the construction of a Controlled Landfill equipped with leachate treatment technology is necessary to ensure that the waste disposed of does not harm the environment.

Controlled Landfill is a waste disposal system that uses PVC layers to contain leachate, preventing it from seeping into the soil, and includes leachate channels with specific requirements (Ahmad, et al., 2017). This system directs the leachate to the Leachate Treatment Plant (LTP) for processing before discharging it into water bodies. Leachate is a byproduct of the biotransformation and decomposition of waste generated by microbes, and it has the potential to contaminate surrounding water bodies, especially groundwater (Wang and Shen, 2000).

Leachate contains a significant amounts of organic substances because the waste produced consists of organic materials with high water content. The primary components of organic materials are carbon, protein, and lipid fats (Apriyanti, 2018). Excessive organic substances in water can cause physical changes, such as discoloration, unpleasant odor, and the death of aquatic organisms due to decreased oxygen levels and water quality (Oktavia, 2018).

The leachate treatment process results in gas emissions such as mercury, carbon dioxide, methane, and other greenhouse gases (PERMENLHK, 2016). Continuous emissions contribute to the increase of greenhouse gases and global warming. With ongoing waste disposal, leachate production also increases, exacerbating environmental conditions and impacting the health of people living near the contaminated area.

Internal tests indicate that the discharged leachate does not meet the quality standards for BOD, COD, and mercury pollutants. Based on this research, the Leachate Treatment Plant (LTP) in the landfill area needs evaluation and improvement by redesigning the treatment units to meet the water quality standards. The leachate treatment process involves biological treatment methods, including control tanks, anaerobic baffled reactors (ABR), aeration, and wetland ponds. However, if the waste contains high chemical characteristics and acidic pH, the bacteria may die or function poorly, necessitating reevaluation. Additionally, the processing time, which requires at least one day, and the relatively low COD removal efficiency (5-20%) should also be considered (Wang and Shen, 2000).

Based on the need for evaluation of the Leachate Treatment Plant (LTP) at the landfill and the understanding of the leachate life cycle, an evaluation using the Life Cycle Assessment (LCA) method is necessary. This method aims to analyze the environmental impacts throughout all stages of the life cycle of a studied product, starting from the extraction of raw materials, the production process, product consumption, and the disposal of the resulting product, as well as the potential for reuse or recycling (SNI ISO 14044, 2017). The Life Cycle Assessment (LCA) method consists of four main stages in its application. The first stage is goal and scope definition, followed by the second stage which is life cycle inventory (LCI). In the third stage, there is life cycle impact assessment (LCIA), and the final stage involves interpretation of data (Curran, 2007). This aims to identify the generated impacts quantitatively and assist decision- makers in determining the best environmental improvement scenarios (Goran, et al., 2009).

In conclusion, it is expected that the environmental impact resulting from the leachate treatment process at the Leachate Treatment Plant (LTP), using the Life Cycle Assessment (LCA) approach, can be reduced or eliminated. This will support environmental improvements in the future.

RESEARCH METHODS

The Life Cycle Assessment (LCA) method is used in this study to identify the environmental impacts and determine mitigation alternatives to reduce the impact of leachate treatment processes. The following are the stages conducted in this research:

1) Goals and Scope Definition

The first stage involves setting the research objectives, identifying the environmental impacts of activities in the leachate treatment process, and formulating the environmental impacts resulting from these issues. The data input includes information on raw materials, while the data output consists of emissions, waste, and environmental impacts generated by the leachate treatment plant. The specific details in this stage include:

1. Functional unit, which represents the unit of the product used, namely 1 m3 of treated water.
2. Product system, which encompasses the leachate treatment plant installation.
3. System boundaries, which define the scope of the research, namely gate to gate.

2) Life Cycle Inventory (LCI)

The second stage involves inventorying inputs and outputs related to the study's scope. The LCI stage is detailed as follows:

1. Inventory activities include inputting data on raw materials, waste, and emissions for each process unit, as well as the amount of electricity and water used.
2. Creating a flow diagram to connect the data to process units and functional units related to wastewater output.

3) Life Cycle Impact Assessment (LCIA)

In this stage, the environmental impacts resulting from processing the inventory data are assessed. The following steps are performed in LCIA:

1. Selection of impact assessment method: The CML-IA Baseline method is chosen to focus on midpoint impact categories, namely global warming (GWP100a), photochemical oxidation, human toxicity, and eutrophication.
2. Classification, where the environmental impacts of a product or system are categorized into several impact categories. This classification helps in understanding and analyzing the impacts in more detail.
3. Characterization, which involves converting all elementary flows from LCI into impact values. The characterization factor is applied to inventory data to calculate the relevant impacts in the selected categories. The SimaPro software using the CML-IA Baseline method directly yields the characterization values.
4. Normalization, which standardizes the units obtained from the selected impact categories using normalization factors. This facilitates comparisons between impact categories. The normalization value is obtained by dividing the characterization result by the normalization factor.
5. Weighting (optional), which is performed to facilitate comparing the impacts between different product alternatives.

4) Interpretation of Data

Interpreting the data is the final stage of life cycle analysis, providing alternatives for each process under investigation. The objective of this stage is to identify hotspots or areas with the most significant impact within the industry's processes. Hotspots represent points with the most significant impact within a process system, determined based on the life cycle impact assessment results.

5) Conclusion and Recommendations

In the final stage, conclusions are drawn and recommendations are made based on the analysis of data and discussions. The conclusion summarizes the findings and addresses the research problem. Furthermore, recommendations are provided for enhancing future research and implementation. These suggestions aim to improve future studies and guide potential improvements in the field.

RESULTS AND DISCUSSION

Goal and Scope Definition

Here are the goal and scope definitions for this LCA study:

1. Goal

The goal of this Life Cycle Assessment (LCA) is to quantitatively assess the environmental impacts of the landfill leachate treatment facility. The study aims to obtain numerical values for the environmental impacts resulting from the treatment of landfill leachate. The assessment's findings will be used to analyze and evaluate mitigation programs aimed at reducing the environmental impacts caused by the leachate treatment process at the landfill site. The study takes into consideration the overall process and emissions generated by the leachate treatment facility until the treated effluent is discharged into the receiving water body.

2. Scope

The scope of the LCA study is conducted "gate to gate," which means it includes the analysis of processes starting from the initial entry of landfill leachate into the treatment facility until the final discharge of treated effluent into the receiving water body.

Within the leachate treatment facility, a mass balance is developed to ensure a balance between the mass of incoming materials and the resulting outputs from each process unit. The system boundary of the leachate treatment facility is defined to encompass all relevant processes and emissions, ensuring a comprehensive assessment.

In summary, the scope of this LCA study includes the following:

a. The study covers the entire process of landfill leachate treatment, starting from the point of entry into the treatment facility until the treated effluent is discharged into the receiving water body.

b. The functional unit used for assessment is 1 m3 of treated effluent, which serves as a standardized measure for quantifying the environmental impacts.

c. Data for the study will be collected from the year 2022 and will include both primary data (such as leachate flow rate) and secondary data from the landfill management agency (UPT TPA) after verification.

d. The analysis will consider a mass balance approach, ensuring a proper accounting of the materials entering and leaving each process unit within the leachate treatment facility.

The system boundary of the leachate treatment facility is visually represented in Figure 1, providing a clear illustration of the processes and emissions considered in the LCA analysis.

Life Cycle Inventory (LCI)

The Life Cycle Inventory (LCI) stage is the second phase in Life Cycle Assessment (LCA), which involves inventorying and quantifying data on inputs (raw materials, energy use, and water use) and outputs (products, air emissions, soil emissions, and water pollutants) for a product throughout its life cycle. The following are the stages in LCI:

1. Data collection

The data collection process includes specifying all input and output flows from the processes within the product system. data will be verified on interested parties.

2. Calculating

Performing the calculation of water pollutant loads from sanitary and household waste. The following are the steps for the calculation:

Mercury (Hg) : 0,005 mg/L

Debit : 216,70 m3/hari

Load of Mercury (Ton)

= (0,005 mg/L× 216,70 m^3/hari × 1000L/m^3 × 10^9 ton/mg)

Load of Mercury (Ton)= 0,005 Ton

3. Data Inventory

Data inventory involves organizing data into a single table. The division of the total quantity of inputs and outputs by the total product serves as a step for normalizing data for each process unit. In 2022, the Sanitary Landfill Facility discharged 11.015,872 m^3 of treated wastewater.

3. Mass balance

Mass balance is an inventory that is presented in the form of a diagram. This is done to facilitate the reading of inventory data and to validate that the input and output data are balanced. The mass balance of the sanitary landfill leachate treatment facility can be seen in Figure 1 below.

Life Cycle Impact Assessment (LCI)

The Life Cycle Impact Assessment (LCIA) stage involves different impact categories identified to capture various environmental issues. The LCIA analysis is divided into three steps: impact classification, characterization, and normalization.

1. Impact classification

Impact classification helps in understanding and categorizing these impacts so that they can be analyzed and evaluated in more detail. The following is Figure 2 of the impact classification diagram based on the unit.

2. Impact characterization

Characterization of impacts in SimaPro software using the CML-IA (CML-IA Baseline) method results in impact scores as shown in Table 1 below.

3. Impact normalization

Normalization stage helps provide a perspective on the generated impacts so they can be compared in a relevant manner by expressing the impact scores as relative values. The value can be seen in Table 2 below. In this study's scope, the weighting stage is equivalent to normalization because the factors presented in SimaPro with the CML-IA Baseline database convey that normalization and weighting are the same.

Interpretation

The interpretation stage shows the results of the environmental impact analysis and evaluation of a product or system. To present the impact results, here is an example of calculating eutrofication impact to be percentage:

$$\text{Persentase Eutrofikasi} = \frac{\text{Karakteristik eutrofikasi constructed wetland}}{\text{Total karakteristik eutrofikasi constructed wetland}} \times 100\%$$

$$= \frac{11328{,}209 \text{ kg PO4eq}}{24624{,}085 \text{ kg PO4eq}} \times 100\%$$

$$= 46\%$$

The results of calculating the process hotpot value can be seen in table 3.

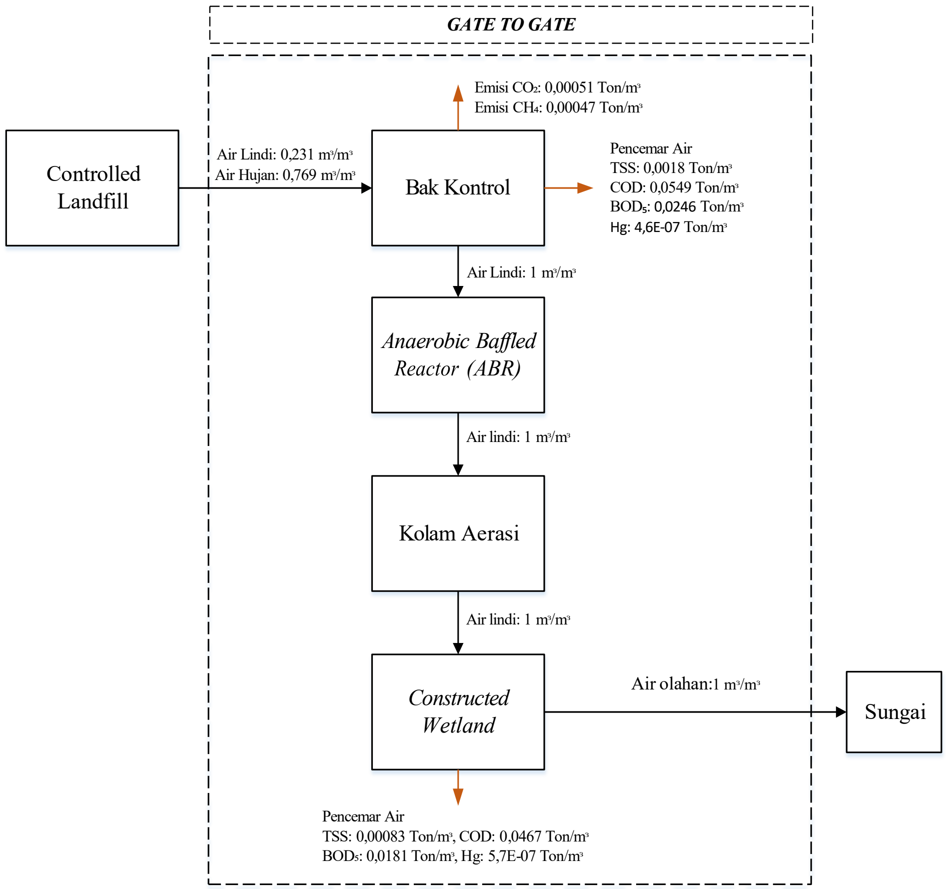

Figure 1. Mass balance

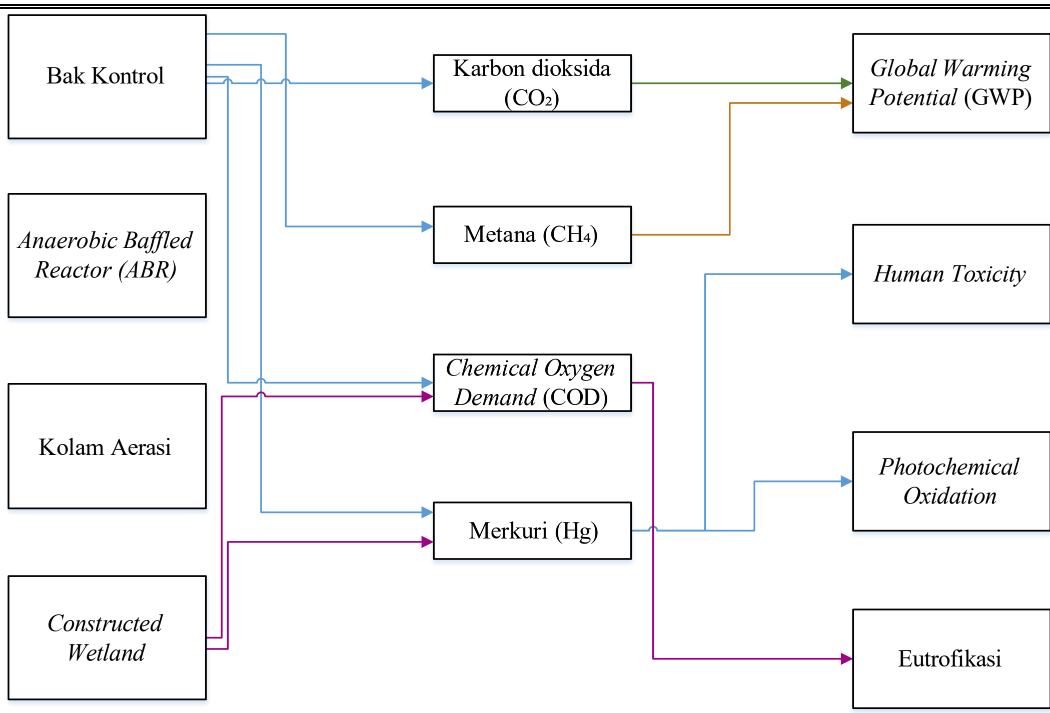

Figure 2. Impact classification

Table 1. Impact characterization

Impact Category	Unit	Total	Aeration	ABR	Pond	***Constructed Wetland***
Global warming (GWP100a)	kg CO_2 eq/m^3	13,805	0	0	13,805	0
Human toxicity	kg 1,4-DB eq/m^3	1,473	0	0	0,663	0,810
Photochemical oxidation	kg C_2H_4 eq/m^3	0,00285	0	0	0,0028	0
Eutrophication	kg PO_4--- eq/m^3	2,235	0	0	1,207	1,028

Impact Category	Total	Aeration	ABR	Pond	Constructed Wetland
Global warming (GWP100a)	3,03E-08	0	0	3,03E-08	0
Human toxicity	2,09E-09	0	0	9,42E-10	1,15E-09
Photochemical oxidation	3,70E-09	0	0	3,70E-09	0
Eutrophication	1,87E-06	0	0	1,01E-06	8,59E-07

Table 2. Impact normalization

Impact Category	pollutant parameters	Pond	Constructed Wetland	Pond	Constructed Wetland
		Pt		%	
Global warming (GWP100a)	*Methane*	3,03E-08	0	3,68	0
	CO_2			96,3	0
Human toxicity	*Mercury*	9,42E-10	1,15E-09	45	55
Photochemical oxidation	*Methane*	3,70E-09	0	100	0
Eutrophication	COD	1,01E-06	8,59E-07	54	46

CONCLUSION

The potential environmental impacts that have been generated from the treatment process of each 1 m^3 of leachate in its respective life cycle stages are as follows: Global warming has been induced by pollutants such as methane and carbon dioxide (3,03E-08 Pt), Photochemical Oxidation has occurred with the parameter pollutant being methane (3,70E-09 Pt), human toxicity has occurred due to the presence of pollutants such as mercury (2,09E-09 Pt), and Eutrophication has occurred with the parameter pollutant being COD (1,87E-06 Pt).

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