Leachate characterization and performance evaluation of leachate treatment plant in Cipayung landfill, Indonesia

E Noerfitriyani*, D M Hartono, S S Moersidik, I Gusniani

Environmental Engineering Study Program, Civil of Engineering Department, Universitas Indonesia, Depok, West Java, 16424, Indonesia

*Corresponding Author: eki.noerfitriyani@ui.ac.id

Abstract. The operation of landfill can cause environmental problems due to waste decomposition in the form of leachate production. Cipayung Landfill has a leachate treatment plant using stabilization ponds. The objective of this research is to evaluate the performance of stabilization ponds at Cipayung Landfill. The data were analyzed based on leachate samples from treatment unit’s influent and effluent under rainy season condition from April to May 2017. The results show the average leachate quality based on parameters of temperature by 34.81°C, Total Suspended Solid (TSS) of 72.33 mg/L, pH of 7.83, Biochemical Oxygen Demand (BOD) of 3,959.63 mg/L, Chemical Oxygen Demand (COD) of 6,860 mg/L, Total Nitrogen of 373.33 mg/L, and heavy metal Mercury of 0.0016 mg/L. The treatment plant’s effluent quality exceeds the leachate standard limit based on Indonesia’s Ministry of Environment and Forestry Law No. 59 of 2016. The results of design evaluation show that the anaerobic pond, facultative pond, and maturation pond system do not meet the design criteria. Therefore, a design improvement is needed to increase the performance of the leachate treatment plant and to ensure that the leachate discharged to water bodies does not exceed the standard limit to prevent contamination of the environment.

Keywords: leachate characteristics, leachate treatment plant, stabilization pond

1. Introduction
The population growth in urban areas leads to the high volume of solid waste generated. Inevitably, this development has a significant impact on the increasing amount of solid waste disposed at Cipayung Landfill, Depok City. Cipayung Landfill has been operated since 1984 using a controlled landfill system [1]. The increasing amount of waste generation can cause problems in its operation. Moreover, an improper waste management is potentially harmful to human health and can lead to environmental degradation. One potential environmental issue driven by the decomposition of waste in landfills is leachate production. Leachate can be derived from rain water seepage, runoff of waste decomposition, and moisture content of the waste itself [2]. The characteristics of leachate produced depend on several factors, including the degree of stabilization of the dumped waste, solid waste collection system, the type and composition of the discarded waste [3], the solubility of solid waste content [4], site and hydrological factors, solid waste compaction, as well as landfill design and operations [15]. Leachate is a liquid manifestation of solid waste and has been considered a serious pollutant that affects natural resources such as water bodies and groundwater, as well as human health. Leachate is a contaminated liquid derived from the bottom of solid waste disposal facilities such as landfills containing dissolved organic compounds and inorganic compounds and suspended solids. The leachate composition depends on the nature of solid waste, chemical, and biochemical processes for the decomposition of waste
materials, as well as the total moisture content of solid waste [6]. Cipayung Landfill has a leachate treatment plant for treating leachate from landfill using a stabilizing pond treatment system. Stabilization ponds are large basins in which wastewater is treated by natural processes involving microorganisms, and are considered as the most appropriate method for wastewater treatment in developing countries where the climate is favorable for its operation [7]. Stabilization pond system can be classified based on the types of biological activity, i.e. anaerobic, facultative, and maturation ponds [8]. Treated leachate is then discharged to the Pesanggrahan River. In Indonesia, the quality standards for liquid waste disposal are stated in [15] to ensure that the disposal of waste to recipient water bodies will not cause damage to the aquatic ecosystem and its potential economic resources, as well as public health affairs. Of the several contaminants carried in leachate, organic matter, nitrogen, and heavy metals are the primary substances of concern. In general, the concentration of the substances contained in the leachate depends on the biochemical decomposition of solid waste in landfills [9]. The main objectives of this study are to analyze leachate characterization and to evaluate the performance and design of leachate treatment plant in Cipayung Landfill, Depok City, Indonesia. The results of leachate characterization of Cipayung Landfill treatment plant is expected to be useful for landfill management, especially to improve the existing leachate treatment system and prevent contamination of discharged leachate to recipient water bodies.

2. Research Method

2.1. Description of Study Area

This study was conducted in Cipayung Landfill, located in Depok, Indonesia. The climate in Depok City is influenced by monsoon season and is relatively similar, characterized by fairly small rain differences. The conditions of rainfall in all Depok areas are practically the same, with the average rainfall of 3,332 mm/year or 278 mm/month and the mean temperature of 26°C [10]. The leachate treatment system applied in Cipayung Landfill is a stabilization pond system. Figure 1 shows that the Cipayung Landfill stabilization pond consists of an anaerobic pond, facultative pond, and maturation pond. The leachate treatment plant has a pretreatment unit equalization tank that is followed by the stabilization pond system. The treated leachate of the treatment plant is discharged to Pesanggrahan River as recipient water body.

![Figure 1. Schematic flow diagram of leachate treatment plant Cipayung Landfill.](image)

2.2. Data Collection and Analysis

In this study, leachate samples were taken every two weeks under rainy season condition from April to Mei 2017. Table 1 describes the sampling locations and shows that samples were taken from the equalization tank, anaerobic, facultative, and maturation ponds effluents. The sampling procedure follows SNI (Indonesian National Standard) number 6989.59:2008 which explains the wastewater sampling method. The leachate samples were collected using pre-sterilized bottles for physicochemical parameter analysis. The parameters analyzed for the performance evaluation of the leachate treatment plant are water temperature (T), Total Suspended Solids (TSS), pH value, Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Nitrogen (TN), and Mercury (Hg). The temperature is measured using a digital thermometer (SNI 6989.23:2005), TSS using gravimetric analysis (SNI 6989.3:2004), pH value using a digital pH meter (SNI 06-6989.11-2004), BODs using Winkler with 5 days incubation time (SNI 6989.72.2009), COD using the close reflux titrimetric method (SNI 06-6989.2-2009), TN using spectrophotometer with Nessler (HACH 399), and Mercury using Atomic Absorption Spectrophotometry method (SNI 6989.78:2011).
The methodology developed to study the performance and assess the design of the leachate treatment plant is divided into several steps, comprising of identification and characterization of leachate influent, performance evaluation based on removal efficiency, and design evaluation by comparing the existing plan and physical characteristics to the design criteria.

3. Results and Discussion

3.1. Leachate Characterization

Cipayung Landfill has been operating since 1984 and is classified as a mature landfill. However, the measured average of raw leachate temperature of around 34.81°C, TSS of 72.33 mg/L, pH of 7.83, BOD of 3,959.63 mg/L, COD of 6,860 mg/L, TN of 373.33 mg/L, Hg of 0.0016 mg/L, and BOD/COD ratio of 0.58 indicate that the leachate characteristics resemble an intermediate landfill. This deviation is due to the mixing of young leachate and old leachate since the solid waste dumping system in Cipayung Landfill does not use cell system to produce leachate with the character between young and old leachate (intermediate). The comparison between the leachate characteristics in Cipayung Landfill and the typical leachate is shown in Table 2.

| Parameter       | Cipayung Landfill (33 years) | Young landfill (<2 years) | Mature landfill (>10 years) |
|-----------------|------------------------------|---------------------------|----------------------------|
| Temperature (°C)| 34.81                        | -                         | -                          |
| TSS (mg/L)      | 72.33                        | 200–2,000[11]             | 100-400[11]                |
| pH              | 7.83                         | 4.5–7.5[11]               | 6.6–7.5[11]                |
| BOD (mg/L)      | 3,959.63                     | 2,000–30,000 [11]        | 100–200 [11]               |
| COD (mg/L)      | 6,860                        | 3.00–60,000[11]          | 100–500[11]                |
| TN (mg/L)       | 373.33                       | 500–1,500[12]             | 50–200 [12]                |
| Hg (mg/L)       | 0.0016                       | -                         | -                          |

The leachate of Cipayung Landfill tends to be alkali which is the typical characteristic of leachate in Indonesia [13]. However, the pH value is still within the range of values 6–9 that is appropriate for biological life. The leachate temperature is in the range of 33.8°C–36.4°C and still conforms to the optimum temperature for microorganisms of 25°C–35°C [11]. The BOD/COD ratio of Cipayung Landfill leachate is 0.58, meaning that it can be treated by biological processing [14].

3.2. Performance and Design Evaluation

The average of raw leachate flow rates entering the stabilization pond system was 91,600 m³/d. The results obtained for each treatment unit and the overall leachate treatment plant are presented in Table 3. The quality of Cipayung Landfill leachate in each treatment unit shows that the removal efficiency does not comply with the design criteria, implying that the effluent quality of Cipayung Landfill leachate does not meet the quality standard based on [15] for BOD, COD, and TN parameters. The examination results of the anaerobic pond leachate samples state that the TSS concentration of 72.33 mg/L at the influent has been increased to 151 mg/L at the effluent since the mud at the base of the pond was too
high. The TSS concentration of the facultative pond effluent was 32.33 mg/L, indicating that the removal of suspended solids at facultative pond processing unit reached 79%. Although the TSS concentration rose back to 60.33 mg/L at the maturation pond effluent, the overall removal efficiency of TSS concentration could reach 17%, and the quality of leachate discharged has fulfilled the requirement. The pH values of leachate in all treatment units are still within the standard quality range. The pH value of the influent leachate is 7.8–7.9 which tends to be alkali. Therefore, the leachate treatment does not require a neutralization process as a pre-treatment because pH 6 is the lowest limit for anaerobic processing [16]. The pH value of the anaerobic pond effluent has increased, indicating that the anaerobic processing has entered the final stage, raising the alkalinity that allows the methane microorganism to live. Volatile acids will be converted to methane and carbon dioxide (CO₂), while organic matter will decrease since its solubility will drop due to the boosted pH value. Supposedly, the pH value will dwindle back in the maturation pond because of the organic matter hydrolysis in the aerobic process, which resulted in the decrease of pH value and mineral dissolution. The rise of pH value to 8.07 in the effluent can be brought by the lack of oxygen concentration in the aerobic treatment within the maturation pond.

Table 3. Average and removal percentage of the parameters in the leachate treatment plant.

| Pond type | TSS (mg/L) | pH  | BOD (mg/L) | COD (mg/L) | TN (mg/L) | Hg (mg/L) |
|-----------|------------|-----|------------|------------|-----------|-----------|
| **AP**    |            |     |            |            |           |           |
| Influent  | 72.33 ±    | 7.83| 3959.63 ±  | 6860 ±    | 373.33 ±  | 0.0016 ±  |
| Effluent  | 151 ± 6.00 | 8.0 ±| 3894.77 ±  | 9956.8 ±  | 793.33 ±  | 0.00076 ± |
| % Removal | -110%      | -2% | 2%         | -45%       | -113%     | 53%       |
| **FP**    |            |     |            |            |           |           |
| Influent  | 151 ± 6.00 | 8.0 ±| 3894.77 ±  | 9956.8 ±  | 793.33 ±  | 0.00076 ± |
| Effluent  | 32.33 ±    | 7.97| 3714.63 ±  | 6155.1 ±  | 186.70 ±  | 0.0031 ±  |
| % Removal | 79%        | 0%  | 5%         | 38%        | 76%       | -307%     |
| **MP**    |            |     |            |            |           |           |
| Influent  | 32.33 ±    | 7.97| 3714.63 ±  | 6155.1 ±  | 186.70 ±  | 0.0031 ±  |
| Effluent  | 60.33 ±    | 8.07| 3399.13 ±  | 9525.6 ±  | 334.43 ±  | 0.00072 ± |
| % Removal | -87%       | -1% | 8%         | -55%       | -79%      | 77%       |
| **Total** |            |     |            |            |           |           |
| % Removal | 17%        | -3% | 14%        | -39%       | 10%       | 55%       |
| Leachate standard[18] | 100 | 6 - 9 | 150 | 300 | 60 | 0,005 |

The BOD concentration decreased toward the end of treatment with a removal efficiency of 14%. However, the leachate effluent has not met the leachate effluent standard. The high BOD concentration is caused by the organic residues contained in the anaerobic treatment that cannot be degraded in abundant quantity [17]. COD effluent concentration of 9,525.6 mg/L has not met the quality standard. The concentration of COD effluent is increased due to the absence of aeration and the presence of organic material residues. The concentration of TN decreased by 6% removal until the end of treatment. However, the effluent concentration of TN of 334.4 mg/L has not met the leachate standard. The concentration of ammonia nitrogen within the range of 25–30 mg/L can be toxic to anaerobic microorganisms because it inhibits their growth, affecting the removal of BOD and COD [18]. The high concentration of TN in the Cipayung Landfill leachate lessen the efficiency of BOD and COD removal. The concentration of Hg effluent was 0.0007 mg/L, and the removal efficiency was 56%. High concentration of heavy metals can be toxic to Chlorella species that are the main species in the stabilization ponds system. The pH value of >8 can cause the metal ions to precipitate, and the treatment process of stabilization ponds can run as usual [19]. Table 4 shows the existing design and physical characteristics of the leachate stabilization ponds system. Anaerobic ponds can be used for waste with a
COD concentration of ≥4,000 mg/L [20]. Loaded with a COD concentration of 6,860 mg/L, the Cipayung Landfill leachate treatment unit has appropriately used an anaerobic pond as the first treatment. BOD removal in an anaerobic pond can reach 90% [21], with the details of 2.5-5 m depth, detention time of 5–50 days [22], and organic loading rate of ≤0.3 kg/m³.day [23]. Based on the measurement, the anaerobic pond’s BOD removal was only 2% and the OLR value of 0.37 kg/m³.day exceeds the design criteria. OLR values above the design criteria can cause odor around the treatment unit. The 3.5 m depth and 10.7 days detention time in the anaerobic pond treatment have met the design criteria.

### Table 4. Physical characteristics of leachate treatment plant Cipayung Landfill.

| Parameter          | Anaerobic Pond | Facultative Pond | Maturation Pond |
|--------------------|----------------|------------------|-----------------|
| Detention time     | 10.7 day       | 3.1 day          | 3.04 day        |
| Useful depth       | 3.5 m          | 3.5 m            | 3.5 m           |
| Area               | 278.85 m²      | 80.29 m²         | 79.21 m²        |
| Organic loading rate (OLR) | 0.37 kg/m³.d | 44,273.96 kg/ha.d | 42,804.31 kg/ha.d |

Facultative pond serves to remove some of the BOD concentration that is still contained in the anaerobic pond effluent with a removal efficiency of up to 95% [24]. However, the efficiency of BOD removal in the Cipayung Landfill facultative pond only reached 5%. The facultative pond’s depth of 3.5 m exceeds the design criteria of 1–2 m [21]. The facultative pond’s detention time of 3.1 days is too short, compared to the design criteria of 7–50 days [24]. The OLR value of the facultative pond of 44,273.96 kg/ha.day exceeds the design criteria of 15–20 kg/ha.day [21]. OLR values exceeding the design criteria can lead to the incapability of the facultative pond to treat incoming BOD concentration. Maturation pond serves to reduce the concentration of BOD that is still contained in the effluent of the facultative pond, as well as to eliminate the pathogen bacteria contained in the leachate by utilizing sunlight penetration into the pond. The efficiency of BOD removal in the maturation pond is normally 80% [21]. However, the removal efficiency of Cipayung Landfill maturation pond only reached 8%. Its depth of 3.5 m exceeds the design criteria of 0.3–1.0 m [21]. This excess may hinder the entirely aerobic condition throughout the pond since the sunlight cannot penetrate deeply inside the maturation pond, leading to the unavailability of oxygen from algae photosynthesis. The OLR value of 42,804.31 kg/ha.day exceeds the design criteria of 40–120 kg/ha.day [21]. The OLR value exceeding the design criteria causes no removal of BOD concentration in the maturation pond. The detention time of facultative pond of only 3.04 days is too narrow compared to the design criteria of 5–20 days [21].

### 4. Conclusion

Based on this research, the effluent of Cipayung Landfill leachate treatment plant exceeds the leachate standard limit based on [15] for BOD, COD, and TN parameters. The evaluation results of leachate treatment plant unit in Cipayung Landfill show that the designs of the anaerobic pond, facultative pond, and maturation pond do not meet the design criteria. To improve the quality of leachate effluent, it is necessary to make physical improvements by redesigning the treatment unit according to the design criteria. Establishing a constructed wetland is recommended as well since the climatic condition of the study area implies that this method is suitable and has a high potential to improve the leachate effluent quality by reducing the nutrients, suspended solids, algae, and BOD concentrations.

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### References

[1] Buku Putih Sanitasi Kota Depok, Dinas Komunikasi dan Informatika Kota Depok, Depok, 2011.
[2] Renou S, Givaudan J, Poulain S, Dirassouyan F, Mouli. Landfill Leachate Treatment Review and Opportunity. pp. 468-493,2008.
[3] Fitzke B, Blume T, Wienands H, Cambiella A. Hybrid Processes for the Treatment of Leachate from Landfills, Economic Sustainability and Environmental Protection in Mediterranean Countries through Clean Manufacturing Methods. Springer, pp. 107-126, 2013.

[4] Salem Z, Hamouri K, Djemaa R, Allia K. Evaluation of Landfill Leachate Pollution and Treatment. Desalination 220, pp. 108-114, 2008.

[5] Baig S, Coulomb I, Courant P, Liechti P. Treatment of landfill leachates: lapeyrouse and Satrod case studies. Ozone: Science & Engineering, pp. 1-22, 1999.

[6] Fatta D, Papadopoulos A, Loizidou M A study on the landfill leachate and its impact on the groundwater quality of the greater area. Environmental, Geochemical, Health, pp. 175-190, 1999.

[7] Mara D D. Domestic Wastewater Treatment in Developing Countries. London: Earth scan, 2004.

[8] C B Gawasiri. Modern Design of Waste Stabilization Ponds in Warm Climates: Comparison with Traditional Design Methods. UK: University of Leeds, 2003.

[9] Jokela J P Y, Rintala, J A. 2003. Anaerobic solubilisation of nitrogen from municipal solid waste (MSW). Reviews in Environmental Science and Biotechnology 2. pp. 67-77.

[10] Balai Data dan Informasi Sumber Daya Air Kota Depok, 2009.

[11] Tchobanoglous G, Hilary Theisen, Samuel Vigil. Integrated Solid Waste Management. Singapore: McGraw Hill, 1993.

[12] J F Crawford, P G Smith. Landfill Technology. UK: British Publishing, 1985.

[13] Damanhuri, Enri, Padmi, Tri. Diktat Kuliah Pengelolaan Sampah Pengurugan (Landfilling) Sampah. Bandung, Program Studi Teknik Lingkungan FTSL ITB, pp. 1-11. 2008.

[14] Grady C P, Leslie Lim, Henry C. Biological Wastewater Treatment Theory and Applications. USA: Marcel Dekker, 1980.

[15] Peraturan Menteri Lingkungan Hidup dan Kehutanan Republik Indonesia Nomor 59 Tahun 2016 tentang Baku Mutu bagi Usaha dan/atau Kegiatan Tempat Pemrosesan Akhir Sampah.

[16] Pescod, Mara. 1998. [Online]. Available: http://stabilizationponds.sdsu.edu/.

[17] Malina, Joseph F, Pohland, Frederick G. Design of Anaerobic Processes for The Treatment of Industrial and Municipal Wastes. USA: Technomic Publishing Company, Inc, 1992.

[18] Sergrist. 1997. [Online]. Available: http://stabilizationponds.sdsu.edu/ 1997.

[19] Murniawati, Camelia Indah. Studi Evaluasi dan Perbaikan Instalasi Pengolahan Lindi TPA (Studi Kasus : TPA Suwung Kota Denpasar. Tugas Akhir S1 Teknik Lingkungan Institut Teknologi Bandung, 2012.

[20] Grady C P, Leslie Lim, Henry C. Biological Wastewater Treatment Theory and Applications. USA: Marcel Dekker, 1980.

[21] Qasim Syed R. Wastewater Treatment Plant, Planning, Design, and Operational. New York: College Publishing, 1985.

[22] Metcalf Eddy, Wastewater Engineering: Treatment and Reuse Fourth Edition. Singapore: McGraw-Hill, Inc, 2003.

[23] WHO. 1987. Wastewater Stabilization Ponds: Principles of Planning and Practice. WHO EMRO Technical Publication No. 10.

[24] Benefield, Larry D., Randall, Clifford W. Biological Process Design for Wastewater Treatment. USA: Prentice-Hall, Inc, 1980.