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RESEARCH ARTICLE

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Leachate Treatment Using Sub-Surface Flow Constructed Wetland by *Hippochaetes lymenalis*

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ABSTRACT

Leachate, which comes from waste landfills, contains high levels of organic and inorganic matter. Constructed Wetland technology is a suitable alternative for leachate treatment. This technology is easy to apply, relatively cost-effective, and can achieve optimal reduction results for treating and controlling leachate, thereby reducing its environmental impact. The objective of this study was to treat the BOD concentration and COD in leachate using a Constructed Wetland. Data collection was performed by conducting leachate experiments for Constructed Wetland treatment using *Hippochaetes lymenalis* plants based on variations in residence time and media height. There was a control group (R1) without any media or plants. The variation combination included R2 (containing 10 cm gravel and 10 cm fertile soil) and R3 (containing 5 cm gravel and 15 cm fertile soil). Residence times were set at 0, 7, 14, and 21 d. This research showed that the reactor with growth media consisting of 10 cm gravel and 10 cm fertile soil had 55% and 85% BOD and COD removal efficiencies, with final BOD concentrations and COD values of 273 mg/L and 1,321, respectively. The reactor with growth media consisting of 5 cm gravel and 10 cm fertile soil had 74% and 95% BOD and COD removal efficiency, with the final BOD concentration and COD at 159 mg/L and 432, respectively.

Introduction

Leachate, which has high levels of organic and inorganic contents, is a waste product from landfills. This leachate is generated from dissolved materials and is the result of the decomposition process of waste that enters the waste pile [1–3]. If not properly managed, this leachate will not only cause problems related to odor, flies, and sanitation but also cause pollution of surface water and groundwater [2,4]. The Benowo landfill site is the largest landfill in Surabaya, East Java, Indonesia [5]. Landfills can receive 1,600 to 1,700 tons of waste per day. The existing leachate management at the Benowo Landfill is performed by draining the leachate water into drainage or ditches around the waste generation [6]. The slope of these drainage channels was between 1–2% to facilitate collection in the containment area. The bottom and edges of the leachate containment area were lined with plastic to prevent surface water contamination of the surrounding reservoir. This leachate subsequently undergoes treatment using an Advanced Oxidation Process (AOP). This technology is expensive because of the energy and materials required for processing [7].

Various alternative technologies are currently available for leachate management. One technology that suits its characteristics and efficiently reduces high organic content is the Constructed Wetland technology [1,8,9]. Constructed Wetlands have a symbiotic relationship between water and microorganisms within their root systems [1,10,11]. Microorganisms bind organic elements in leachate and convert them into simple molecules that plants use as nutrients. Oxygen, which plays a role in the metabolism of microorganisms, is produced by the root system [1,12–14]. The CW use conventional treatment systems with low operating and maintenance costs due to their natural processes. The specific type of Constructed Wetland system used was subsurface flow. This system is a treatment that occurs when wastewater moves slowly through plants

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growing on porous media. The media typically used have limits ranging from gravel to coarse sand. This process, known as filtration, involves adsorption of organic material by microorganisms and growing media by plant roots. The flow utilized in Constructed Wetlands to allow water to reach the deeper layers of soil is a horizontal flow. The leachate entered through an inlet pipe and flowed slowly through the porous substrate located at the bottom of the surface layer in a horizontal path until it reached the outlet.

Previous studies have reported the Constructed Wetland technology for leachate treatment [3,7,14–17]. Leachate treatment using the Constructed Wetland method has the efficiency of reducing BOD5, COD, TSS, and N-total by 96%, 87%, 58%, and 47%, respectively. Similarly, research conducted by Apriana et al. [8], Rizqia and Slamet [16], demonstrated the efficiency of reducing BOD, COD, nitrate, and phosphate concentrations up to 77%, 77%, 98%, and 98%, respectively. The efficiency of reducing pH, BOD, COD, TSS, and N-total by 17.4%, 30.9%, 22.6%, 70.7%, and 66.8% was shown [18]. One plant that can be used for leachate reduction is *Hippochaetes lymenalis*. This plant has long and slender rhizomes and a root system called a rhizosphere that plays a role in absorbing organic substances in the water body [8,12]. *Hippochaetes lymenalis* plants in the Constructed Wetland method, they had an average efficiency of reducing BOD and COD by 30.05% and 31.82% within a period of 14 days [19]. Additionally, *Hippochaetes lymenalis* was able to reduce pH, BOD, COD, TSS, and N-total by 17.4%, 30.9%, 22.6%, 70.7%, and 66.8% within a period of 6 days [18].

Constructed Wetland performance include limited land availability so that the dimensions of the Constructed Wetland do not meet the residence time and insufficient hydraulic retention time (HRT) due to hydraulic overload when the flow exceeds the design capacity, and the speed of the process depends on the conditions of temperature, pH, and oxygen availability [13,17]. The characteristics and design of the media used can have an impact, and the use of appropriate types of plants can also reduce significant contaminants [1]. Plants help the settling process by reducing the water velocity and turbulence. This study aimed to treat the BOD concentration and COD in leachate using a Constructed Wetland [19].

Materials and Methods

Leachate landfill

Leachate landfills were collected from the Benowo Landfill, which is located in Surabaya City, Indonesia. The leachate landfill was obtained from a leachate storage tank at the Benowo Landfill. The sample size was 100 L, which was required in this study.

Acclimatization Process

The acclimatization process aims to help Hippochaetes lymenalis plants adjust to their new growth medium [12]. Acclimatization took place over a period of seven days with gravel and soil in a reactor using tap water. The *Hippochaetes lymenalis* plants selected for this study showed characteristics of thriving growth, with no reported mortality and an average height that can range from 30 to 80 cm [11,17].

Constructed Wetland

The six experimental conditions were tested in duplicate using laboratory-scale reactors. Each Constructed Wetland reactor measured 55 × 33 × 40 cm with a thickness of 5 mm, ½ inch PVC pipes, L-shaped pipes, pipe connectors, pipe adhesive, plastic funnel, plastic valve, 25 L jerry can, and 100 L bucket. The Constructed Wetland study was conducted using a batch system. The reactor was then placed in a closed room with sufficient air circulation. The variation used in the Constructed Wetland involved the height variation of the combination of planting media (gravel and fertile soil).

Gravel of size 5 to 7 mm, fertile soil of size <0.002 mm. Reactor R1 consisted of a mixture of 10 cm of gravel and 10 cm of fertile soil, whereas Reactor R2 used a combination of 5 cm of gravel and 15 cm of fertile soil. The *Reaktor Kontrol* (RK) was filled with leachate and contained no additional planting medium or plants. Each *Hippochaetes lymenalis* plant used in the study weighed 3 kg per reactor. The Constructed Wetland process lasted 21 days, with samples collected every seven days. The BOD concentration analysis followed the SNI 6989.72:2009 standard for BOD testing using titrimetry. COD concentration analysis followed the SNI 6989.73:2009 standard for COD titrimetric testing using the closed reflux method.

Results and Discussion

Initial Leachate Characteristics

Table 1 shows that the initial leachate characteristics indicate BOD and COD levels of 603 mg/L and 8,730 mg/L, respectively. These initial BOD and COD levels exceed the quality standards set by the environment regulation [20]. The standards specify BOD and COD levels of 150 and 300 mg/L, respectively. Generally, leachate characteristics include high BOD and COD levels owing to recent waste accumulation. The increased acid production and decreased pH due to rapid biodegradation increased the ability of water to dissolve waste components. This situation is compounded by the infiltration of runoff water and human waste [21,22]. High BOD and COD values indicate high water pollution caused by organic matter [3]. The BOD and COD levels in Benowo's Landfill leachate are higher than research conducted by by Ramadhani et al. [18] and Saragih et al. [23] that the BOD and COD values are 230 to 466.39 mg/L and 662.26 to 1,718.33 mg/L, respectively.

Table 1. Characteristics Leachate Landfill.

Parameter	Results	Standard*)	Unit
BOD concentration	603	150	mg/L
COD concentration	8,730	300	mg/L

*) [20].

Reduction of BOD Levels in Leachate

BOD levels in the leachate decreased throughout the study (Figure 1). The initial BOD concentration in the leachate was 603 mg/L. In reactor R1 (10 cm gravel and 10 cm fertile soil), the BOD level gradually decreased to 453 mg/L by day 7. This is likely due to the fertile soil media, which serves as a site for microorganism activity and breaks down the organic matter. Gravel media also provides a breeding ground for microorganisms, which convert organic matter into simple molecules that serve as nutrients for plants [8,24]. In turn, plant roots produce oxygen, which is a source of energy for microorganisms [1,12,13]. On day 14, there was a slight increase in the BOD level to 468 mg/L, possibly because of dead and decomposing plants in the reactor.

The increase in organic matter in water originates from plant decomposition [19]. *Hippochaetes lymenalis* plants grow upward, with new members growing on top. *Hippochaetes lymenalis*, dies start from the stem immediately above the root; the stem decays and falls into the reactor. The death of this stem requires no replacement, causing the plant roots to be unable to produce oxygen. The increase in BOD levels may be due to root saturation during the absorption of organic particles in the leachate. Consequently, this leads to blockage of the flow path at the interface between the soil and roots, similar to the symptoms of absorption saturation. The final BOD concentration in R1 was 273 mg/L.

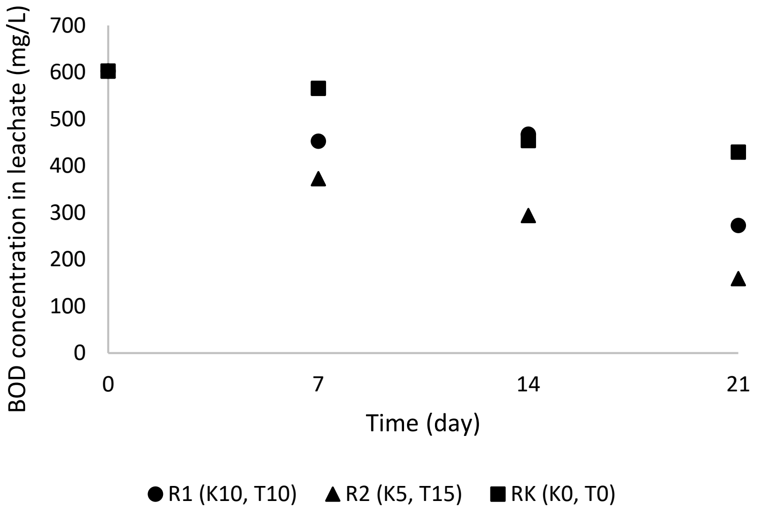

Figure 1. Reduction of BOD levels in leachate.

In reactor R2 (which consisted of 5 cm gravel and 15 cm fertile soil), the BOD level decreased by 373 mg/L on day seven and continued to decline to 159 mg/L on day 21. This reduction stems from the symbiotic relationship between microorganisms in the soil and *Hippochaetes lymenalis* plants. Microorganisms break down organic matter into molecules that plants can absorb easily [10]. In this system, organic matter is removed through sedimentation and anaerobic decomposition at the bottom of the wetland, followed by absorption by *Hippochaetes lymenalis* plants through their roots. In the RK, the BOD levels were 566 mg/L on day 7 and 454 mg/L on day 14. The control reactor employed sedimentation as a treatment method, where organic particles settled to the bottom of the reactor [19], leading to a decrease in the BOD levels of the leachate. At the end of the study period, the final BOD concentration in the control reactor was 430 mg/L. When compared to variations in the height of the combination of planting media, the reduction in R2 reactor was higher than that in R1 and RK because the ratio of fertile soil was greater than that of gravel. A higher ratio of fertile soil allows plant roots to spread more freely in the reactor, enabling the plant roots to release higher levels of oxygen. High oxygen values also cause high decomposition activity of microorganisms [17].

The efficiency of reducing BOD levels in leachate for each reactor gradually increased throughout the study, as shown in Figure 2. The efficiency of reducing the BOD levels in reactors R1 and R2 reached 55% and 74% on day 21, respectively. In the RK reactor, the efficiency of reducing BOD levels in the leachate was 29%. Hadi and Pungut [25], revealed that the efficiency of reducing BOD levels in leachate using Constructed Wetland with *Echinodorus paleafolius* was 61%. An efficiency of reducing BOD in leachate using constructed wetlands with *Typha angustifolia* plants by 30.9–98.8% [16,18]. The high efficiency of reducing BOD levels is attributed to the longer residence time, which allows the Constructed Wetland to perform better.

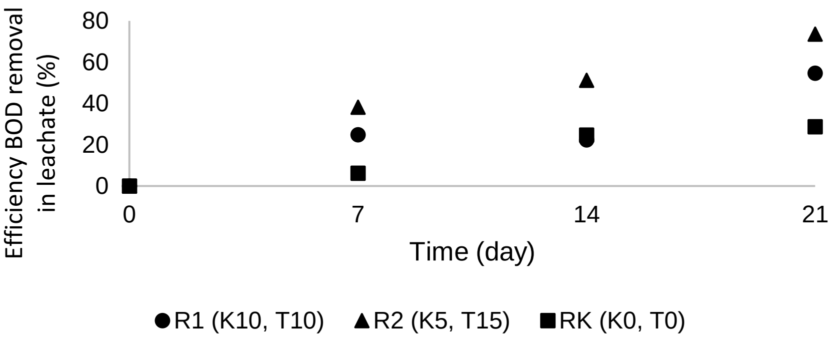

Figure 2. The efficiency of BOD Level Reduction in Leachate.

Reduction of COD Levels in Leachate

The reduction in COD levels in the leachate occurred across all reactors (Figure 3). The initial COD level in all three reactors was 8,730 mg/L. In reactor R1 (which contained 10 cm of gravel and 10 cm of fertile soil), there was a sharp decrease from day 7 to 1,746 mg/L. It then gradually decreased until the end of the study, reaching a final COD level of 1,321 mg/L in reactor R1. This reduction was attributed to the presence of *Hippochaetes lymenalis* plants, planting media (gravel and soil), and organic elements and microorganisms present in the leachate. This process involves organic particles in the leachate being utilized by *Hippochaetes lymenalis* as nutrients for photosynthesis [13,26]. Microorganisms play a role in decomposing organic elements in leachate using the oxygen released by *Hippochaetes lymenalis* plants. Oxygen travels through the stems to the roots, diffusing from the atmosphere through the pores in the stems of *Hippochaetes lymenalis* plants [27].

A similar trend of COD reduction in leachate was also observed in reactor R2 (which contained 5 cm of gravel and 15 cm of fertile soil). In reactor R2, a sharp reduction in COD levels was observed from day seven until the end of the experiment. The final COD concentration in R2 was 432 mg/L. The reduction in COD levels occurred because of the important role of the plants and their planting media. The planting media (gravel and fertile soil) provided a place for microorganism growth, supplied oxygen to the plant roots, and acted as a region for the decomposition of organic particles by soil microorganisms. *Hippochaetes lymenalis* plants help transfer air through their root systems. Additionally, *Hippochaetes lymenalis* is crucial for transforming organic elements into nutrients through physical and chemical processes, including the sedimentation of suspended particles. The process of organic element degradation and nutrient adsorption continues in a cycle, which helps reduce the amount of pollutants in the wastewater.

The RK reactor also experienced a gradual reduction in COD levels from the beginning to the end of the study, with values decreasing from 8,730 mg/L to 4,109 mg/L. This reduction results from the sedimentation process in R1 reactor, where organic particles settle and undergo gravitational sedimentation. Typically, 60% of the suspended particles in wastewater consist of sedimented elements [25,26]. Therefore, it can be said that the control reactor, which has no treatment, can reduce the COD levels of the leachate owing to the sedimentation of organic particles in the reactor. When compared to the variations in the height of the combination of planting media, the reduction in COD levels in reactor R2 was the highest compared to reactors R1 and RK. This was due to the ratio of gravel to fertile soil present in each reactor. A larger amount of fertile soil leads to an increased plant root distribution. This increased distribution results in higher levels of oxygen being released by plant roots and facilitates effective organic matter degradation [17].

The efficiency of reducing COD levels in the leachate increased gradually in each reactor throughout the study (as shown in Figure 4). By the end of the study, the reduction efficiency of COD levels in reactors R1 and R2 reached 85% and 95%, respectively. However, in the RK reactor, the reduction efficiency of COD levels in the leachate was 53%. Wulandari et al. [27] reported COD level reduction efficiencies using Constructed Wetlands of 85 to 92%. The highest efficiency in reducing COD levels was achieved in a last study, who managed to reduce COD levels by up to 99% [16].

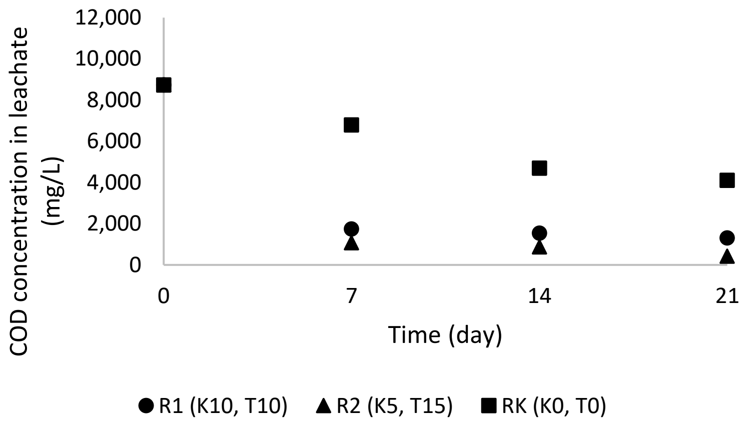

Figure 3. Reduction of COD levels in leachate.

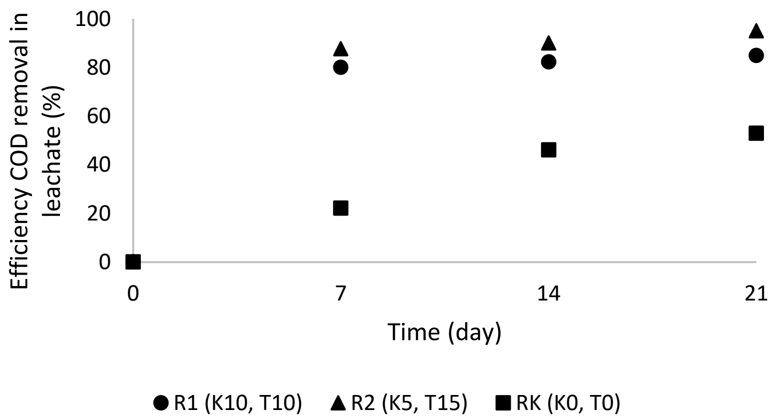

Figure 4. The efficiency of COD level reduction in leachate.

Morphological Conditions of *Hippochaetes lymenalis*

Figures 5 to 8 depict the physical state of *Hippochaetes lymenalis* plants during the research phases. On day 0, the plants appeared fresh with green stems. However, by day 7, some stems had turned brown and dried at the tips. Towards the end of the study, the plants became progressively drier, particularly in reactor R2, compared to reactor R1.

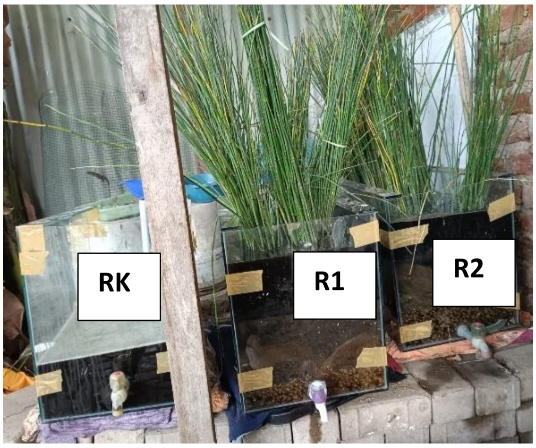

Figure 5. Morphological conditions of *Hippochaetes lymenalis* (Day 0).

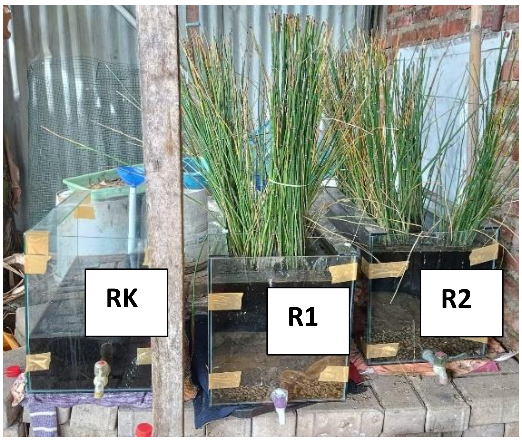

Figure 6. Morphological conditions of *Hippochaetes lymenalis* (Day 7).

Figure 7. Morphological conditions of *Hippochaetes lymenalis* (Day 14).

Figure 8. Morphological Conditions of *Hippochaetes lymenalis* (Day 21).

Conclusion

The reactor with growth media consisting of 10 cm gravel and 10 cm fertile soil had 55% and 85% BOD and COD removal efficiencies, with final BOD concentrations and COD values of 273 mg/L and 1,321, respectively. The reactor with growth media consisting of 5 cm gravel and 10 cm fertile soil had 74% and 95% BOD and COD removal efficiency, with the final BOD concentration and COD at 159 mg/L and 432, respectively.

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