Original Research Article

Use of Sante Plants (*Alocasia Macrorrhiza*) in Microbial Fuel Cell (MFC) Systems in Leachate as a Producer of Alternative Electrical Energy Sources and COD Processing Media

Adistia Dian Kurniawati[1], Badrus Zaman[1*], Purwono[1], Michael El Roy Heriyanto[1]

[1] Department of Environmental Engineering, Faculty of Engineering, Universitas Diponegoro, Jalan Prof. Soedarto, SH, Semarang, Indonesia 50275

* Corresponding Author, email: nurandanihardyanti@gmai.com

Abstract

Leachate, a liquid formed in accumulated solid waste in landfills, contains a variety of pollutants, particularly organic compounds. Evapotranspiration is an effective biological process for removing Chemical Oxygen Demand (COD) in leachate. This leachate treatment method can also generate electricity through the microbial fuel cell (MFC) process. The main aim of this study was to evaluate the efficiency of COD removal by evapotranspiration using the Giant Taro plant and to assess the potential electrical energy generated from the MFC system during the evapotranspiration process. The experiment involved a laboratory-scale system with two Giant Taro Plant Reactors (main reactors) and one control reactor. The results showed that the removal efficiency of COD ranged from 28% to 89%. The main reactor achieved the highest COD removal, reaching 77% on the 12th day of the experiment. In comparison, the control reactor demonstrated its highest performance (89% COD removal) on the third day of the experiment. The lowest COD removal by the main reactor was 28%, occurring on the sixth day, and the control reactor's minimum removal was 49% on the ninth day. The study also included the measurement of electrical energy generation. Throughout the 15-day experiment, the electrical energy generated ranged from 2.15 μW to 104.78 μW. The main reactor produced the highest electrical energy (104.78 μW) on the 14th day. In comparison, the control reactor generated the highest electrical energy (44.55 μW) on the last day of the experiment. The lowest electrical energy generated from the primary and control reactor was 2.15 μW (on the third day) and 3.32 μW (on the sixth day), respectively.

Keywords: Leachate, Evapotranspiration; Microbial Fuel Cell; COD; Electricity; Sente

1. Introduction

Leachate is the liquid formed as water seeps through landfill waste, carrying a variety of contaminants. It is created when precipitation filters through layers of waste material, dissolving soluble components and carrying them along. The composition of leachate can vary significantly based on the nature of the landfill waste but typically includes high levels of organic matter, inorganic ions, heavy metals, and xenobiotic organic compounds (Kjeldsen et al., 2002). Leachate generation poses a significant challenge for municipal solid waste (MSW) landfills. It refers to the liquid that permeates a landfill, extracting dissolved and suspended matter. Leachate is formed when precipitation enters the landfill and comes into contact with the moisture present in the decomposing waste. The environmental impact of leachate is considerable. If not adequately managed, leachate can seep into groundwater and surface water systems, contaminating drinking water sources and natural habitats. A high Chemical Oxygen Demand (COD) in leachate indicates significant organic pollution, which can deplete oxygen levels in aquatic environments, harming aquatic life and disrupting ecosystems (Renou, Givaudan, Poulain, Dirassouyan, & Moulin, 2008).

Furthermore, heavy metals and persistent organic pollutants in leachate pose long-term health risks to humans and wildlife(Slack, Gronow, & Voulvoulis, 2005). Various effective techniques are available for treating leachate, including physical, chemical, and biological processes. Physical methods such as sedimentation and filtration, chemical treatments like coagulation, flocculation, and oxidation, and biological treatments utilizing microbial activity such as aerobic and anaerobic digestion are all commonly employed. While these methods have demonstrated success, it is essential to acknowledge that they can be expensive, require significant energy, and may not permanently remove contaminants altogether (Foo & Hameed, 2009). Microbial fuel cells (MFCs) offer an innovative and sustainable approach to treating leachate and producing renewable energy. Microbial fuel cell (MFC) is a technology capable of generating electrical energy through the decomposition of organic matter by microorganisms (Kumar et al., 2019). These bio-electrochemical systems harness the metabolic processes of microorganisms to directly convert organic substrates into electrical energy, providing a dual benefit of reducing organic pollutants in wastewater and generating electricity (Logan, 2008). The use of microorganisms in MFC technology can be aerobic, facultative anaerobic, or obligate anaerobic (Deng et al., 2020).

An exciting development in MFC technology involves integrating plants such as Alocasia macrorrhiza (giant taro) into these systems. Alocasia macrorrhiza is recognized for its rapid growth and ability to thrive in various environmental conditions, including polluted environments. Supplying additional organic substrates and promoting microbial activity through root exudates can enhance the efficiency of MFCs in reducing COD and generating electrical power (Rabaey & Verstraete, 2005). MFC technology is crucial in treating leachate, a highly contaminated liquid produced from landfill sites. Leachate contains elevated levels of Chemical Oxygen Demand (COD), heavy metals, and other pollutants that pose significant environmental risks. Conventional leachate treatment methods are often expensive and energy-intensive. In contrast, MFCs can efficiently reduce COD and heavy metal concentrations in leachate while simultaneously generating electricity, providing a dual benefit (Ahn & Logan, 2010). In addition, the advantages of MFC include high efficiency, mild operating conditions, and its applicability in various locations with limited electrical infrastructure (Vidales, Omanovic, & Tartakovsky, 2019).

The effectiveness of Microbial Fuel Cells (MFCs) in reducing COD (Chemical Oxygen Demand) has been well-documented. The microbial communities within the MFCs break down complex organic compounds in the leachate, leading to significant reductions in COD levels. This process not only helps to reduce pollution but also enhances the overall performance of the MFC by supplying a continuous source of electrons for electricity generation (Liu, Cheng, & Logan, 2005b). Furthermore, MFCs effectively remove heavy metals from leachate, as microbial activity can precipitate and sequester them, reducing their bioavailability and toxicity (Zhao, Slade, & Varcoe, 2009). Various plant species have been integrated into MFC systems to enhance the performance of MFC systems. Commonly used plants in plant-MFCs include Typha latifolia (cattail), Phragmites australis (common reed), and Ipomoea aquatica (water spinach). These plants contribute to the MFC system by providing root exudates as additional organic substrates for the microorganisms, thereby increasing microbial activity and electron production (Mohan, Mohanakrishna, Reddy, Saravanan, & Sarma, 2008).

Alocasia macrorrhiza, commonly known as the giant taro or sante plant, is an emerging candidate for use in MFC systems. This plant is known for its rapid growth, extensive root system, and high tolerance to various environmental conditions, including polluted environments. Integrating Alocasia macrorrhiza in MFCs could potentially enhance the system's efficiency in reducing COD and generating electricity by providing a stable and prosperous source of organic matter through its root exudates (Li WenWei, Yu HanQing, & He, 2014). This study explores using Alocasia macrorrhiza in MFC systems to treat landfill leachate. It focuses on evaluating the plant's effectiveness in improving COD reduction and its potential as a sustainable source of electrical energy. The findings aim to contribute to developing innovative solutions for managing landfill leachate and generating renewable energy.

Two studies have been conducted to test the effectiveness of the MFC method in reducing COD parameters in leachate. In the first study by Jiang, Zhao, Zhang, Zhang, and Lee (2009), an MFC system with a carbon cloth anode and a platinum cathode was used to treat leachate with an initial COD concentration of approximately 20,000 mg/L. After 30 days, the MFC system reduced COD by up to 60%. This research highlighted drawbacks, including the high cost of the platinum cathode, which increases production and maintenance costs, and performance instability, leading to decreased efficiency after several weeks of operation, indicating the need for further investigation into electrogenic microbial instability. In the second study by Liu, Cheng, and Logan (2005a), an MFC system with carbon electrodes and batch operation mode was employed to treat leachate with an initial COD concentration of 15,000 mg/L. Over 25 days, the cost of damages was reduced by 50%. However similar to the first study , the study identified limitations such as the batch mode, which affects processing continuity and efficiency, and fluctuations in substrate concentration, leading to performance instability. In the conducted experiments, several differences were observed from previous tests. This study employed a carbon cathode and utilized a continuous testing method for leachate discharge, as opposed to the batch method. It is anticipated that the implementation of the MFC reactor will lead to reduced maintenance costs and improved performance in reducing COD parameters and other aspects.

2. Material and Methods

2.1 Research and Experimental Methods

For 15 days, our research involved three key stages: preparation, implementation, and data analysis. To prepare, we conducted literature studies, built the reactor, and acclimatized the plant. The implementation stage took place at the Jatibarang TPA in the leachate processing section using the constructed reactor. Additionally, we conducted duplicate sample tests to ensure precise data and conclusions. Furthermore, during the implementation stage, we tested the MFC method to reduce COD parameters in leachate water and generate electric currents as valuable by-products.

2.2 Raw Leachate, Plants, and Soil

Leachate sampling was conducted in accordance with SNI 6989.59:2008 using the instantaneous sampling method. The leachate was collected using a long-stemmed ladle and then stored in a 30-liter container. The research spanned 15 days with sampling on the 3rd, 6th, 9th, 12th, and 15th days. The plant species employed in this experiment is Alocasia macrorrhiza, frequently located near landfill sites. The soil medium was procured from the Jatibarang landfill in Semarang City, Indonesia.

2.3 Reactors Set up

The evapotranspiration reactor comprises two containers. The inner container has a 15-liter capacity and contains holes at the bottom for the growth medium, while the outer container has a 30-liter capacity and serves as the influent, allowing leachate to enter the inner container through capillary action. Furthermore, carbon-based anodes and cathodes, known as the MFC series, were developed for this reactor. The anode is located at the bottom of the reactor, and the cathode is exposed to the elements on the surface. Each type of generator has three reactors, as the reactor circuit is made in triplicate for each type. One limitation of the volume used for measuring discharge is that it can only be measured using the volume of an empty bucket.

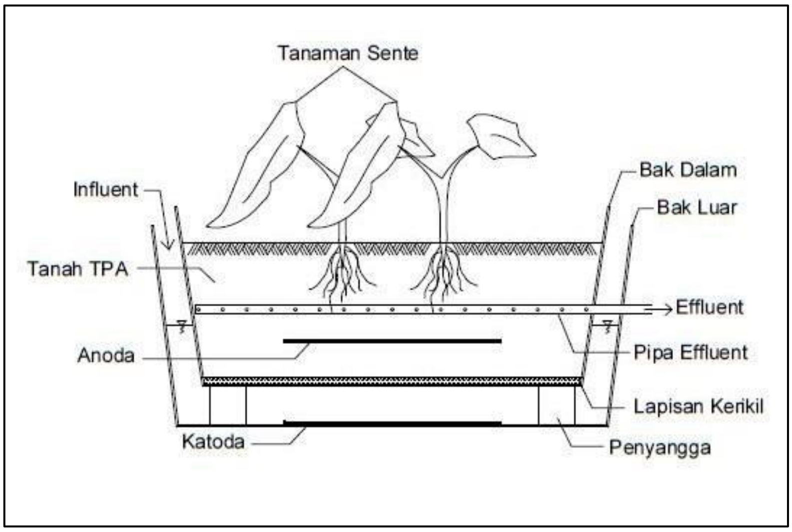

Figure 1. Research Reactor Design

As illustrated in Figure 1, three reactors have been constructed using 15-litre buckets and have a detention time (td) of 3 days (Amalia, Zaman, & Hadiwidodo, 2013). The influent flow for the reactor is 0.06 ml/second. In this study, electrodes are employed to capture electrons produced from bacteria's metabolic process in the reactor. Carbon electrodes are chosen for their excellent electron conductivity, cost-effectiveness, and compatibility with bacterial growth (Karthikeyan et al., 2015). The electrodes used in the research are sized at 40 cm x 10 cm x 1 cm, with the electrode preparation stages for the reactor depicted in Figure 2.

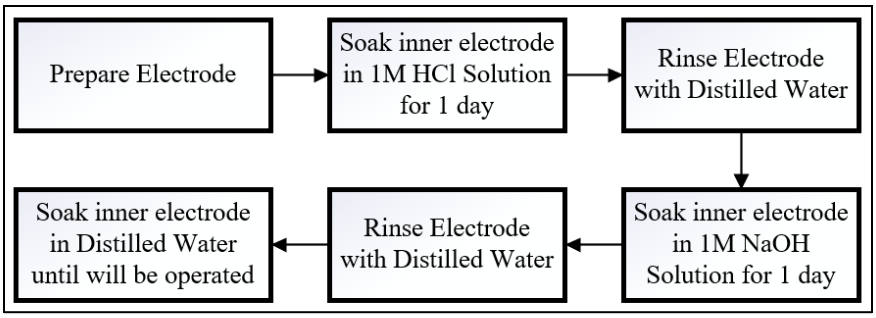

Figure 2. Stages of the Electrode Preparation Process

The electrode preparation stage for MFCs involves soaking graphite carbon electrodes in a 1 M HCl solution for one day, followed by rinsing with distilled water. Then, the electrode is immersed in a 1 M NaOH solution for one day and rinsed again with distilled water. Finally, the electrode is soaked in distilled water until used in the anode and cathode compartments. This preparation eliminates metal contamination and organic materials attached to the electrode (Ardhianto, Samudro, & Hadiwidodo, 2014).

2.4 Plants Cultivation

Before planting, a five-day acclimatization stage is conducted to prepare the reactor, fill it with landfill soil, assemble the electrode components, and introduce the sensitive plants. This acclimatisation stage aims to facilitate the plants' adaptation to the soil media utilized in the Jatibarang Landfill reactor. Given that landfill waste is representative of natural field conditions, it was employed as the medium for acclimatization in this study, drawing from previous research that utilized acclimatization to aid plants in adjusting to the soil waste media (Amalia et al., 2013). The plant acclimation stage spans five days and commences with preparing a reactor containing assembled electrode components and soil from the landfill, facilitating the planting of Sente plants. Each reactor hosts senta plants with two tubers consisting of two leaves. Throughout the acclimatization process, the reactor is consistently supplied with fresh water.

2.5 Experiment Set up

Following the completion of acclimatization, reactor testing is initiated. The reactor operates continuously and is linked to a drum containing leachate. The flow rate used for the reactor is 3.6 ml/minute. During testing, it was observed that plants could thrive using leachate as a water source, and the chemical oxygen demand (COD) was reduced at the electrodes. During operation, various analyses are conducted, including measuring current strength (I), voltage (V), COD, physical conditions of the greenhouse environment (temperature, light intensity, humidity), and the condition of each reactor (pH and temperature).

3. Results and Discussion

3.1 COD Reduction

In the research process, the reactor can remove COD from leachate. The reduction in COD at the continuous stage is determined based on the efficiency of COD removal with consistent influent. The COD removal efficiency is determined by subtracting the effluent COD concentration from the influent COD concentration, dividing this value by the influent COD concentration, and multiplying by 100%. The initial COD concentration refers to the COD concentration at the time of the preliminary test, which is 4,200 mg/l. The leachate used for the experiment is initially diluted with fresh water to achieve a salinity level suitable for plants, resulting in a COD concentration of 1,325 mg/l after dilution. COD effluent measurements are conducted every three days during the running stage.

Table 1. COD Removal Efficiency Results

Days to-	Sente Plant Reactor	Control Reactor
0 (Inlet)	0%	0%
3	76%	89%
6	28%	75%
9	57%	49%
12	77%	70%
15	65%	56%

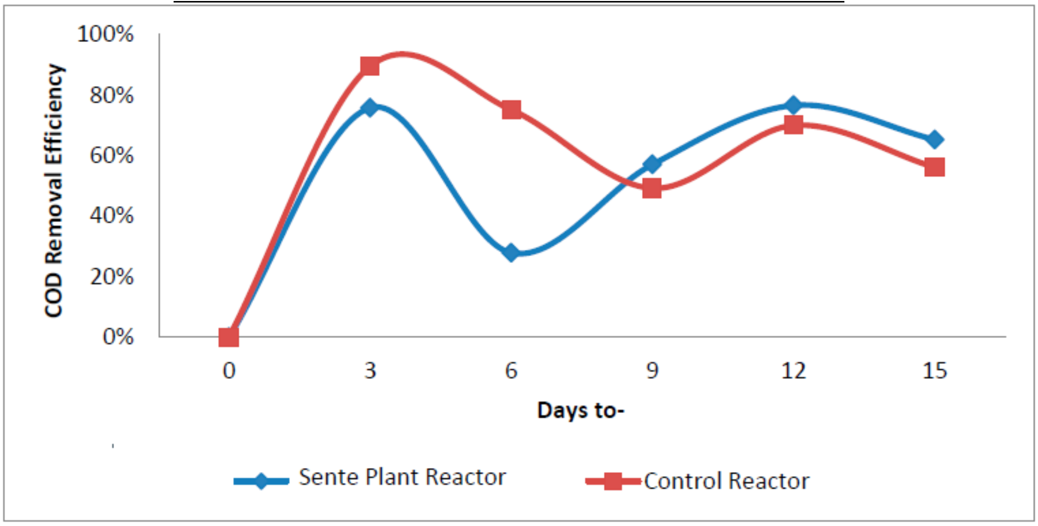

Figure 3. COD Concentration Removal Efficiency

The figures and table provide insight into COD concentration removal efficiency fluctuations. On day 3, the COD removal efficiency in the control reactor stood at 89%. In comparison, the Sente plant reactor exhibited a 13% lower efficiency at 79%. By day 6, the COD removal efficiency in the control reactor decreased by 75% compared to day 3, while the Sente plant reactor showed a 47% lower efficiency at 28%. This suggests that plants do not significantly eliminate pollutants, with the media playing a more substantial role. The removal of COD in reactors primarily occurs through physical processes in filtration, assisted by the degradation of organic materials trapped between the media by degrading microorganisms (Zaman & Istirokhatun, 2014). Muhajir (2013) suggested that the decline in COD values was due to solid materials settling, resulting in reduced waste material in wastewater. Another possibility is that bacteria growing in sand media significantly influence leachate processing more than bacteria from plants (Zaman & Istirokhatun, 2014). On days 9, 12, and 15, the role of plants became evident, with the COD removal efficiency in the Sente Plant Reactor proving to be greater than that of the Control Reactor. Plants, microorganisms, and residence time influence the decrease in COD values, with the ability to reduce COD content increasing with the length of residence time.

The disparity in COD removal efficiency between the Sente plant reactor and the control reactor stays consistent. By day 9, the control reactor's COD removal efficiency decreased by 49% compared to day 6, while the Sente plant reactor's efficiency increased by 57% during the same period. The difference in efficiency between the two reactors is minimal, at 8%.

On the 12th day, both the control reactor and the Sente plant reactor showed increased COD removal efficiencies of 70% and 77%, respectively, compared to the ninth day. The marginal 7% difference in efficiency between the reactors may be attributed to the role of microorganisms and plants, as explained by Supradata (2005). Microorganisms play a crucial role in processing organic material in wastewater, transforming it into valuable nutrients essential for plant growth. Additionally, the root systems of aquatic plants produce oxygen, serving as an energy source for the metabolic processes of microorganisms. On the 15th day, both reactors exhibited decreased COD removal efficiencies compared to the 12th day, registering 56% and 65% for the control reactor and the Sente plant reactor, respectively. The slight 9% difference in efficiency between the two reactors suggests a consistent pattern in COD removal. The decline in efficiency on the sixth day may be due to the compounds involved in the degradation process producing simpler compounds, thereby affecting the COD value (Parasara, Suyasa, & Adhika, 2015).

3.2 Electricity Production

Table 2. Current and Voltage Measurement Data for the Running Stage

Days to-	Sente Plant Reactor		Control Reactor	
	Voltage (V)	**Strong Currents (μA)**	**Voltage (V)**	**Strong Currents (μA)**
0	0.41	12.25	0.18	37
1	0.26	252.75	0.24	107.50
2	0.11	100.25	0.14	63.50
3	0.04	50.5	0.17	96
4	0.16	356.25	0.10	89.50
5	0.15	253.5	0.13	71.50
6	0.12	253.5	0.04	83
7	0.15	175.25	0.05	96
8	0.13	191.25	0.07	139
9	0.13	272	0.06	125
10	0.16	330.5	0.06	116
11	0.19	392.75	0.07	117.50
12	0.18	383.5	0.16	276
13	0.17	369.75	0.12	257
14	0.22	476.25	0.12	240
15	0.22	472.75	0.18	247.50

The data table reveals that the voltage values during reactor testing ranged from 0.04 V to 0.41 V, while the current values spanned from 12.25 μA to 476.25 μA. The Sente Plant Reactor attained its highest voltage of 0.41 V on day 0, while the control reactor reached its maximum voltage of 0.24 V on day one. Furthermore, the Sente Plant Reactor achieved its highest current strength of 476.25 μA on day 14. In contrast, the control reactor recorded its maximum current strength of 276 μA on day 12. The lowest voltage in the Sente Plant Reactor was measured on day three at 0.04 V; for the control reactor, it was on day six at 0.04 V. The lowest current strength in the Sente Plant Reactor was on day 0 at 12.25 μA, while for the control reactor, it was on day 0 at 37.00 μA.

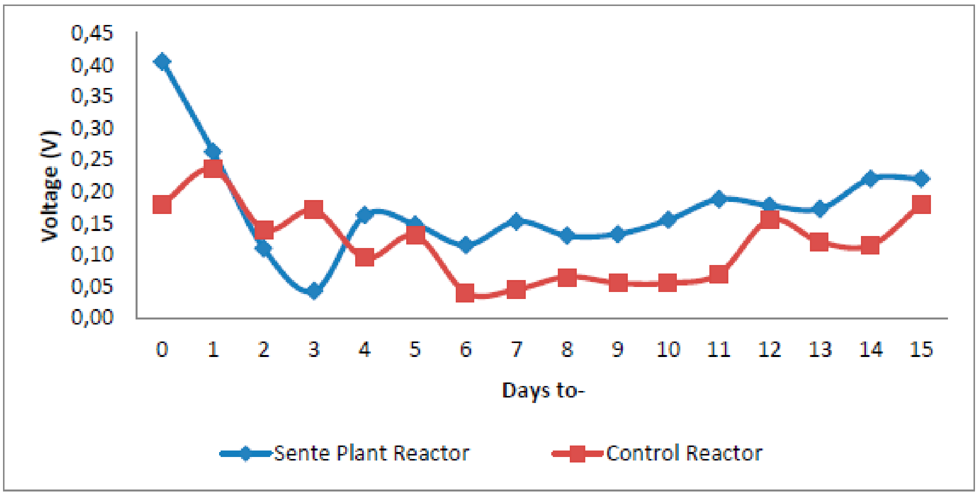

Figure 4. Voltage Graph

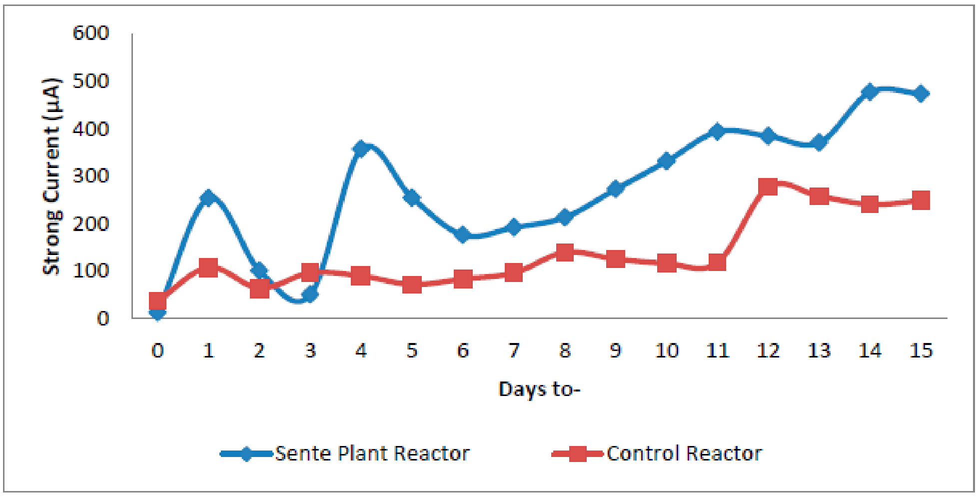

Figure 5. Strong Current Graph

The two graphs above illustrate the voltage and current generated during reactor testing. The voltage and current strength increase as the residence time in the reactor extends. This prolonged contact between the leachate in the reactor leads to a more pronounced degradation process. However, obstacles in the process can cause a decrease in the generated electric current. According to Vimala, Natesan, and Rajendran (2009), factors such as corrosion from electrodes, cables, and crocodile clips in electrical circuits inhibit the generation of electric current. Additionally, the presence of S and N elements in the leachate acts as electron traps, reducing the electrons captured by the electrode.

Based on the graph, it can be observed that electricity production in the Sente Plant Reactor continues to increase and is greater compared to the Control Reactor. Electricity is generated because the reactor utilizes solar energy as a power source through the activity of bacteria, which oxidize organic compounds and deposit organic compounds via the plant's roots (Timmers, Strik, Hamelers, & Buisman, 2010).

3.3 Comparison If Using the *Eleusine Indica* Grass

In a study by Zaman and Wardhana (2018), Eleusine Indica Grass was investigated for its potential to generate electricity through the MFC system. The experiment was conducted at the Jatibarang landfill in Semarang, Indonesia, using leachate water and soil media. The testing period lasted 30 days, longer than the 15 days used by other researchers. During the 30-day test, the electric power generated by the Eleusine Indica grass in the MFC system fluctuated. On the first day, the average electric power reached 50 µwatts, decreased to 10 µwatts by the 9th day, and gradually increased to 60 µwatts by the 30th day. This fluctuation was attributed to the bacterial growth pattern in the soil media and the plant roots, which adapted during the initial period and stabilised until the test's end. In addition to being influenced by fluctuations, the photosynthetic ability of plants is also affected by the growth adaptation of bacteria. This process involves bacterial inhibition and adjustment before they can eventually grow. Bacterial growth around the root surface is also influenced by the plant's metabolic activity, particularly in providing oxygen and nutrients that are unavailable in the leachate to support bacterial growth (Sente, 2017).

The study also compared the electric power potential of the Eleusine Indica grass with that of the *Alocasia macrorrhiza* plant in a short-term (30-day) operation. Recent research has discovered that the Alocasia macrorrhiza plant has a 60-95% higher electric power potential than Eleusine Indica grass. This difference is due to the plant's ability to release oxygen and biodegradable substrates through its root systems. This influences the redox conditions and evapotranspiration within the treatment bed, ultimately impacting the performance of the MFC (Microbial Fuel Cell) system. Furthermore, the effectiveness of the MFC system is influenced by a combination of biological, chemical, and electrical factors(Corbella, Guivernau, Viñas, & Puigagut, 2015).

3.4 Growth of *Alocasia Macrorrhiza* Plants in The Reactor

During the reactor testing, plant growth was monitored daily to assess the impact of leachate on the plants. The observations over the 15 days revealed significant and consistent growth in the number of leaves, plant length, and leaf size, indicating fertile growth.

Table 3. Sente Plant Growth Data in Reactors

Days To-	Leaf Area (Cm^2)	Stem Height (Cm^2)
0	58.23	9.25
1	60.33	10.31
2	65.73	11.23
3	68.94	11.73
4	69.60	12.63
5	71.35	13.25
6	77.10	13.93
7	80.22	14.63
8	80.22	15.13
9	83.21	15.78
10	84.97	16.48
11	84.97	17.08
12	86.89	17.65
13	86.89	18.38
14	86.95	18.98
15	87.05	19.58

From the table, it can be seen that the sense plant (Alocasia macrorrhiza) can grow with leachate water. The increase in stem height and leaf area proves that sense can grow in leachate conditions. The condition of the sense plants on the last day of reactor testing can be seen in the following picture.

Figure 6. Condition of Sente Plants

The sente plant in the reactor test influences the value COD concentration. This is seen from the role of plants as pollutant reducersin leachate. The following are the COD values and plant growth during reactor testing.

Table 4. Sente Plant Growth Values and COD Concentrations During

Days To-	Growth		COD Contrentation (mg/l)	
	Leaf Area (Cm^2)	Stem Height (Cm^2)	Reactor	Control
0	58.23	9.25	1325	1325
3	68.94	11.73	321.67	139.67
6	77.10	13.93	955.83	330
9	83.21	15.78	569.17	673.33
12	86.89	17.65	310.83	398.33
15	87.05	19.58	460.83	581.67

The table above illustrates that higher COD concentration allowances correspond to increased plant growth in the reactor. As the plants in the reactor thrive, their stem height and leaf area also increase, suggesting concurrent root development. This root growth will likely impact the reactor's ability to remove pollutants, including COD. The reduction in COD levels can be attributed to the settling and filtration of solid materials by the roots, resulting in a diminished presence of waste material in the wastewater. This filtration process is facilitated by the reactor's media and plant roots, which form a filter capable of retaining solid particles in the wastewater (Tangahu & Warmadewanthi, 2001).

4. Conclusion

In the short term, the *Alocasia Macrorrhiza* plant has demonstrated more Zaman and Wardhana (2018) made an exciting discovery indicating that the Alocasia macrorrhiza plant exhibited 60-95% higher electric power potential than Eleusine Indica grass over 30 days. Moreover, the microbial fuel cell (MFC) system integrated into the evapotranspiration reactor holds significant promise for generating renewable electric power. The test results suggest that the leachate processing process and microbial fuel cells in an evapotranspiration system hold the potential for electrical energy generation. Over the 15-day research period, power values during reactor testing ranged from 2.15μW to 104.78 μW. Furthermore, the chemical oxygen demand (COD) concentration removal efficiency during reactor testing ranged from 28% to 89%. The highest COD removal efficiency in the Sente Plant Reactor occurred on day 12 at 77%, while the Control Reactor exhibited the highest COD removal efficiency on day three at 89%. The lowest COD removal efficiency in the Sente Plant Reactor was observed on day six at 28%; this occurred on day nine at 49% for the Control Reactor. The MFC method shows promise for leachate management. It harnesses microbial metabolism and plant activity to degrade leachate components while also yielding valuable end products that can serve as small-scale electricity generators. Further research is necessary to refine the method and minimize errors, enhancing its appeal for wastewater management.

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