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Bioelectricity Generation from Bamboo Leaves Waste in a Double Chambered Microbial Fuel Cell

(Penjanaan Bioelektrik daripada Sisa Daun Buluh dalam Sel Bahan Api Mikrob Dua Kebuk)

Siti Kudnie Sahari[1,2,*], Amir Maina Butit[1], Zainab Ngaini[3], Yanuar Zulardiansyah Arief[1,2], Kuryati Kipli[1], Martin Anyi[1,2], Asmahani Awang[4], Muhammad Kashif[5], Mohamad Rusop Mahmood[6] , Zaidi Embong[7], Lilik Hasanah[8] , Abdul Rahman Kram[1] & Marini Sawawi[9]

[1]*Department of Electrical and Electronics Engineering, Faculty of Engineering, Universiti Malaysia Sarawak, 94300 Kota Samarahan, Sarwawak, Malaysia*
[2]*Institute of Sustainable & Renewable Energy, Universiti Malaysia Sarawak 94300 Kota Samarahan, Sarawak, Malaysia*
[3]*Faculty of Resources Science and Technology, Universiti Malaysia Sarawak, 94300 Kota Samarahan, Sarawak, Malaysia*
[4]*Faculty of Science and Natural Resources, Universiti Malaysia Sabah, 88400 Kota Kinabalu, Sabah, Malaysia*
[5]*School of Electrical and Information Engineering, Tianjin University, 92 Weijin Road, Nankai District, Tianjin, 300072, China*
[6]*Faculty of Electrical Engineering, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia*
[7]*Faculty of Applied Science and Technology, Universiti Tun Hussein Onn Malaysia, 86400 Muar, Johor, Malaysia*
[8]*Faculty of Mathematics and Sciences Education, Indonesia University of Education*
[9]*Department of Mechanical and Manufacturing, Faculty of Engineering, Universiti Malaysia Sarawak, 94300 Kota Samarahan, Sarawak, Malaysia*

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ABSTRACT

This study investigated the utilization of bamboo leaf waste and two varieties of bacterial sources, chicken manure and effective microorganism, in a microbial fuel cell (MFC) at three substrate concentrations (40 g/liter, 80 g/liter, and 160 g/liter). The primary objective was to investigate the kinetics of bacterial growth at various substrate concentrations in the MFC, as well as the effect of light conditions and pH on MFC power generation. The MFC had dual chambers with graphite electrodes serving as the cathode and anode. Within 72 h, the highest power density of 90.05 mV was attained using the highest substrate concentration of bamboo leaf waste and chicken manure during the logarithmic growth phase, albeit with a shorter duration. The longest sustained phase of bacterial activity was observed during the stationary phase, at the highest substrate concentration of 160 g/liter, followed by 80 g/liter and 40 g/liter. These results indicate that the logarithmic phase is the optimal time for bacterial activity in the MFC. However, attaining long-term stability in power generation in the logarithmic phase requires careful parameter optimization.

Keywords: Bamboo leaves; bioelectricity generation; chicken manure; Microbial Fuel Cell; substrate concentration

ABSTRAK

Penyelidikan ini mengkaji penggunaan sisa daun buluh dan dua jenis punca bakteria, tahi ayam dan mikroorganisma berkesan, dalam sel bahan api mikrob (MFC) pada tiga kepekatan substrat (40 g/liter, 80 g/liter dan 160 g/liter). Objektif utama adalah untuk mengkaji kinetik pertumbuhan bakteria pada pelbagai kepekatan substrat dalam MFC, serta kesan keadaan cahaya dan pH pada penjanaan kuasa MFC. MFC mempunyai dua ruang dengan elektrod grafit berfungsi sebagai katod dan anod. Dalam masa 72 jam, ketumpatan kuasa tertinggi 90.05mV telah dicapai menggunakan kepekatan substrat tertinggi sisa daun buluh dan baja ayam semasa fasa pertumbuhan logaritma, walaupun dengan tempoh yang lebih singkat. Fasa paling lama berterusan aktiviti bakteria diperhatikan semasa fasa pegun, pada kepekatan substrat tertinggi 160 g/liter, diikuti oleh 80 g/liter dan 40 g/liter. Keputusan ini menunjukkan bahawa fasa logaritma adalah masa yang optimum untuk aktiviti bakteria dalam MFC. Walau bagaimanapun, untuk mencapai kestabilan jangka panjang dalam fasa logaritma untuk penjanaan kuasa memerlukan pengoptimuman parameter yang teliti.

Kata kunci: Baja ayam; daun buluh; kepekatan substrat; penjanaan bioelektrik; sel bahan api mikrob

Introduction

The use of fossil fuels as a primary source of energy in industrialized and emergent nations has resulted in a variety of negative environmental consequences, such as global warming and air pollution (Parera 2018). Therefore, it is essential to supplant fossil fuels with alternatives that are more environmentally friendly, such as renewable energy (Slate et al. 2018). A Microbial Fuel Cell (MFC) is currently an environmentally beneficial technology capable of producing electrical energy via microbial metabolism.

Due to the biological factors that can affect the overall performance of MFCs, including bioelectricity generation and operational cost, the substrate has received considerable attention (Ullah & Zeshan 2020). Numerous studies have examined the utilization of organic compounds derived from food and plant waste (Hongzhi et al. 2018; Qingliang et al. 2017). The majority of studies have concentrated on liquid solid waste as opposed to solid waste. Yoshimura et al. (2018) discovered that using rice bran and bottom mud as a source of bacteria produced a maximal power density of 16.5 mW/m2. Using 20 g/L of sago hampas, Jenol et al. (2019) measured a maximal power density of 73.8 mW/cm^2 with a stable cell voltage output of 211.7 mV. Sonu et al. (2022) recently reported a wheat straw MFC with a maximal power density of 127 mW/m^2. These results demonstrate that MFCs have the potential to generate bioelectricity from organic solid waste.

Bamboo trees are typically found in tropical, subtropical, and temperate regions of the world (Hossain, Islam & Numan 2016). The rapid development of bamboo causes bamboo industries to generate a significant amount of waste, which, if improperly managed, contributes to environmental pollution issues. Consequently, bamboo waste should be regarded as a valuable biomass for resource recovery. Approximately ninety percent of bamboo's mass is comprised of cellulose, hemicellulose, and lignin, which make up the majority of bamboo's chemical composition. Resins, tannins, waxes, and inorganic salts are additional secondary components. In addition, bamboo leaves contain numerous organic compounds, including carbohydrate, deoxygenated saccharide, fat, and protein (Azeez & Orege 2016). The presence of cellulose and hemicellulose makes bamboo leaves a potential food source for microbes, and their high nutritional and organic component content makes them suitable MFC substrates.

Due to the strong molecular interactions between its constituent components, the biodegradability of solid biomass, such as bamboo leaves, presents a significant obstacle to its utilization (Nakamura et al. 2020). Bamboo waste must be pretreated to maximize energy production through bacterial decomposition. Recent research indicates that the pH of river water, which is used as the MFC electrolyte, can influence power density generation (Halim et al. 2021). In addition, the choice of bacteria source, substrate concentration, and consideration of the kinetics of bacteria growth are interconnected factors that influence the performance, efficiency, and stability of MFC in order to achieve high performance. Thus, this study employed two kinds of bacterial sources, namely chicken manure and effective microorganisms, in addition to varying substrate concentrations. The purpose of this study is to examine the impact of substrate concentration on the performance of Microbial Fuel Cells (MFCs) and the kinetics of the bacteria growth. To the best of our knowledge, there was no report on the kinetics of bacteria growth with the substrate concentration dependence in MFC by using bamboo leaves was reported to date. The kinetics of bacterial proliferation provide information regarding the duration and sustainability of bacterial activity. By identifying the substrate concentration that sustains bacterial growth for extended periods, MFCs can be designed to produce stable and continuous power, reducing the need for frequent maintenance or substrate replenishment.

Materials and Methods

Substrate and Microorganisms

Bamboo leaves were collected from Universiti Malaysia Sarawak, Malaysia. The leaves were then washed and ground with a blender to ensure size homogeneity and to ease biodegradation by the microbes. The bamboo leaves that were inoculated in the MFC ranged from 40 g/liter to 160 g/ liter. Cocopeat was accessed economically and used in this project as a bulking agent, to increase the volume of the sample properties, as well as a secondary food source for the microbes, cocopeat was set at a fixed amount of 5 g in each cell. The 5 g chicken manure (CM) or Effective Micro-organisms (EM) was used as the main sources of bacteria in separate cells. The performance of the MFC cells was measured based on bacteria dependencies of the sources. The pH level of the electrolyte was measured during the experiment.

FABRICATION OF MFC AND OPERATION

Two 745 mL containers were utilized to create the anode and cathode of a double chamber microbial fuel cell (DCMFC). The containers were joined by a salt bridge made of salt-soaked and woven manila straw. The manila straw was then sealed tightly with water-resistant tape to prevent water leakage and air syphoning between the chambers. Anode chamber of DCMFC contains CM or EM, bamboo leaves, cocopeat, and water, whereas cathode chamber contains 250 mL of domestic wastewater (DWW). The substrates concentration was tabulated in Table 1.

Graphite plates with the dimension of 5 cm × 4 cm × 0.3 cm were used as the electrodes for the cathode and anode. The biocompatible property of graphite material can increase the attachment of bacteria, resulting in greater power production of MFC as discussed in our previous study (Sahari et al. 2022). Figure 1 shows the experimental setup of dual chamber MFC.

TABLE 1. Composition of MFC

Type of MFC	Bacteria Source	Anode	Cathode
MFC-A		40g/liter (BL)+5g CM+5g CP	DWW
MFC -B		80g/liter (BL)+5g CM+5g CP	DWW
MFC-C	Chicken Manure	160g/liter(BL)+5g CM+5g CP	DWW
MFC-D		40g/liter (BL)+5g CM+5g CP	DWW
MFC-E		80g/liter (BL)+5g CM+5g CP	DWW
MFC-F	Effective Microorganism	160g/liter (BL)+5g CM+5g CP	DWW

*CM-chicken manure, EM-Effective microorganism, BL-bamboo leaves, CP- cocopeat, DWW-domestic wastewater

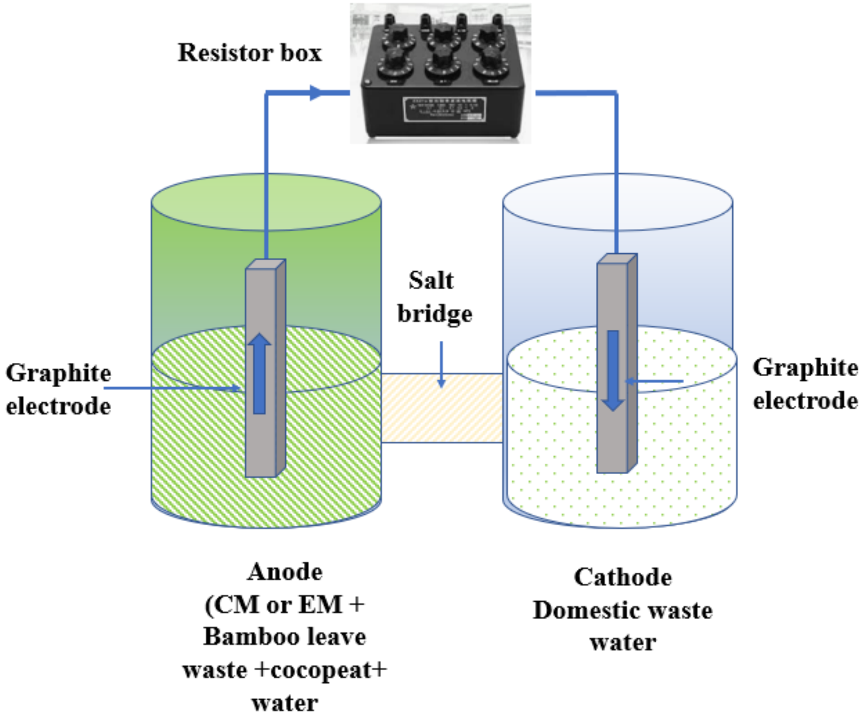


FIGURE 1. Construction of double chamber bamboo leave MFC

MEASUREMENT OF VOLTAGE AND CURRENTS

The MFC was operated in closed circuit. The cells were then connected to various external resistors (300, 500, 700, or 1 K), which were controlled by an RDB-10 resistor box from global specialties. Using a digital multimeter, the voltage and current of the cells were measured twice daily at 0800 and 2100 within 21 days. Each day, using a pH universal indicator, the pH of each cell (both anode and cathode) was determined. The power density and current density are computed based on the surface area of the anode electrode. Equations 1 and 2 show the equations used to formulate the electrical parameter (Ullah & Zeshan 2020).

$$P=IV \quad (1)$$

$$PD=P/A \quad (2)$$

where I is current (mA); A is surface area; P is power (mW); V is voltage (V); and PD is power density (mW/m^2).

RESULTS AND DISCUSSION

POWER AND CURRENT DENSITY COMPARISON BETWEEN CHICKEN MANURE AND EFFECTIVE MICROORGANISM

The pretreatment of bamboo leaf waste is crucial to ensure its degradation by energy-generating bacteria. In this section, therefore, the level of power and current density produced by MFC from various bacterial sources was investigated. Figure 2 shows the power and current density of MFC that containing 40 g/liter bamboo leaves with different bacteria source, effective microorganisma (EM) or chicken Manure (CM) Overall, the power densities produced by both MFCs (CM and EM) were low. However, if compares both MFCs, CM outperformed EM by producing higher power density level in cells. It can be observed that the power density levels in CM did not begin at zero level if compared to EM. The current density generation trends were similar. The higher power density of CM may be attributable to the efficiency of developing electron-producing microbial communities, whereas EM is manufactured as a supplement of a specific type and amount of nutrients to plants (Ning et al. 2017). Higher power density production by MFC utilizing CM may be caused by an increase in microbial activity that is better in animal waste fertilizer than in commercial fertilizers, and the development and growth of electrons have also been demonstrated (Akeredolu et al. 2017; El-Nahhal et al. 2020; Gazali et al. 2017). In addition, the voltage and current generation for CM increased over time, indicating that the electricity generation was unsustainable. As discussed in a previous report, the sustainable generation of electricity could be enhanced by increasing the observation period to more than 45 days (El-Nahhal et al. 2020).

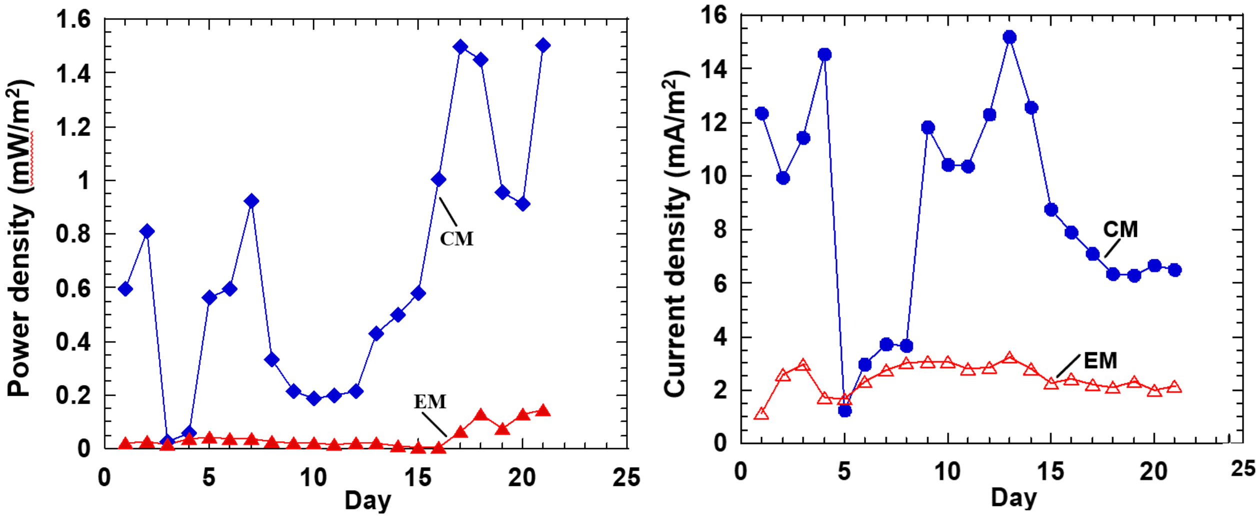


FIGURE 2. Power and current density of MFC from different bacteria source

INFLUENCE OF SUBSTRATE CONCENTRATION OF VOLTAGE GENERATION

The microbial activity at varying concentrations of substrates was investigated. Figure 3 depicts the voltage generation at various substrate concentrations with chicken manure as the primary bacteria source and a fixed external resistor of 1k. MFC-A contains 40 g/liter of waste bamboo leaves, MFC-B contains 80 g/liter of waste bamboo leaves, and MFC-C contains 160 g/liter of waste bamboo leaves, respectively. The graph in Figure 3 demonstrates that the bacterial activity is dependent on the concentration of the substrate. For 80 g/liter and 160 g/liter bamboo leaves, the bacterial activity can be divided into four phases: phase (1), phase (2), phase (3), and phase (4). Phase (1) represents the lag phase or adaptation of bacteria, phase (2) represents the logaritmic phase in which the number of bacteria increases exponentially, resulting in the highest level of voltage, phase (3) represents the stationary phase in which the number of bacteria has reached a plateau, and phase (4) represents the death phase of bacteria in which the number of bacteria decrease, resulting in the decline of electric generation. For all substrate concentrations, the power density began to increase at the first peak between days 2 and 3 and then dropped to a certain level over the subsequent days. The increase in power density at the first peak may be attributable to the assimilation of other organic compounds in bamboo leaves, such as starch, deoxidized saccharide, fat, and protein, whereas the increase in power density generation at the second peak is likely attributable to the degradation of macromolecular compounds, such as cellulose, hemicellulose, and lignin. As the overall kinetics of bacterial activity for 40 g/liter bamboo leaves differed from 80 and 160 g/liter bamboo leaves, additional experimental time may be required to observe electric generation. Similar to a previous report, our findings indicate that the kinetics of bacterial oxidation vary with substrate concentration and substrate degradation rates (Reimers et al. 2007). Clearly, the voltage generation could be enhanced by increasing the concentration of the substrate. The MFC containing 160 g/liter of bamboo leaves exhibited the highest voltage level of 90.05 mV on the fourth day. In addition, it is evident from the study of the graph in Figure 3 that sustained voltage was generated during the stationary phase. The duration of each phase for three distinct substrate concentrations is provided in Table 2. Our concentration corresponds to the stationary phase, which indicates the stability of voltage generation in the microbial fuel cell (MFC). Notably, MFCs with higher substrate concentrations generated stable voltage for extended durations during the stationary phase.

In general, the phase that occurs in the midst of the logarithmic growth phase or during the transition from the log phase to the stationary phase tends to exhibit superior power performance. This is predominantly due to its increased growth rate and metabolic rate. These observations provide useful insights for improving MFC performance. Nevertheless, it is important to note that this phase's sustained duration is relatively short. Further research is required to optimize the parameters and extend the sustainable period, which has the potential to considerably enhance the performance of MFCs.

TABLE 2. Summary of generated voltage by phase

Substrate concentrations	Phase (1)	Phase (2)	Phase (3)	Phase (4)
g/liter	Duration (Day)			
40	1-8	9-12	12-21	-
80	1-8	9-11	12-17	18-21
160	1-4	5-7	8-20	21~

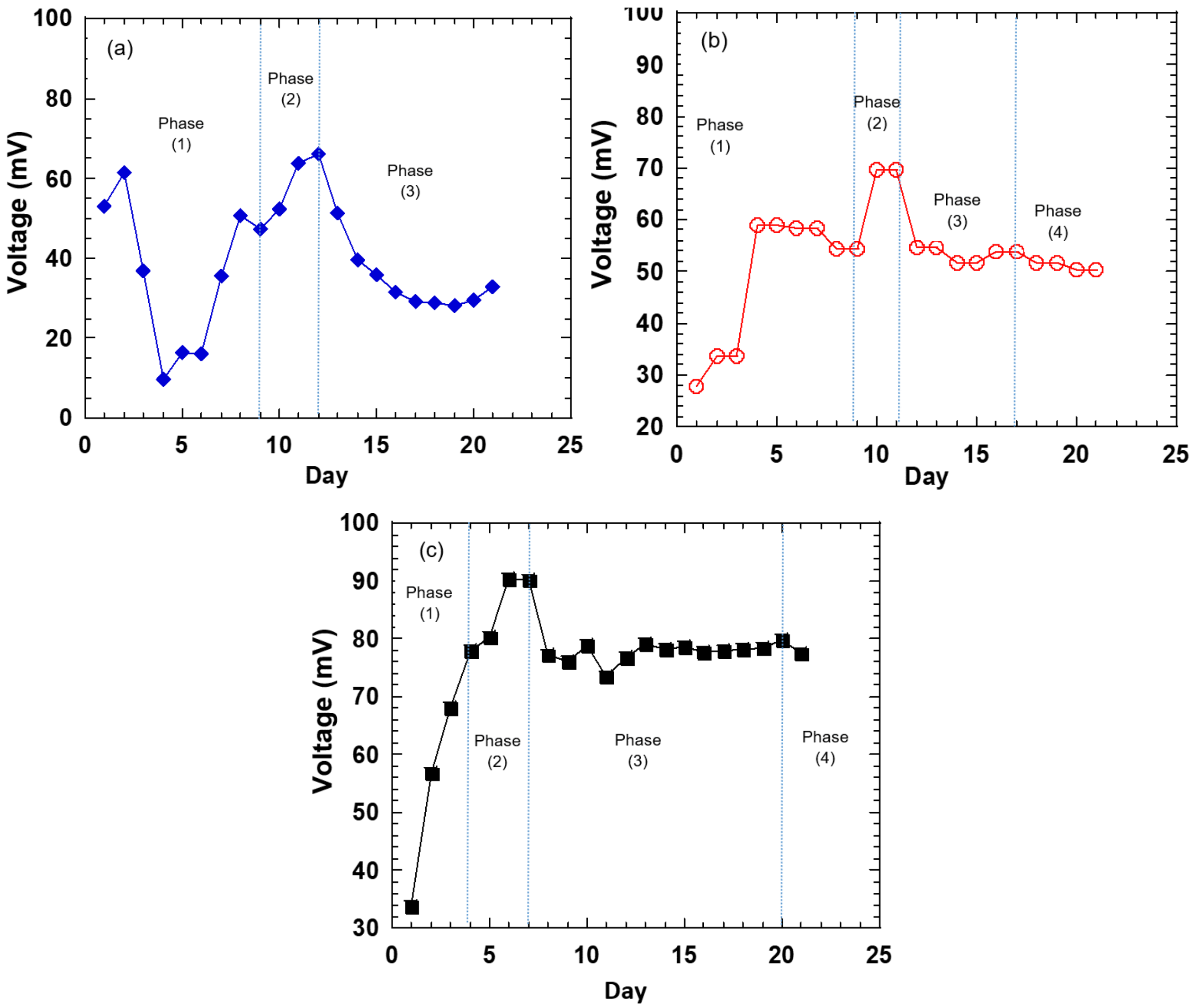


FIGURE 3. Voltage level of different substrate concentrations

INFLUENCE OF LIGHT CONDITION ON VOLTAGE GENERATION

Figure 4 compares the energy production of EM and CM between 0900 and 2000 in the morning and evening, respectively. The results overall indicate that power generation is greater in the morning than in the evening for both CM and EM bacteria sources during the first three days and last nine days of the experimental period. Similar to the findings of a recent publication, these data demonstrate that the exposure of MFC to sunlight can generate ionic species and stimulate the photosynthetic activity of some microbial communities, such as cynobacteria in animal manure and phototrophic bacteria in EM, thereby enhancing the power generation (Bodhipaksha et al. 2017; Carena et al. 2019; Miersch et al. 2019; Sankoda et al. 2019).

GENERATED VOLTAGE IN COMPARISON TO SUBSTRATE CONCENTRATION IN OHMIC ZONE

The activity of MFC cells in the ohmic zone is investigated in this section. Figure 5 depicts the generated voltage at various substrate concentrations for a given external resistance (300 Ω, 500 Ω,700 Ω, and 1000 Ω), within the Ohmic zone. The average voltage was calculated for each substrate concentration over the duration of 21 days. Voltage generation exhibited ohmic behavior, with 1000 resistor generating the highest

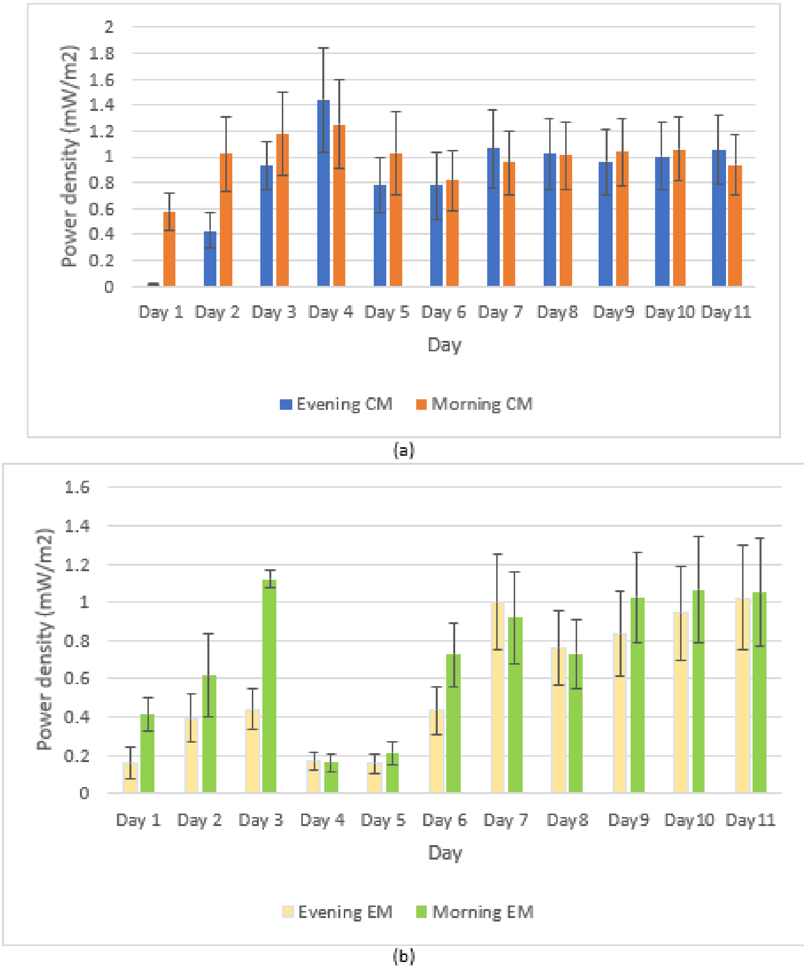


FIGURE 4. Power density production comparison of different bacteria source at different light condition

average voltage of 58.01 mV. As shown in Figure 5, there is a small correlation between voltage and substrate concentration, where significant voltage was observed between the cell containing 80 g/liter and 160 g/liter bamboo leaves. These outcomes may be the result of concentration-induced inhibition of bacterial metabolism (Marashi & Kariminia 2015).

INFLUENCE OF ANOLYTE PH ON THE POWER GENERATION

As mentioned previously, domestic wastewater was used as the electrolyte of MFC. The experiment was conducted for 21 days to determine the effect of pH level on the power and current density of MFC, as depicted in Figure 6(a) and 6(b). It is evident that the power density and current density increase gradually for four days before beginning to decrease. The optimal output was achieved at a pH of 8. The maximum power density measured was 1.77 mWm^{-2}, while the maximum current density was 19.06 mAm^{-2}. The trend of power production at various pH levels indicates that an alkaline environment is optimal for the growth of electrogenic bacteria. This agreement is consistent with the findings of the previous study, which showed that the highest voltage was produced on day 4 at a pH of 8, where the electrochemical contact of the bacteria increases significantly, resulting in increased power under alkaline conditions. (Marashi & Kariminia 2015).

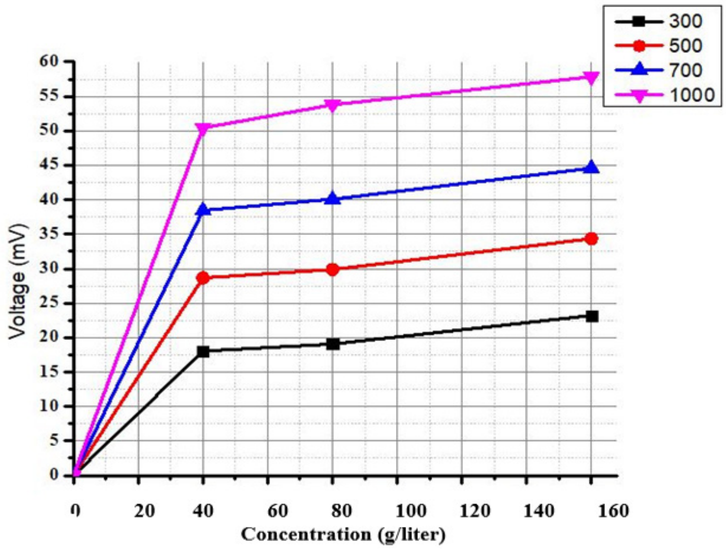
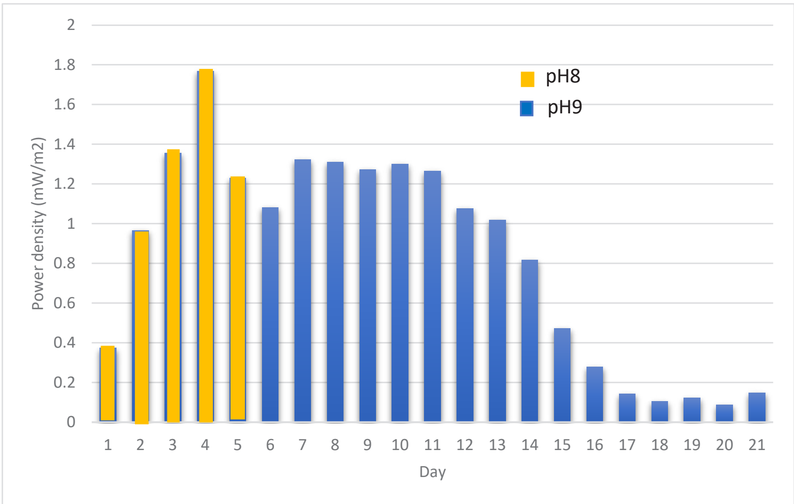
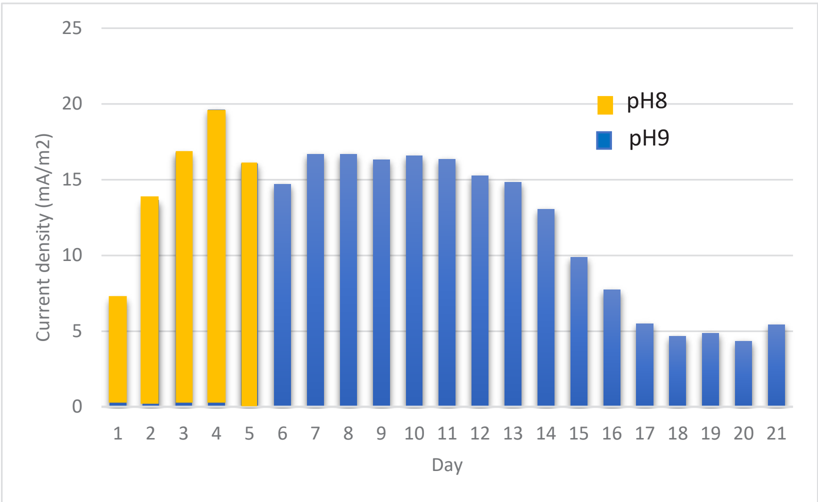


FIGURE 5. The generated voltage with different substrate concentration at different resistance



(a)



(b)

FIGURE 6. (a) pH level versus power density of 40 g bamboo leave waste and chicken manure (b) pH level versus current density of 40 g bamboo leave waste and chicken manure

LIMITATION OF STUDY

The uncontrolled experimental environment, such as humidity, temperature, pH, and oxygen level, which affect microbial growth, was a limitation of the study. Fluctuation in air humidity may influence the development and persistence of pathogenic microorganisms. Therefore, the error bars representing the standard deviation in Figure 3 are larger, indicating greater variability among a small population of microorganisms in MFCs. To solve this issue, it is suggested that the experimental environment must be controlled for improved experimental outcomes.

CONCLUSION

This study highlights the potential for generating electricity from bamboo leave waste and bacterial sources. This investigation yielded several observations. First, chicken manure is the best source of bacteria to combine with a greater quantity of bamboo leave waste, resulting in a higher voltage output. Second, increased substrate concentrations resulted in extended periods of stable voltage generation during the stationary phase. Furthermore, the phase that occurs in the middle of the logarithmic growth phase or during the transition from the logarithmic phase to the stationary phase is typically characterized by a superior power performance. In addition, the study elucidates the effect of light exposure and electrolyte pH on the production of energy by microbial fuel cells (MFCs). Overall, these results demonstrate the viability of MFCs for producing energy from inexpensive materials, such as bamboo leaves and animal waste.

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*Corresponding author; email: sskudnie@unimas.my