

EFFECT OF SUBSTRATE C/N RATIO ON BIOELECTRICITY GENERATION USING SEDIMENT MICROBIAL FUEL CELLS (SMFCs)

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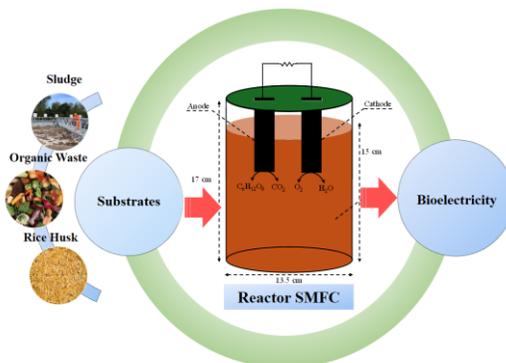
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Graphical abstract



Abstract

Fossil fuel is the primary energy source for electricity generation. Nevertheless, finding alternative renewable energy sources is emerging for electricity generation because of excessive electricity consumption and depletion of fossil fuels. Sediment Microbial Fuel Cells (SMFCs) technologies convert nutrients into bioelectrical by biochemical reactions. This study investigated the impact of C/N ratio substrate on bioelectrical generation using SMFC technology. A combination of leachate treatment sludge, organic waste, and rice husks were used as substrates for SMFCs. The study was conducted using an SMFCs reactor with a volume of 2 L and was operated in a single batch chamber under aerobic conditions. Electrodes made of zinc and carbon with a surface area of 40 cm² were used. The initial electric conductivity (EC), pH, and salinity of sludge were 15700 μs/cm, 7.36, and 8660 mg/L, respectively. The composition of sludge, organic waste, and rice husks in the reactor was adjusted based on a C/N ratio of 18 and 27. After 17 operating days, the substrate with C/N ratio 27 generated power density of 370 mW/m² and substrate with C/N ratio of 18 generated 336 mW/m². The final C/N ratio of substrate with C/N ratio 27 decrease by 71.6% that indicates nutrient degradation by the activity of microorganisms.

Keywords: electricity, leachate treatment sludge, organic waste, sediment microbial fuel cells, zinc-carbon electrode

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1.0 INTRODUCTION

Fossil fuel is still the primary energy source all over the world. In Indonesia, most power plants are operated by using fossil fuels. In 2024, the total installed power plants capacity in Indonesia reached 101 Gigawatt (GW), of which 85% was derived from fossil energy sources, while only 15% originated from renewable energy sources [1]. Some research show that fossil fuel use has some harmful effects on the environment, especially emission contribution to greenhouse gases. Estimates from the Ministry of Energy and Mineral Resources indicate that Indonesia's greenhouse gas emissions exceed 400 million tons of CO₂ equivalent (CO₂eq) in 2025 [1]. One of the Sustainable Development Goals (SDGs) is to provide all individuals with dependable, affordable, environmentally friendly, and modern

energy [2]. The exploration of energy alternatives has become a main topic over the last decade, with a primary goal of mitigating the rise in greenhouse gas emissions. Microbial Fuel Cell (MFC) outperform other renewable energy sources for several reasons, including their effectiveness in transforming organic matter into electricity, versatility in deployment across different scales, abundance of raw materials (such as organic matter or wastewater), and multifaceted applications like wastewater treatment [3]. Therefore, microbial fuel cell (MFCs) technology has emerged as a promising approach for electricity generation.

Microbial fuel cells (MFCs) utilize the metabolic activity of microorganisms to convert the chemical energy stored in organic matter directly into electrical energy. These microorganisms transform organic substrate into carbon dioxide, protons, and electrons. Electrons move from the anode to the cathode via an external wire, generating an electrical

current, thus leading to the production of bioelectricity on the anodic surface [4]. Sediment microbial fuel cells (SMFCs) are a branch of MFC that harvest bioelectricity from sediment and treat the sediment simultaneously. SMFCs can capture electrical energy from sediment by immersing an anode electrode within the sediment and soaking a cathode electrode in the overlying water. In this configuration, electrons are released through bacterial oxidation of organic matter in the sediment, moving through an external circuit to the cathode electrode. Simultaneously, protons migrate to the overlying water layer, where they combine with electrons and oxygen to form water [5]. SMFCs method is known for its high efficiency of organic degradation, low greenhouse emission, applicability to operate in an aerobic and anaerobic system with ambient temperature, and high electrical potential in the range of 42-2668 mW/m² [6]. The type of sediment significantly influences electricity generation. Various studies have explored different sediment types, with fat, oil, and grease (FOG) sludge producing a power density of 1787.26 mW/m² [7], sewage sludge yielding a power density of 2171 mW/m² [8], and sediment generating a power density of 2790 mW/m² [9]. Electric production of SMFCs also depends on factors like the surface area of electrodes and the ratio of carbon (C) and nitrogen (N) in the substrates.

Each substrate contains varying amounts of carbon and nitrogen, and the composition of these elements in a substrate is referred to as the C/N ratio. The C/N ratio plays a crucial role in the SMFCs process, particularly in contexts involving composting and bioremediation. The C/N ratio is a crucial factor in compost treatment, with carbon serving as the primary energy source for microbes, while nitrogen acts as the source of synthetic cell nutrients. Nitrogen is essential for the growth of microbial communities involved in the biochemical processes of sediments [5]. The optimum C/N ratio of microorganism growth is between 20-40. When the quality compost source material possesses an optimum C/N ratio, the solid-phase microbial fuel cell will achieve optimal electrical performance as its ratio approaches the ideal composting ratio [10]. Previous research demonstrated that a favorable C/N ratio of 30:1 was observed when utilizing a mixture of food waste, piggery waste and sludge as the substrate [10]. Various C/N ratios of the substrate should be studied to evaluate the effectiveness of microorganism activities and optimum electricity generation.

By proposing a different C/N ratio from other studies, this research investigates the potential for alternative electrical energy by utilizing sludges, organic waste, and rice husks as substrates with SMFC technology. The C/N ratio is expected to influence SMFC performance as it can affect microbial metabolism, and the bioelectricity produced.

2.0 METHODOLOGY

2.1 Substrate Preparation

Three types of substrates were used in this study: leachate treatment sludge, organic waste, and rice husk. The leachate treatment sludge was collected from the biofilter pond of the wastewater treatment plant at the Manggar landfill site. The purposive sampling method was conducted to collect samples from three sampling points in the surface (around 5-10 cm) to ensure a representative sample. The collected sludge was mixed

homogeneously and stored at a temperature of 4°C prior to the experiments. In the Manggar landfill site, the organic waste was separated before entering the composting facility. Organic waste, mostly vegetable waste, was taken from a composting facility at the same landfill site. The raw organic waste was taken before entering the composter. All organic waste was cut into small sizes around 1-5 cm to facilitate more degradation by microorganisms. Rice husk was used to provide carbon sources for microorganisms. Rice husk was collected from the plant store in Balikpapan, Indonesia. Organic waste and rice husk were used immediately in the SMFCs process after collection. The composition of sludge, organic waste, and rice husks was mixed based on the C/N ratio. Equation (1) was used to calculate the range of C/N ratio.

$$C/N \text{ Ratio} = \frac{M_1 \times C_1 + M_2 \times C_2 + M_3 \times C_3}{M_1 \times N_1 + M_2 \times N_2 + M_3 \times N_3} \quad (1)$$

where M_1, M_2, M_3 is dry mass of substrate and C_1, C_2, C_3 is carbon content of substrate. The value of N_1, N_2, N_3 represent nitrogen content of substrate. The leachate treatment sludge had water content of 88% and C/N ratio of 6.39:1. The organic waste had water content of 62% and C/N ratio of 13.37:1. The rice husk had water content of 10% and C/N ratio of 71:1. The C/N ratio calculation for mixture of leachate treatment sludge, organic waste, and rice husk are,

$$C/N \text{ Ratio} = \frac{(330 \times 12\%) \times 6.39 + (220 \times 38\%) \times 13.37 + (19 \times 90\%) \times 71}{(330 \times 12\%) \times 1 + (220 \times 38\%) \times 1 + (19 \times 90\%) \times 1} = 18:1$$

$$C/N \text{ Ratio} = \frac{(330 \times 12\%) \times 6.39 + (110 \times 38\%) \times 13.37 + (35 \times 90\%) \times 71}{(330 \times 12\%) \times 1 + (110 \times 38\%) \times 1 + (35 \times 90\%) \times 1} = 27:1$$

Substrate with C/N ratio 18:1 had ratio of leachate treatment sludge, organic waste, and rice husk = 330:220:19, and substrate with C/N ratio of 27:1 had ratio of leachate treatment sludge, organic waste, and rice husk = 330:110:35.

Composting process can be accomplished by using a C/N ratio range of 10-40. Dume et al. [11] reported that composting can be conducted in C/N ratio of 10-40 and the initial value of C/N ratio influences the quality of the final product. Chiarelto et al. [12] also reported that C/N ratio of 16 to 35 can be used in sewage sludge composting. The ideal C/N ratio for composting is 20-30 for optimal results [13]. Furthermore, Wang et al. [14] used substrate with ratio of 30:1 in simultaneous composting and MFC systems. If the C/N ratio is higher than ideal ratio, the deprivation of nitrogen for microorganisms occurs. On other hand, if the composting ratio is lower than ideal, the residue of nitrogen remains in substrate that affects the microorganism growth. The sewage sludge as the main substrate in the study contains the highest nitrogen content among organic waste and rice husk. This study aims to evaluate the addition of sewage sludge as nitrogen source inside and outside in the range of ideal C/N ratio for composting. The experiments were conducted in triplicate for each C/N ratio.

2.2 Electrode Preparation

An electrode made of zinc was used as an anode, and a cathode made of carbon was used. Each rectangular electrode had a size of 10 x 4 x 0.1 cm and a surface area of 40 cm². The electrode was soaked in 98% ethanol solution 24 hours before being used to remove the dirt on the surfaces of the electrodes. Then, the electrode was washed using demineralized water and dried at room temperature.

2.3 SMFCs Reactor Design and Operation

The cylinder reactor made of plastic with a diameter of 13.5 cm and a height of 17 cm was used in the SMFCs process. The working volume of the reactor was 2 L. The reactor was an aerobic single chamber without a membrane. The reactor was operated in batches without substrate feeding. The mixed substrate was deposited in the bottom part of SMFCs reactor. The reactor was covered with plastic that held electrodes in their position. The cover holder was constructed with holes to maintain aerated conditions. The distance between the anode and cathode was 4 cm. The electrodes were immersed inside the substrate, covering three-quarters of their length. The anode and cathode were connected through the insulated copper wire that linked to the multimeter (SPARDIO SP880 L). A multimeter was used to measure the generation of current and voltage. The reactor configuration is shown in Figure 1.

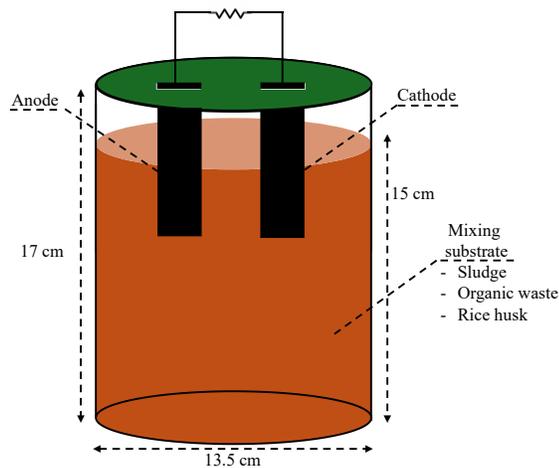


Figure 1 Configuration of SMFCs reactor

2.4 Analysis

2.4.1 Current and Voltage Measurement

Current and voltage were measured using multimeters in 3-hour intervals for 21 days. However, there were technical issues in the first three days, so the data that was obtained from the fourth day until 21 days was used in the results section. The power is proportional to current (I) and voltage (E_{cell}) and calculated using equation (2). Power density is the power generated per surface area and determined using equation (3).

$$P = I \times E_{cell} \quad (2)$$

$$P_D = \frac{P}{A_{An}} \quad (3)$$

Where P and P_D are power (mW) and power density (mW/m²), respectively, I and E_{cell} represent current and voltage in mA and mV, respectively. The power density was determined based on the surface area of an anode (A_{An}) in m².

2.3.2 Substrate Characteristics Analysis

The pH, electrical conductivity (EC), salinity, and total dissolved solids (TDS) were measured daily using water quality tester instruments. Buffer solution and conductivity standard solution (Horiba) were used to calibrate the water quality tester instrument. Water content and volatile solids were analyzed based on the Indonesia National Standard (SNI) for testing of

sediments or substrates. Organic carbon content and total nitrogen were determined using spectrophotometry methods. Water content, volatile solids, carbon content, and total nitrogen were measured before and after SMFCs reactor operation.

2.5 Statistical Analysis

The t-test (confidence interval of 95%) was used to evaluate the significant difference between the variable of C/N ratio. The data was normally distributed and had similar value of variance, so the independent t-test can be carried out. When normality and equal variance of obtained data failed, the Mann-Whitney test was used to test the statistical significance of the variable.

3.0 RESULTS AND DISCUSSION

3.1 Substrates Characteristics

The characteristics of the substrates were determined before SMFC operation to investigate the substrate condition before bioelectricity production. Table 1 shows the characteristics of substrates used in the research.

Table 1 Substrate characteristics

Parameter	Unit	Substrates		
		Sludge	Organic Waste	Rice Husks
pH	-	7.36	7.6	-
Electricity Conductivity	μs/cm	15700	13200	-
Total Dissolved Solid	mg/L	8730	6600	-
Salinity	mg/L	8660	6610	-
Water content	%	88	62	10
Volatile Solid	mg/g	139.95	639.65	658
Organic carbon	%	6.39	40.12 (13.37)	71
Total Nitrogen	%	1	3.00 (1)	1

The pH values of sludge and organic waste, which are in the neutral range, indicate that the pH levels are within the tolerance range for living microorganisms, which typically ranges from 7.0 to 8.0 [15]. The initial electrical conductivity (EC) of the sludge and organic waste was 15,700 μs/cm and 13,200 μs/cm. The electricity conduction level is also influenced by salinity concentrations in the substrate, with values of 8,660 mg/L for sludge and 6,610 mg/L for organic waste. Higher salinity concentrations are associated with increased electricity conduction [16]. Thus, it influences the performance of MFC. A study by Nosek [17] utilizing wastewater demonstrated that anode modification enhanced conductivity, leading to a rise in power density from 0.5 mW/m² to 4.5 mW/m². This suggests that improved conductivity significantly contributes to power density enhancement.

Total Dissolved Solid (TDS) and volatile solids of substrate provide insight into the amount of solid and organic material available for microorganisms to degrade organic substances and convert them into electricity. Organic waste is more readily degraded by microorganisms than sludge or rice husk. Therefore, the composition of the substrate is important to

optimize not only organic degradation but also electricity generation.

The water content of the substrate plays a crucial role in the composting processes and microorganism activity [5]. The water content of sludge (more than 80%) is sufficient to support microorganism growth. The C/N ratio for each substrate was found to be 6.39:0.96 for sludge, 40.12:3 for organic waste, and 71:1 for rice husks. Sludge had low organic content, so rice husk and organic waste were added as carbon sources of substrate.

3.2 Effect of C/N Ratio on Current, Voltage, and Power Density Generation

Organic and trace elements in the substrate play a significant role in bioelectricity generation in SMFCs because they provide nutrition for microorganisms. The SMFCs combine the process to degrade organic waste and produce electricity simultaneously. The electricity was determined by measuring current, voltage, and power density.

3.2.1 Current

Figure 2 presents the generated current by different substrate C/N ratios. At the beginning of operation, the reactor with a C/N ratio of 18 produced 1.53 mA, while the reactor with a C/N ratio of 27 generated 1.61 mA. The low current and fluctuation occurred at the beginning of operation because microorganisms are still adapting to the new environment conditions, and there is low microbial activity at the anode surface [18]. Both reactors exhibited an increase within the initial 50 hours of operation, which aligns with the incubation period of microorganisms. Subsequently, during the 100-hour operation period, the reactor with a C/N ratio of 27 demonstrated higher electric power production than the one with a C/N ratio of 18. Nordin et al. [19] found that the C/N ratio of 27 is the optimum condition for microbial food. The highest electric power production for the C/N ratio of the 18 reactors was 1.83 mA in the 57th hour of operation, whereas the C/N ratio of the 27 reactors reached 1.86 mA in the 75th hour of operation. The current generation indicates biofilm formation at the anode interface [20]. Moreover, the biofilm releases enzymes during the redox process, which generates charge as current [21]. The statistics test result shows that there was a difference ($p < 0.05$) between current generation on a substrate with a C/N ratio of 18:1 and 27:1. Statistically, the substrate with a C/N ratio of 27:1 had a higher mean current than the C/N ratio of 18:1.

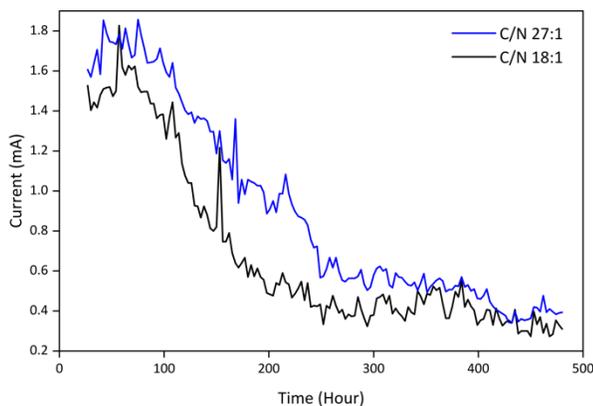


Figure 2 Effect of C/N Ratio on Electric Current

In the following hours of operation, there was a stable decrease in electric power. However, the reactor with a C/N ratio of 18 exhibited a surge in power density during the 144th and 153rd hours of operation, producing 0.81 mA and 1.53 mA, respectively. This phenomenon indicates that there are still nutrients present that microorganisms have not consumed [22]. At the end of the operational period, the reactor with a C/N ratio of 18 and a C/N ratio of 27 demonstrated a current generation of 0.31 mA and 0.39 mA, respectively.

3.2.2 Voltage

Figure 3 presents the measurement for the voltage for the substrate with a C/N ratio of 18 and 27. According to Ohm law, an increase in electric current is typically followed by a corresponding increase in electric voltage [23]. At the beginning of the operation, the voltage for the C/N ratio of 18 and 27 was 0.74 mV and 0.75 mV, respectively. The maximum current voltage productions for the C/N ratio of 18 and 27 were recorded at 0.76 mV in the 54th hour of operation and 0.80 mV in the 75th hour of operation. These values gradually decreased within the range of 0.65 mV to 0.80 mV until the 100th hour, indicating the end of the stationary phase. A stable graph and lower voltage are evident after the 250th hour of operation, attributable to carbon limitations. Carbon limitation can hinder bacteria metabolism, thus lowering electricity generation [24]. At the end of the operational period, a C/N ratio of 18 produced a current voltage of 0.28 mV, while a C/N ratio of 27 produced 0.3. The independent sample t-test shows that the substrate with a C/N ratio of 27:1 had a statistically higher voltage than a C/N ratio of 18:1 ($p < 0.05$). Li et al. [25] also reported that the substrate with a C/N ratio of 26.7 obtained the highest output voltage among substrates with a C/N ratio of 6.7, 13.3, and 26.7. A higher C/N ratio provides sufficient organic substance for the metabolism of electric-producing microorganisms. The organic waste increases the organic matter, thus increasing the voltage. A similar result was also obtained by Al-Defiery [26], in which the addition of organic waste to the mixture of soil in the MFC system increased the generation of voltage.

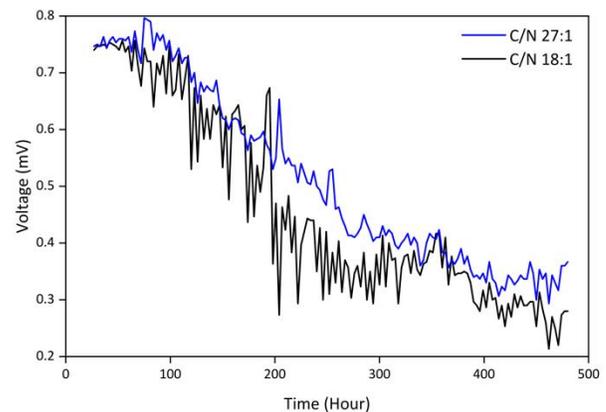


Figure 3 Effect of C/N Ratio on Voltage

3.2.3 Power Density

The power density is the amount of electric power production in the surface area of the anode [27], and it indicates the performance of the microbial fuel cell. At the beginning of the operation, the substrate with a C/N ratio of 18 and a C/N ratio of

27 were 282 mW/m² and 300 mW/m², respectively. Figure 4 shows that substrates with a C/N ratio of 18 and a C/N ratio of 27 experienced a lag phase in the first 50 hours and an exponential phase by the 100th hour of the operational period. The substrate, with a C/N ratio of 18 and a C/N ratio of 27, reached the maximum power density of 336 mW/m² and 370 mW/m², respectively. Mann-Whitney statistics test results show that substrate with a C/N ratio of 27:1 generated higher mean power density than a C/N ratio of 18:1 ($p < 0.05$). Besides organic matter, nitrogen also plays an important in microorganism metabolism. The nitrogen supply should be optimized for optimal nutrient intake of microorganisms. While nitrogen concentration below threshold uptake can enhance the microbial activity in anodic, the concentration above the limit can inhibit the electrochemical activity of biofilm because of low electron donors [28]. The substrate with a C/N ratio of 18 had higher nitrogen content than the substrate with a C/N ratio of 27. The higher nitrogen content in the substrate hinders microbial activity in the anode. A stable decrease was observed after 250 hours of the operational period. In the experiment, the substrate with a C/N ratio of 27 produced 27 mW/m², which is higher than the C/N ratio of 18 (22 mW/m²). The lowering power generation was attributed to the ability microorganisms to grow during the death phase [18].

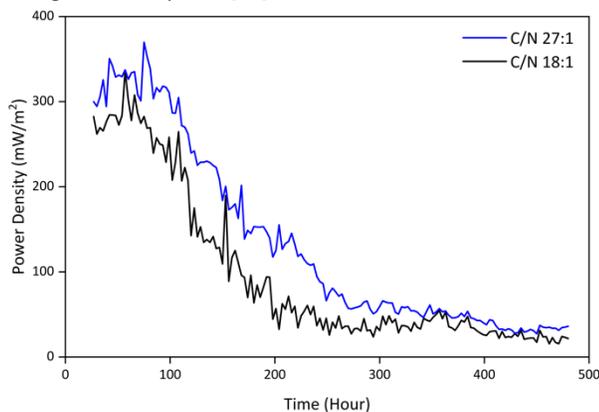


Figure 4 Effect of C/N Ratio on Power Density

3.3 Effect of C/N Ratio on Substrate Conditions

The SMFC process not only influences current, voltage, and power generation but also parameters of substrate conditions such as pH, electrical conductivity (EC), salinity, and TDS. The volatile solids, water, and C/N ratio parameters also change during the power generation process because microorganisms consume them. Power density generation correlates with pH levels, internal resistance, and nutrient depletion for microorganisms. Additionally, other parameters such as electrical conductivity, total dissolved solids (TDS), and salinity can affect electric generation [16], [29].

3.3.1 pH

Figure 5 illustrates the pH of the substrate throughout the operational period. The pH exhibits fluctuation but remains within the neutral range of 6-8, and this range of pH is tolerated for microorganism growth [30]. The substrate with a C/N ratio of 27 demonstrated a stable increase, while C/N 18 showed a pH increment from 7.4 to 6.78 on the seventh day. The growth of

microorganisms changes the pH and environmental conditions, and this can support or inhibit the microorganisms growth [31]. At the end of the operation, a substrate with a C/N ratio of 18 had a pH of 7.76, while C/N 27 showed a slightly lower pH of 7.72. Although slightly elevated from the beginning of the operation, the pH levels are not toxic to the microorganisms, allowing them to continue electricity production. Therefore, the pH levels of both C/N 18 and C/N 27 remain within the acceptable range. There was no statistical difference in pH for both types of substrates ($p > 0.05$).

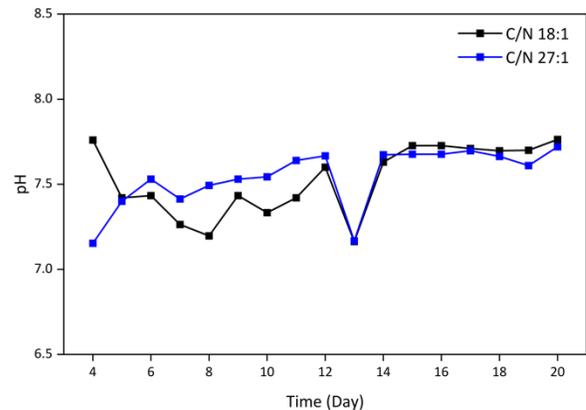


Figure 5 Factor of pH

3.3.2 Electrical Conductivity (EC)

Electric conductivity facilitates the transfer of electron charge between the substrate and the anode. Figure 6 presents the measurement of electrical conductivity during reactor operation. At the beginning, a substrate with a C/N ratio of 18 had an electrical conductivity of 12,510 $\mu\text{S}/\text{cm}$, while C/N 27 had 11,583 $\mu\text{S}/\text{cm}$. The EC values experienced a decreasing trend during the initial 5 days of measurement, followed by an increase on the seventh day, reaching maximum EC values of 15,310 $\mu\text{S}/\text{cm}$ for C/N 18 and 11,583 $\mu\text{S}/\text{cm}$ for C/N 27. During the first 7 days, the EC value experienced an increase and decreased sharply. Variation of this EC value occurred because substrates settle and suffer the loss of component over the time [32]. Decrease of resistance organic waste that used as substrates also contributed to sharp increases of EC [33]. After 20 days of operation, C/N 18 and C/N 27 generated 9,550 $\mu\text{S}/\text{cm}$ and 9,106 $\mu\text{S}/\text{cm}$, respectively. The electric conductivity decreased after 20 days of operation because of zinc corrosion [34]. The lower conductivity over time indicates increasing resistance, thus lowering the power outcome. This finding is in line with the decrease in power density over time. Low conductivity limits electron transfers from the anode to the cathode and obstructs the balance of electro-neutrality in the SMFC system [29]. The statistical test showed that there was a significantly different EC between the two types of substrates ($p < 0.05$), and the mean EC in the substrate with a C/N ratio of 18 was higher than the C/N of 27.

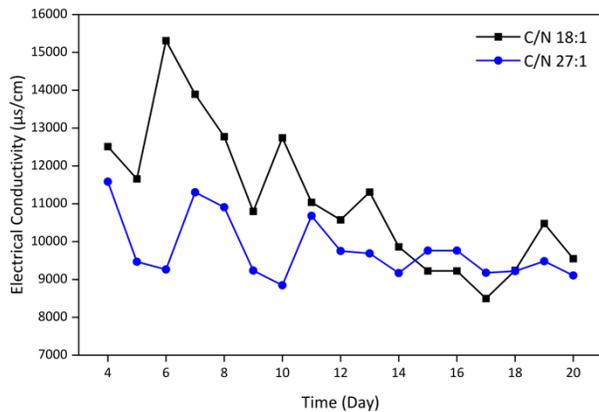


Figure 6 Factor of Electrical Conductivity

3.3.3 Total Dissolved Solid (TDS)

Figure 7 shows that at the beginning of the operation, the substrate with a C/N ratio of 18 and 27 had TDS concentrations of 6,206 mg/L and 5,793 mg/L, respectively. Like the electric conductivity, the TDS concentration experienced a decreasing trend until the seventh day of operation, followed by an increased concentration of TDS. TDS value increases especially inorganic dissolved solid because some parts of suspended solid in substrate convert into dissolved solid [35]. The experimental data show that suspended solids decreased by 37.42% from initial value 238.8 mg/g in substrate with C/N ratio of 18. Meanwhile, the substrate with C/N ratio of 27 experienced a slight increase by 1.24%. Suspended solid not only accounts for organic or inorganic matter but also for microorganism biomass. Therefore, there is input and output of suspended solid during MFC reactor operation. The TDS graph shows a similar trend with electrical conductivity due to a linear relationship between TDS and electrical conductivity. At the end of the operation, TDS concentrations converged to similar values within the range of 4,500–4,800 mg/L. The decreasing TDS concentration suggests nutrient depletion in the substrates and microbial death [30]. Based on the statistics test, there was a significant difference in TDS for both ratios of the substrate ($p < 0.01$), and the mean TDS of the substrate with a C/N ratio of 18:1 was higher.

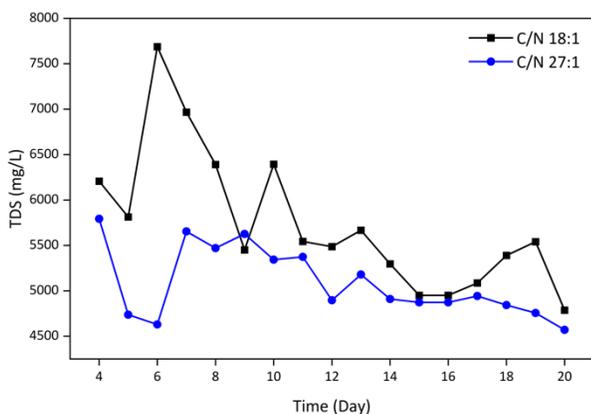


Figure 7 Factor of Total Dissolved Solid (TDS)

3.3.4 Effect on Salinity

Salinity refers to the amount of dissolved salt in one kilogram of seawater. Higher concentrations of ionized salinity increase electrical conductivity [29]. Figure 8 illustrates salinity concentration and shows a similar trend with TDS concentration. Figure Optimal salinity can enhance the power generation in an MFS system. Source of salinity might be from different sources such as substrate, salt addition. Initial measurements show salinity concentrations of 6,203 mg/L for C/N 18 and 5,803 mg/L for C/N 27. Within the first 5 days of measurement, the salinity decreased until it was within the range of 5,000–6,000 mg/L. Then, salinity increased in day 7 for both type of substrates. Inoculum source and acclimatisation phase during first week operation affected the increase and decrease trend of salinity during first week operation [16]. The substrate with a C/N ratio of 18:1 had higher salinity than the substrate with a C/N ratio of 27:1 statistically ($p < 0.05$). The salinity, EC, and TDS amounts maintained a stable condition due to nutrient limitations.

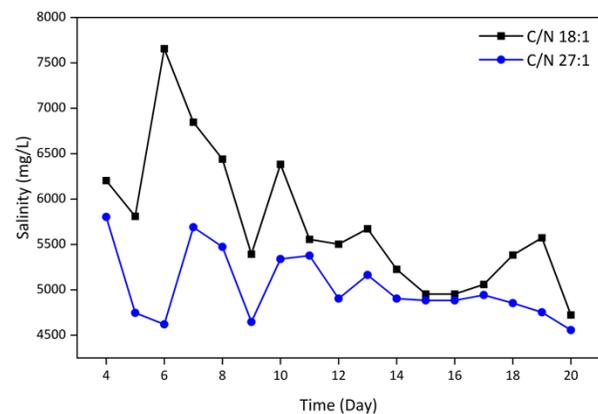


Figure 8 Factor of Salinity

3.3.5 Volatile Solids, Water Content and C/N Ratio

The initial water content for both substrates with C/N ratios of 18 and 27 was 83–85%. Water content influences the substrate degradation rate, nutrition transport and dissolution, metabolism, and oxygen transfer on the surface of the electrode [36]. After 17 days of the operation, the water content for the substrate decreased. The substrate with a C/N ratio of 18 had an average final water content of 71%, while C/N 27 had an average water content of 67%. The decrease in water content may be attributed to microorganism consumption and external temperature changes leading to evaporation.

At the beginning of the experiment, volatile solids (VS) were measured at 238.8 mg/g for substrate with a C/N ratio of 18 and 198.51 mg/g for substrate with a C/N ratio of 27. Substrate with C/N ratio 18 exhibited a decrease in VS of 37.42%, while C/N 27 showed an increase in VS of 1.24%. Decreasing in VS occurred due to organic substance degradation to generate electricity [37]. On the other hand, the increase in VS for a substrate with a C/N ratio of 27 probably correlates with the higher biomass concentration measured as volatile solids.

Regarding the C/N ratio, a decrease was observed for both C/N 18 and C/N 27, accounting for 53.7% and 71.6%, respectively. The higher decrease in C/N 27 suggests that the efficient metabolic processes of microorganisms at the ideal C/N ratio facilitate the organic decomposition and microorganism

growth [10]. The decline in organic carbon can be attributed to dissimilation processes converting nutrients into energy. The reduction in the C/N ratio directly correlates with the ability to generate electric power [10], [38].

4.0 CONCLUSION

The performance of SMFCs with different C/N ratios was evaluated in a batch laboratory study. The substrate was a mixture of sludge, organic waste, and rice husk. The maximum power density of 370 mW/m² was achieved by the substrate with a C/N ratio of 27. This finding indicated that a C/N ratio of 27 is ideal for microorganism metabolism for electricity generation, considering the recognized ideal C/N ratio of 24:1 for metabolic microorganisms and 30:1 for composting processes. The importance of water content in facilitating the composting process and its subsequent impact on power production is highlighted. Further study may focus on refining substrate compositions and optimizing operational parameters to enhance electricity generation efficiency.

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Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper

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