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ANALYSIS OF TOFU LIQUID WASTE AND RICE WASHING WATER COMBINATION IN MICROBIAL FUEL CELL (MFC) SYSTEM USING TAGUCHI EXPERIMENTAL DESIGN

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ABSTRACT

Tofu production generates residue in the form of liquid sewage, which is frequently disposed of in sewers. This has the potential to pollute streams and emit a distinct stench that may disturb the neighboring population. Tofu liquid waste can be converted into electrical energy using a Microbial Fuel Cell (MFC) technology. MFC uses the metabolic activity of microorganisms to transform organic chemicals in the substrate into electrical energy. This study will use Taguchi experimental design to provide recommendations for the optimal composition of the substrate usage ratio, incubation period, and addition of bioactivators, as well as their effect on the electrical power produced in MFC system using a combination of tofu liquid waste and rice washing water as the substrate. According to the findings of the research, the parameter with the greatest influence is incubation period (74.81%), followed by addition of bioactivator (19.45%), and substrate ratio (5.46%). The optimal composition is recommended to be incubated for one day with a 5% bioactivator addition and an 80:20 substrate ratio of tofu liquid waste and rice washing water.

Keywords: Microbial Fuel Cell, Energy, Electrical Power, Experimental Design, Taguchi Method

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1. INTRODUCTION

Tofu is a popular soybean preparation among Indonesians, in addition to fermented soybean cake (tempe). The low cost and ease of processing make this food ingredient increasingly popular among the general public. Tofu consumption per week has also increased over the last five years, making it a distinct attraction for manufacturers in satisfying tofu's demand in Indonesia (Badan Pusat Statistik, 2023).

Aside from the main result, tofu, the coagulation process produces residue which is generally discarded. Tofu producing process produces two forms of waste: solid waste and liquid waste. Tofu solid waste consists of solids from soybean cleaning process and pulp residue, often known as tofu dregs meanwhile tofu liquid waste consists of waste water from the tofu washing process (Pagoray, Sulistyawati and Fitriyani, 2021). Until now, tofu liquid waste is usually used as liquid organic fertilizer (Amalia *et al.*, 2022). Aside from that, on a bigger scale, tofu liquid waste can be used as a raw material in the production of biogas, which can provide fuel gas and electrical energy (Niam *et al.*, 2023).

However, tofu liquid waste has not been used to its full potential. This can be seen from the preponderance of waste water being disposed of through sewers. The disposal of liquid tofu waste has the potential to harm streams and clog waterways. Aside from that, liquid tofu waste with a distinct odor will harm the environment and may disturb residents near the tofu factory.

Tofu liquid waste contains a significant concentration of organic components, particularly protein and amino acids. The chemical constituents in tofu liquid waste are predominantly protein (40-60%), followed by carbs (25-50%), and fat (around 10%) (Amalia *et al.*, 2022). The proteins in this liquid waste can be degraded into inorganic chemicals. The decomposition of organic molecules occurs in two stages: the decomposition of organic compounds into inorganic compounds and the oxidation of unstable inorganic compounds into more stable inorganic compounds.

Microorganisms serve as the functional foundation of wastewater management procedures. Bioremediation is a wastewater treatment procedure that uses microorganisms to reduce contaminants and enhance the damaged environment. Bacteria, fungus, algae, protozoa, rotifers, crustaceans, and viruses are examples of microorganisms that can be used (Bachry, 2019). Bacteria are the most important microorganisms in the wastewater treatment process. Bacterial cultivation is used in wastewater treatment to eliminate undesirable organic and mineral contaminants. Bacteria come in variety forms and sizes. Temperature and acidity level (pH) will both play crucial roles in bacterial survival.

Rice is the most often consumed food in Indonesia. In 2022, Indonesia's rice production for food consumption would reach 32.07 million tonnes, increasing 2.29 percent from 2021 (BPS Provinsi Lampung, 2022). Before Indonesians consume rice, it is typically rinsed three times to reduce impurity content. Rice washing waste water, especially white rice, has high quantities of organic compounds (Supraptiningsih, Nuriyanti and Sutrisno, 2019). The murky white tint of the water from the initial washing of the rice demonstrates this. Untreated waste water from rice washing might generate an unpleasant odor and pollution of the water (Setiawan, Aji and Astuti, 2020).

Microbial fuel cell (MFC) technology generates power by utilizing the metabolic activities of microorganisms. MFC, in addition to providing power, is environmentally favorable because it may be utilized as a waste processing technology (Maharani, 2019). Microorganisms in MFC system act as enzyme replacements that can produce cheaper substrates. This system may also generate energy using organic fuels and renewable biomass. This is another benefit of MFC. Bacteria in biomass and organic waste operate as catalysts, interacting with a various organic molecules to generate electrons. Glucose, fatty acids, starch, protein, amino acids, and waste from living creatures are examples of organic molecules that can be employed as substrates in the MFC system.

MFC uses bacteria that metabolize in anode to accelerate the conversion of organic molecules into electrical energy. Bacteria are capable of converting a wide range of organic molecules into energy, water, and carbon dioxide. Bacteria that may transfer electrons from other cells are classified as exoelectrogens (Zuo *et al.*, 2008). Microbes use the energy produced to digest and manufacture their groups in massive amounts.

Zulfikar et al. did research using waste water from cooking instant noodles as a substrate to generate power using an MFC system (Zulfikar, Tamjidillah and Ramadhan, 2021). His investigation revealed that after a 7-day incubation period, the maximum current and voltage produced by the substrate were 528 mA and 627 mV. Prasidha et al. investigated the performance of MFC using tofu liquid waste as a substrate (Prasidha *et al.*, 2022). They incubated tofu liquid waste for 7 days at 31°C room temperature. According to the findings of their investigation, the maximum voltage achieved when reading data at 6 p.m. for 7 days of MFC operation, 139 mV, was created on the fifth day of operation.

Manufacturing industry aims to produce items that match consumer expectations for as long as the product is used. Taguchi method of quality improvement focuses on decreasing existing variations. The primary idea behind this method is to detect interactions between control parameters and variables by connecting correct control parameter adjustment with robust system performance in the face of uncontrolled fluctuations. Taguchi parameters are used to reduce the influence of uncontrollable factors while determining the ideal amount of controllable factors.

MFC system will be tested in this study using tofu liquid waste and rice washing water as substrates with the addition of bioactivators. Taguchi method was used to determine substrate composition, optimum incubation time, and percentage of bioactivator by varying percentage ratio of tofu liquid waste and rice washing water, incubation time, and the amount of added bioactivator to obtain maximum electrical power using MFC system.

2. METHODS

This study employs an object in the form of electrical power generated by evaluating MFC system from a substrate consisting of tofu liquid waste and rice washing water with the addition of bioactivators. An Effective Microorganism 4 (EM4) is utilized as a bioactivator. The study begins by identifying selected control parameters, determining orthogonal array using Minitab 21 statistic software, testing the MFC system based on experimental design and analysis the response of the control parameters to the mean electric power value and signal to noise ratio (S/N ratio), and concluding with ANOVA analysis to determine the influence of each control parameter on the electrical power produced. Figure 1 depicts the research flow chart.

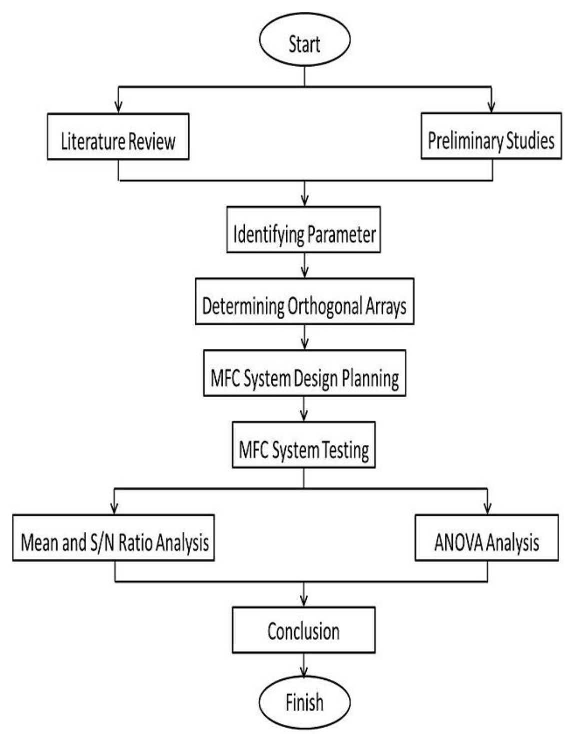

Figure 1. Research Flow Chart

2.1 Identifiying Parameter

Parameters that can be controlled and the amounts that will be employed are determined during parameter identification. Substrate ratio, incubation time, and percentage of additional bioactivator that will be used are the experiment's control parameters. Each of the selected control parameters has three levels. Table 1 shows the results of the experiment's control parameters and level determination.

Table 1. Experiment's Control Parameters and Level

Control Parameters	Unit	Level		
		1	2	3
Substrate ratio (A)	%	20 : 80	50 : 50	80 : 20
Incubation period (B)	days	1	2	3
Bioactivator (C)	%	0	5	10

2.2 Orthogonal Array Determination

Orthogonal array is determined by experiment control parameters and level variations. It serves as a determinant in experimental arrangement based on the previously chosen control factors and levels. The orthogonal array used in this study is L_9 with 9 experimental designs determined using Minitab 21 Statistics Software.

Table 2. Orthogonal Array

Exp	Control Parameters		
	A	B	C
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

2.3 MFC System Testing

Preparation of electrodes is the first step in testing an MFC system. Electrode used in this research is a carbon rod with a diameter of 10 mm and a length of 100 mm. First, carbon electrode was soaked in 1 M HCl solution for 24 hours and rinsed with distilled water before undergoing a second 24 hour soaking operation in 1 M NaOH solution. Then, soaked electrode is rinsed with distilled water until it reaches a neutral pH. Next step is to create a salt bridge by boiling 150 ml of 0.1 M NaCl solution with 5 grams of Nutrient Agar (NA). The solution is poured into ¼ in PVC pipe and permitted to solidify.

MFC system is designed by connecting two vessels using a salt bridge that has been made previously. Multimeter is linked via a cable to measure voltage and electric current in order to calculate the amount of electrical power created during the experiment. Figure 2 shows MFC system design.

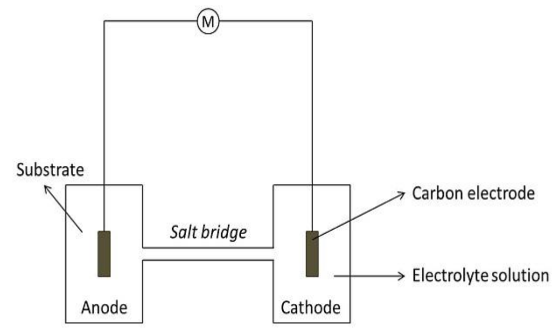

Figure 2. MFC System Design

Substrate is made out of tofu liquid waste and rice washing water. This combination is placed into the vessel in accordance with experimental design on an orthogonal array. The experiment began by entering 1500 ml of substrate with bioactivator according to experimental design into the anode vessel, while 1500 ml of 0.1 M $KMnO_4$ electrolyte solution was placed into the cathode vessel. Voltage and electric current are measured with a multimeter to generate an electrical power value from MFC system testing process.

2.4 Mean and Signal to Noise Ratio (S/N Ratio) Response Analysis

Signal to noise ratio (S/N ratio) value illustrates the effect of each factor level on the experiment. S/N ratio value can be used to calculate maximum power value from all trials that have been performed. Characteristic of Larger is Better are used in this research. This characteristic is utilized to generate maximum power values from the response parameters of substrate ratio, incubation time, and bioactivator addition that resulting in new recommended parameters.

2.5 Analysis of Variance (ANOVA)

Analysis of variance (ANOVA) method is used to determine the impact of control parameters on this research. ANOVA is commonly used in Taguchi method (Aprilyanti and Suryani, 2020). ANOVA is used in this research to assess the effect of control parameter modifications on power value produced by MFC system. ANOVA compares $F_{statistic}$ and $F_{critical}$ values to assess the influence of control factors on the electrical power produced. $F_{statistic}$ will be calculated using Minitab 21 Statistics Software, whereas $F_{critical}$ will be calculated using the formula below (Damanik, 2018).

$$df_1 = k - 1 \quad (1)$$

$$df_2 = n - k \quad (2)$$

with,

k : number of control parameters

n : number of sample used

3. FINDINGS AND DISCUSSION

3.1. Calculating Mean Electrical Power

Voltage and electrical current monitored while MFC system is operational electrical power. In one experiment, voltage and current were measured 3 times. Table 3 displays mean electrical power values.

Table 3. Mean Electrical Power

Exp	Electrical Power (mW)			Mean (mW)
	1	2	3	
1	1.157	1.159	1.162	1.160
2	1.017	1.016	1.017	1.017
3	0.771	0.769	0.771	0.770
4	1.504	1.507	1.504	1.505
5	1.012	1.011	1.010	1.011
6	0.800	0.800	0.801	0.801
7	1.241	1.241	1.241	1.241
8	0.819	0.819	0.819	0.819
9	0.973	0.974	0.974	0.974
Total				9.297
Mean				1.033

Mean electrical power from Table 3 above is reprocessed in order to assess the effect of each control parameter on electrical power produced in each trial using Larger is Better characteristic. Mean electrical power value obtained from testing the MFC system with a mix of tofu liquid waste and rice washing water substrate is 1.033 mW. The effect of control parameters on mean electrical power in MFC system is given in Table 4 and graphical representation in Figure 3.

Table 4. Effect of Control Parameters on Mean Electrical Power

Level	A	B	C
1	0.982	1.302	0.926
2	1.106	0.949	1.165
3	1.011	0.848	1.008
Delta	0.123	0.454	0.239
Rank	3	1	2

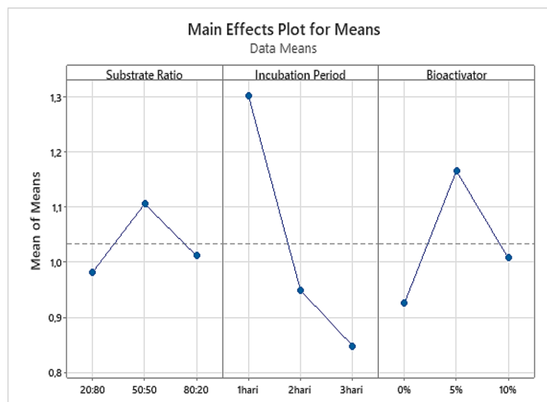

Figure 3. Main Effects Plot for Mean Electrical Power

3.2. Rasio S/N

Signal to noise ratio shows the distribution features and influence of parameter characteristics in each experiment (Aprilyanti and Suryani, 2020). Signal to noise ratio quality characteristic chosen is Larger is Better, which means that the MFC system has good quality if the electrical power value produced by operational MFC system is greater than a certain threshold. Table 5 displays signal-to-noise ratio when the Larger is Better quality attributes are used.

Table 5. Effects of Control Parameters on Signal to Noise Retio

Exp	Electrical Power (mW)			S/N
	1	2	3	
1	1.157	1.159	1.162	1.286
2	1.017	1.016	1.017	0.145
3	0.771	0.769	0.771	-2.266
4	1.504	1.507	1.504	3.551
5	1.012	1.011	1.010	0.093
6	0.800	0.800	0.801	-1.933
7	1.241	1.241	1.241	1.877
8	0.819	0.819	0.819	-1.733
9	0.973	0.974	0.974	-0.229
Total				0.792
Mean				0.088

The effect of control parameters on signal-to-noise ratio is given in Table 6 and graphical representation in Figure 4.

Table 6. Effects of Control Parameters on Signal to Noise Retio

Level	A	B	C
1	-0.278	2.238	-0.793
2	0.571	-0.498	1.156
3	-0.028	-1.476	-0.098
Delta	0.849	3.714	1.949
Rank	3	1	2

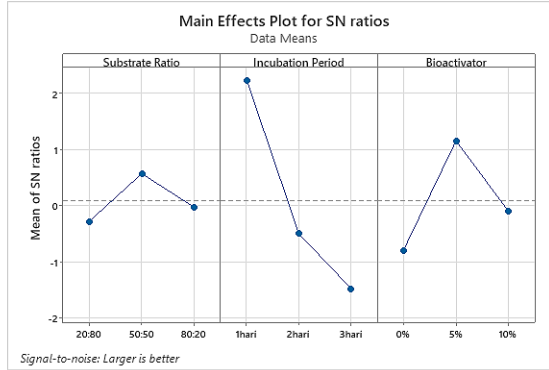

Figure 4. Main Effects Plot for SN Ratios

According to Table 6, the incubation period has the highest influence on electrical power generated from MFC system experiments, followed by addition of bioactivator and substrate ratio. Optimal composition that recommended based on signal to noise ratio value with the most influential level is 1 dau incubation period with 5% of bioactivator addition and 80 : 20 substrate composition of tofu liquid waste and rice washing water.

3.3. Analysis of Variance

Level variations of each control parameter are evaluated and described using analysis of variance. Analysis results will be utilized to determine influence of the control parameters in each experiment, allowing recommendations for new parameters to be obtained in order to achieve maximum electrical power from MFC system. Table 7 shows the results of the analysis of variance calculation.

Table 7. Analysis of Variance Calculation

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F Value	P Value
A	2	0.025	5.46%	0.025	0.012	20.130	0.047
B	2	0.341	74.81%	0.341	0.170	275.590	0.004
C	2	0.089	19.45%	0.089	0.044	71,650	0.014
Error	2	0.001	0.27%	0.001	0.001		
Total	8	0.058	100.00%				
S	0.025						
R-Sq	99.73%						

The computation results in Table 7 are utilized to compare the hypothesis of $F_{statistic}$ to $F_{critical}$ value. H_0 indicates that there is insignificant influence between parameter A treatment for the electrical power produced. H_1 indicates that the treatment of parameter A has significant influence on the electrical power produced. The level of significance (α) employed is 0.05.

$$F_{critical}\ (\alpha; df_1; df_2)$$
$$F_{critical}\ (0.05; 3; 5) = 5.410$$

Table 7. Statistical Test Result

Control Parameter	$F_{statistic}$	$F_{critical}$	Result	Description
A	20.13	5.410	H_1	Significant
B	275.59		H_1	Significant
C	71.65		H_1	Significant

Based on Table 7, parameters A, B, and C have a significant influence on electrical power that produced from MFC system experiment employing a mix of tofu liquid waste and rice washing water as a substrate. This is due to $F_{statistic}$ value of the three parameters exceeding $F_{critical}$ value. $F_{statistic}$ are derived from ANOVA test results, whereas $F_{critical}$ value is derived through formula computations. $F_{statistic}$ results show that parameter B has the biggest influence of the three parameters discussed above, namely 275.59, followed by parameters C and A, namely 71.65 and 20.13, respectively. This is verified by contribution percentage value derived from ANOVA test results, where parameter B contributes the most to electrical power generated from MFC system test, 74.81%, followed by parameter C at 19.45% and parameter A at 5.46%. MFC system is also influenced by external influences, but only in a very tiny percentage, precisely 0.27%, such that parameters A, B, and C influence the electrical power output resulting from MFC system testing reaching 99.73%.

4.CONCLUSION AND SUGGESTION

MFC system has been shown to produce electrical power when tofu liquid waste and rice washing water are used as substrates. Taguchi method is used to develop the experimental design such that the implementation time is reduced. Based on the experimental results, it was established that the control parameters of substrate ratio, incubation period, and addition of bioactivators had a significant influence on electrical power produced by MFC system. The most significant control parameter was incubation time (74.81%), followed by the addition of bioactivator (19.45%) and substrate ratio (5.46%). External factors were still influencing the experiment, but their contribution percentage was very tiny, precisely around 0.27%. Based on the results of the trials, the optimal composition is one day incubation with 5% bioactivator and an 80 : 20 substrate ratio of liquid tofu waste and rice washing water..

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