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Modelling the Effect Size of Microbial Fuel Cells Using Bernstein Polynomial Approach via Iterative Method

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Abstract

Microbial fuel cells are one of the most important issues in today's science. The studies in the literature on the subject are very limited. Nowadays, research on renewable energy sources brings scientists to the point of obtaining renewable energy sources from microbial fuel cells. In this study, we designed a battery using a microbial fuel cell. The four independent variables taken into account in the experiment are open-circuit voltage, short circuit current, measured voltage when loaded, the current measured when loaded, and dependent variable effect size. The numerical values of the effect size were obtained by using independent variables. Then, the obtained values from the effect size were modeled using Bernstein polynomial. Using the iterative calculations belonging to the Bernstein polynomial in calculations, the error of the model has been reduced to a minimum and thus the estimation model used has been made statistically significant for the effect size.

Keywords: microbial fuel cell, biosensor, organic materials, renewable energy, Bernstein polynom

1. INTRODUCTION

The amount of use of fossil-based fuel materials is increasing day by day. This situation has had negative consequences for the environment and human health. In addition, the emergence of the energy crisis has shown the need for more sustainable, lower-cost and environmentally friendly energy resources. Due to the increasing population and the risk of energy crisis, rapid urbanization and population growth, more comprehensive studies are required on both environment, health and renewable energy [1].

Various countries around the world have created large-scale energy production resources by

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making serious investment studies on renewable energy resources. In these resources, they generate energy from solar energy, wind energy and water. These efforts are very important breakthroughs to tackle the energy problem, in other words, the energy crisis. One of the renewable energy production sources is fuel cells. Fuel cells produce little or no gas emissions (such as SO_x, NO_x, CO_2 and CO) that pollute the environment. Therefore, fuel cells have a great advantage in terms of environmentalism. In addition, fuel cells have advantages such as high efficiency, no moving parts, and no noise pollution. Microbial fuel cells, one of the fuel cell types, are an emerging technology. Microbial fuel cells are bio-electrochemical devices that produce green energy by decomposing the waste biomass with bacteria [2].

Microbial fuel cell systems are a promising technology in terms of economy and environment. Full-scale applications in wastewater cleaning and electricity generation are still not possible due to difficulties such as biological contamination of electrodes and membrane surfaces, unstable and long-term performance, electrolyte resistance, reversible voltages and excessive potential increase [3].

Microbial fuel cells are electrical production systems that convert the chemical energy of organic substances directly into electricity by means of bacteria [4-6]. Organic matter and the bacteria that catalyze them are renewable energy systems, as long as there are anodes and cathode electrodes. Thus, it is possible to produce continuous electrical energy with microbial fuel cells [4-6]. Microbial fuel cells are mostly used in electricity generation, wastewater cleaning and biosensor applications [4-6]. The open-circuit voltage (Voc), short circuit current (Isc), voltage under load (V) and current (I) values of microbial fuel cells used in various applications do not correspond well with each other. This makes it difficult to predict future performance of applications for microbial fuel cells and therefore narrow the view of microbial fuel cells. This gives priority to the statistical modeling of microbial fuel cells. By performing statistical modeling, various parameters of microbial fuel cells and most importantly their performances will be obtained. Thus, calculations and visions related to microbial fuel cells will be generated more effectively.

2. SOME REMARKABLE NOTES ABOUT THE EXPERIMENT

In recent years, energy expenditure has tended to increase in the world. Energy resources are divided into three parts: fossil fuels, renewable resources and nuclear energy. Fossil fuels have an unfavorable influence on the environment due to carbon dioxide emissions. Expenditure of fossil fuels causes major problems such as global warming and atmospheric pollution. Therefore, it is stated that it will cause great problems for human life [7].

Since climate change is always a strong concern for the world, various efforts are never enough to resolve it. The International Energy Agency (IEA) proposed the 2 °C scenario (2DS) to deal with this problem. The 2DS has been widely examined by many researchers. According to this scenario, carbon dioxide (CO_2) emissions in 2060 should be reduced by 70% compared to 2014. 23% of the total CO_2 emissions come from the transportation sector. To achieve this goal, CO_2 consumption in transportation should be reduced. Nowadays, electric vehicles have become a hopeful option in transportation. However, biofuels are expected to be a key alternative energy source for CO_2 reduction in the transport sector. According to the results of the mobility model for 2DS published by the IEA, the biofuel and electricity share of total transport-fuel consumption by 2060 is estimated to be 30.7% and 27% respectively. To achieve these goals, biofuel production must be increased 10 times. Unfortunately, several major barriers to the realization of biofuels' implementation goal currently exist [8].

Despite all these, biomass-derived biofuels are used to directly generate energy. Biomass is used as a source of biofuels in microbial fuel cells (MFCs) and direct electricity is produced. MFCs are environmentally friendly electricity generation systems [9].

The chemical energy from the renewable carbohydrate structure of biomass and other organic wastes such as wastewater is an interesting alternative compared to the existing large fossil fuels. MFCs simultaneously produce both wastewater treatment and electrical energy [10].

MFCs have received great interest in recent years as a new renewable energy source. MFCs, which are regarded as direct bio-electrochemical reactors, use the redox reaction to produce direct electricity with microorganisms in the chemical energy in the biomass [9, 11].

In the literature, the principle of electrical energy production in MFCs has been examined in detail. Bacteria catalyze organic matter in biomass and release electrons (e-) and protons (H+). The released electrons go to the anode electrode. After, the electrons then travel from the anode electrode to the cathode electrode by an external circuit. The released protons go through the electrolyte to the cathode electrode. Oxygen (O2) in the air, electrons (e^-) and protons (H^+) form water (H_2O) in the cathode. This ensures the electrical load balance of the MFC. As a result, oxidation reaction for anode and reduction reaction for cathode take place. Thus, the microbial fuel cell produces electrical energy as follows in Figure 1 [4-5].

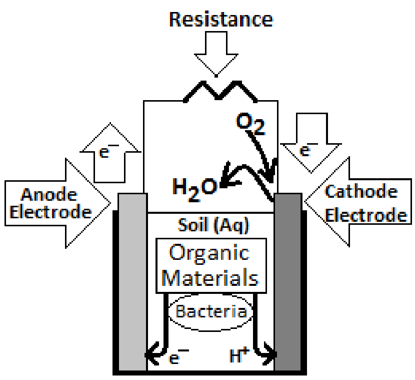

Figure 1 Operating principle of MFC at example study [4]

Biochemical and electrochemical reactions in MFCs are a complex and hybrid system. It is difficult to control and optimize the electrical power generation of MFCs. It is useful to establish a mathematical model to observe the power generation performance of MFCs [11].

3. STATISTICAL INFORMATION

Statistical methods are important scientific tools that provide a more effective and understandable presentation of the observed data. It is very important that the observed data is observed depending on time. The fact that the observed data varies over time and the character of this change is more accurate. Accordingly, it is important for the regression models whether the data are time-dependent or not. Regression models differ according to this situation.

Assuming that the time-dependent data generally comes from the same distribution, it is considered to be the realization of an appropriate stochastic process. It is important to create a stochastic process with continuous parameters that can represent the data. In many physical experiments, the creation of the stochastic process depending on the nature of the experiment allows more accurate interpretation of the observed experiment.

Let X_t be the observation value at time $t \geq 0$. Then, $X_1, \cdots, X_n$ are the realization of continuous parameter stochastic process $\{X_t : t \geq 0\}$. Discrete parameter stochastic process $\{X_n : n = 0, 1, \cdots\}$ is called the embedding process in $\{X_t : t \geq 0\}$.

4. METHOD

In experimental studies, modeling of the observations made in equal time periods is very important in evaluating the data obtained from the study. In general, this type of observation is examined in two groups. When data have an increasing structure due to observation order, observation values are considered as growth data and growth models are used in data analysis. On the contrary, time series models are used when data does not have an increasing structure. Depending on the type of methods used in examining time series, the model cannot always give the optimal estimate.

The model that shows the best fit among the equally spaced regression models is generally the Bernstein polynomial. Bernstein polynomial as follows [12],

$$B_n(y) = \sum_{k=0}^{n} \binom{n}{k} y_k x^k (1-x)^{n-k} \qquad (1)$$

where $y_0, \cdots, y_n$ are observation values.

Since the kernel structure of the polynomial is similar to the binomial distribution, the Bernstein polynomial can also be expressed as the expected value of the binomial distribution. The convergence characteristics of Bernstein polynomial have been studied by many researchers such as Voronovskaya [13], Butzer [14] and Phillips [15] in the literature. Kelisky and Rivlin [16], Sahai [17] who researched the iterative calculation process in the Bernstein model are the major authors in the literature related to the subject.

The method used for the iterative calculation is based on the formation of a new Bernstein polynomial by using the error terms obtained from the polynomial formed with the help of observation values. The iterative calculation formula, after estimating the error in the first step, the estimation values of the errors are subtracted from the estimated values of the data and new estimation values are generated for the data. As follows,

$$B_n^{(r+1)}(y) = B_n^{(r)}(y) - B_n\left(B_n^{(r)}(y) - y\right) \qquad (2)$$

5. INVESTIGATION OF DATA

The observation values obtained from the experiment are shown in the table 1 (Appendix). The correlation calculated between the measured short-circuit current and the measured current when loaded is 0.84. In this case, there is an 84% relationship between them. The linear equation of the open-circuit voltage according to time is obtained as follows when three median methods are used,

$$V_{oc} = 0.516 - 0.007t \qquad (3)$$

In the analysis of decrease of open-circuit voltage according to time, the use of three median methods instead of the least squares estimation method is more useful in terms of obtaining linear equation. Three median methods can minimize errors due to measurement.

The effect size (fill factor) of MFC was evaluated by $f = P_{max}/(I_{sc} * V_{oc})$, where $P_{max} = VR * IR$ [18].

Effect size is defined as the ratio of real maximum power to theoretical maximum power. The closer the real power is to the maximum power, the more efficient the system. Measurement and estimation values of the effect size values obtained from the data in table 1 (Appendix) and their graphs are available below

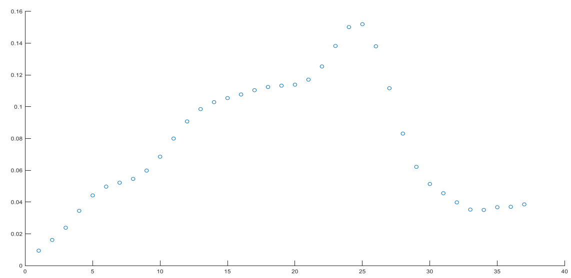

Figure 2 Graph of observed effect size values according to time

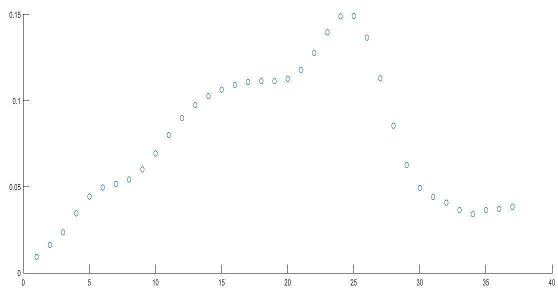

Figure 3 Graph of estimated effect size values according to time

6. CONCLUSIONS

The need for renewable energy sources is increasing day by day. Undoubtedly, today's science stands sensitively on this subject with all its resources. Investigation of different renewable energy sources is one of the most important issues of modern science. Examining the performance of a renewable energy source is very important for identifying where it can be used and for the development of the energy source.

Since effect size is designed as the ratio of maximum power to theoretical power, it is an important indicator for energy generators. The performances of energy generators can be evaluated in real terms according to this parameter. The reason for this is related to the biofilm formation process in the anode electrode of the bacteria in the structure of the MFC and the catalysis reactions of the bacteria. When the MFC is at maximum efficiency, the effect size also reaches its maximum value. Maintaining efficiency varies depending on the surface structure of the electrode and the state of bacteria sustaining the catalysis reaction.

In this study, the performance of microbial fuel cells which is a renewable energy source has been tried to be analyzed statistically. In the experiment, the effect sizes obtained from the battery produced by using microbial fuel cells were modeled according to time and the effect size plot was formed. Change of effect size according to time can be examined easily with this model.

APPENDİX

Table 1
Obtained measurement values

Day	VOC (V)	ISC (μA)	VR (V)	IR (μA)	Effect Size	Estimated Effect Size
1	0.75	14	0.009	11	0.0094	0.0094
2	0.6875	21	0.01475	15.75	0.0162	0.0163
3	0.625	28	0.0205	20.5	0.0238	0.0236
4	0.5625	35	0.02625	25.25	0.0345	0.0346
5	0.50	42	0.032	30	0.0442	0.0444
6	0.495	40.5	0.032	30.5	0.0497	0.0497
7	0.49	39	0.032	31	0.0522	0.0518
8	0.485	27.5	0.032	31.5	0.0546	0.0543
9	0.48	36	0.032	32	0.0598	0.0601
10	0.48	45.75	0.039	39	0.0685	0.0694
11	0.48	55.5	0.046	46	0.0800	0.0802
12	0.48	65.25	0.053	53	0.0908	0.0899
13	0.48	75	0.060	60	0.0985	0.0974
14	0.48	77.75	0.062	61.75	0.1029	0.1027
15	0.48	80.5	0.064	63.5	0.1054	0.1064
16	0.48	83.25	0.066	65.25	0.1077	0.1092
17	0.48	86	0.068	67	0.1104	0.1109
18	0.4825	89.5	0.06975	69.25	0.1124	0.1114
19	0.485	93	0.0715	71.5	0.1133	0.1114
20	0.4875	96.5	0.07325	73.75	0.1139	0.1128
21	0.49	100	0.075	76	0.1170	0.1180
22	0.4775	109.25	0.08075	81.5	0.1253	0.1277
23	0.465	118.5	0.08650	87	0.1382	0.1398
24	0.4525	127.75	0.09225	92.5	0.1501	0.1490
25	0.44	137	0.098	98	0.1519	0.1492
26	0.44	121.5	0.08475	84.75	0.1380	0.1366
27	0.44	106	0.0715	71.5	0.1116	0.1131
28	0.44	90.5	0.05825	58.25	0.0831	0.0855
29	0.44	75	0.045	45	0.0621	0.0627
30	0.45	86.25	0.045	45	0.0514	0.0494
31	0.46	97.5	0.045	45	0.0456	0.0441
32	0.47	108.75	0.045	45	0.0398	0.0409
33	0.48	120	0.045	45	0.0353	0.0366
34	0.47	108	0.042	43	0.0350	0.0342
35	0.46	96	0.039	41	0.0368	0.0365
36	0.45	84	0.036	39	0.0370	0.0373
37	0.44	72	0.033	37	0.0385	0.0385

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The Declaration of Conflict of Interest/ Common Interest

No potential conflict of interest was reported by the authors.

The Declaration of Ethics Committee Approval

Ethics Committee Approval is not required.

The Declaration of Research and Publicatıon Ethics

In the writing process of this study, international scientific, ethical and citation rules have been followed.

Authors' Contribution

The authors contributed equally to the study.

The Declaration of Research and Publication Ethics

The authors of the paper declare that they comply with the scientific, ethical and quotation rules of SAUJS in all processes of the paper and that they do not make any falsification on the data collected. In addition, they declare that Sakarya University Journal of Science and its editorial board have no responsibility for any ethical violations that may be encountered, and that this study has not been evaluated in any academic publication environment other than Sakarya University Journal of Science.

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