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The Effects of Surface Roughness of the Stainless-Steel Anode on Electricity Enhancement of Microbial Fuel Cell

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Abstract

Microorganisms actively catabolize substrate, and bioelectricity is generated. Microbial fuel cells (MFCs) could be utilized as a power generator in small devices. The discovery of species of microorganisms is called Rhodopseudomonas palustris KU-EGAT 13. The experiments have been conducted with the production of electricity from this type of microorganism in a single chamber microbial fuel cell. The study used 4 surface roughness of anode electrode single chamber micro fuel to study the performance of microbial fuel cell effect from the anode. Three stainless steel plates were polished to uniform roughness to the magnitude between 0.05 and 1 µm. After 24 h of experimentation, the rough electrode's open-circuit voltage (OCV) and power densities were much higher than that produced by the smooth one. Moreover, the smooth surface is higher than the charge-transfer resistance of the rough electrode. The rough surface's better electrochemical performance is due to denser biofilm grown on the surface, which was observed by scanning electron microscopy (SEM) and figuring out the microbial number in an image using an ImageJ program.

Keywords: Renewable energy, Microbial fuel cells, Anode, Roughness, Open circuit voltage

Introduction

The microbial fuel cell has gotten attention very much according to their clement operating condition and using a variety of biodegradable substrates. The tradition MFC composed of anode and cathode compartment [1]. Microorganism catabolize substrate actively and effect bioelectricity generation [1]. The MFCs can be used as a power generator in a device [2]. There is the utility of technology as follow; it could face the barrier practically as low power and current density. The study also explained that the MFCs in different parts such as anode and cathode had got a review [3]. It can get through a challenge. However, the compatible solution were studies also. The research had shown the demonstration of MFC development and also summarized the practical application in the future [4].

MFCs are devices that use microbes as catalysts to oxidize organic and inorganic matters for electricity generation and serve as an ideal technology for wastewater treatment and power output simultaneously [5]. The study shown that the remarkable electrode material was an accomplishment, also the operation methods and reactor designs. Those were supported the MFC electricity production [6]. The study also explained the importance of anode material, using in MFC performance developing [7].

The anode or the bacteria carrier significantly affect the efficiency rate of power generation in MFC [8]. Biocompatibility, the efficient transport of nutrients and waste system, also are influenced the formation of biofilm and microbes' proliferation on the surface area which directly. However, most research works focus on materials and design [9]. Little has been researched on features such as roughness, which this research will do. Only research investigated 2 types of anode surface which were smooth surface and rough surface [10]. They wanted to prove whether the rough surface has an impact on electricity generation [11]. Low power is the significant problem of MFC. The association between organic bacteria and inorganic electrode highly affects the production of MFC's power. Additionally, the connected areas of bacteria and anode also affect MFC's effectiveness [12].

Surface topography is a strong impact on the shape and performance of electroactive biofilms. At a scale of around a hundred micrometres and above, the surface can be used to increase the electrode surface area. Optimal topographies are likely found by improving mass transfer and mitigating local acidification inside the micro-structure. At the micrometre scales, local shear stress and cell-electrode contact angle seem to play the major roles. The nanoscale opens up thrilling horizons, with some hope of acting on the intimate mechanisms of biofilm formation and extracellular electron transfer [13]. Therefore, in this study, the surface characteristic will be investigated more to gain more understating.

In this research indicates the electrochemical performance of MFCs has gotten an effect from anode surface roughness significantly. A substantially larger biomass growth on a rougher anode surface which contributes to better performance of the anode was demonstrated [14]. The study shows the results from this work can be used towards the development of anodes with optimal surface topographical features for a better electron to which can use to improved power density even though we cannot verify the number of microorganisms attached to the surface.

Materials and methods

Cultivation and activation of bacteria

The experiments have been conducted with the microorganisms that Kasetsart University has registered is called Rhodopseudomonas palustris KU-EGAT 13. It was from Nakhon Si Thammarat. The KU-EGAT 13 was born from collaborating between Electricity Generating Authority of Thailand State enterprise and Kasetsart University. All of substrates were kept in room temperature until use.

Experimental platform

Single-Chamber MFC (SCMFC) was made up of 1 chamber only that contains both the anode and the cathode. Evading the use of catholyte as a result of joining 2 chambers and thus raises the power density could be accomplished. Not only simple and economical construction, but such MFC were easy to implement in the industrial or agricultural applications also. The MFCs were single compartment, air-cathode devices. The anodic was made by stainless steel sheet as anodic material; the surface area was about 2×10 cm^2 and 1 mm thickness. The cathode of our MFC was a flexible carbon cloth. In the airside, the cathode was in contact with the proton exchange membrane (PEM). In an MFC, the electrons produced in the anodic chamber were transferred to the anode and subsequently conducted through an external circuit to the cathode. On the other hand, internally, protons migrate from the anodic chamber to the cathode region through a Nafion 117 membrane also called PEM as shown in **Figure 1**.

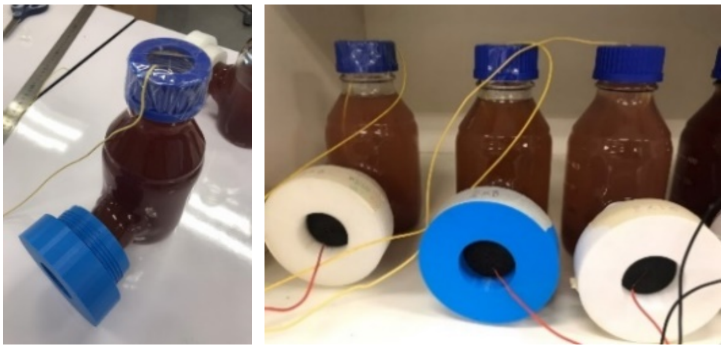


Figure 1 SCMFC platform.

Preparation of anode surface

Create different roughness on the anode surface. The pretreatment process of polishing the electrode by sandpapers could also encourage the stainless-steel sheet's surface roughness and also enhance the microorganism's adhesion for high power generation. Prepared a stainless-steel sheet which size was 2×10 cm^2 and used a sheet of sandpaper with grit sizes 80 (coarse) polished onto the sheet and measured the sheets via a surface roughness tester.

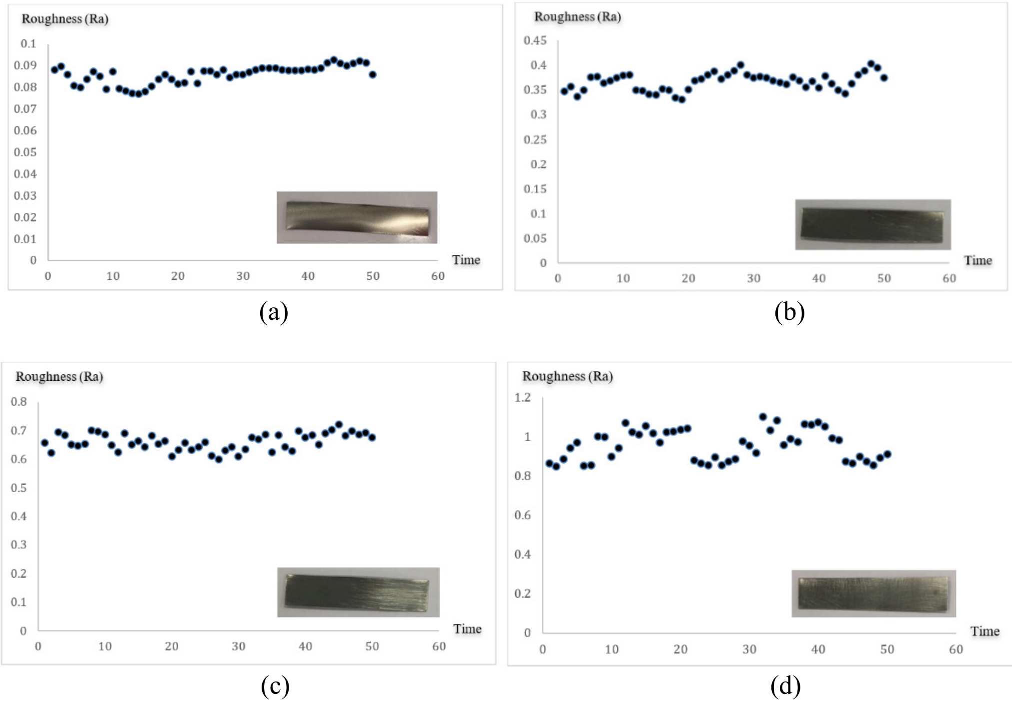


Figure 2 Four different roughness anodes: 0.0858 (a), 0.3662 (b), 0.6601 (c) and 0.9562 Ra (d).

The 4 different roughness anodes are shown in **Figure 2**. One sheet was divided into 10 sections, whereas each section took 5 repeating times of testing. After recording all results, the trend had not concluded to the exact but varying roughness. Thereby aggregating them with approximation, which was the overall summation divide by the number of times that was 50. The final roughness of each stainless-steel anodes was approximate 0.0858, 0.3662, 0.6601 and 0.9562 Ra respectively.

Electrochemical measurement and data recording

The cell emf is a thermodynamic value that does not take into account inside losses. The OCV can be measured the cell voltage after the absence of current. Theoretically, the OCV should approach the cell emf. In practice, however, various potential losses are the reason for the OCV rate is at the lower rate compare to the cell emf.

In this experiment, KU-EGAT 13 was used as microorganisms. Using a single chamber as a reactor contained stainless steel with 2×10 cm^2 as an anode, carbon fabric as a cathode and Nafion 117 as a PEM. The researchers started the experiment by bringing the anode and cathode connected with a multimeter to measure the OCV every 2 min in 24 h in room temperature.

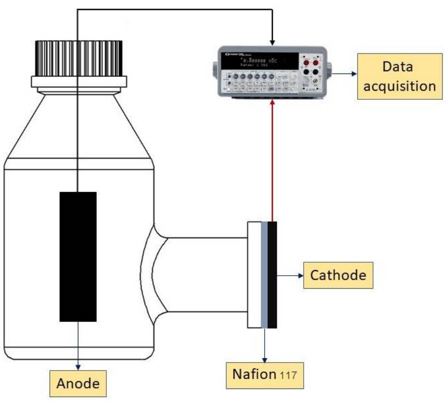


Figure 3 Single chamber connected with multimeter model.

For a polarization and power curve, they use to analyze and characterize the fuel cells. The polarization curves can be measured by using a decade resistor box to set adjustable external loads. Changing microbial fuel cell voltage under diverse external resistance by increasing periodically from 1,000 ohm to 1 MOhm. The voltage is recorded, and the current is determined using Ohms law.

Anode surface inspection by SEM

Another set of 4 different surface anodes were derived from cutting 5×5 mm² of the experimented anodes then inspected by SEM. However, before going to SEM, the small anodes had to be fixation and coating with Platinum. The fixation procedure started by immersing 4 squares with 5×5 mm² anodes in a microcentrifuge tube with a fixative solution (modified Karnovsky's fixative 2.5 % glutaraldehyde in phosphate buffer) and kept for 24 h or more in a refrigerator. Then the specimens were washed in phosphate buffer (3 times, for 10 min each wash) post-fix in 1 % osmium tetroxide aqueous solution in water for 1 h at room temperature. Rinse in distilled water (3 times, for 10 min each rinse). Follow dehydration in crescent series of acetone solutions (20, 40, 60, 80 and 100 %) for 15 min each. Next, there was a transformation of the samples to a critical point dryer to complete the drying process with carbon dioxide as a transition fluid. The specimens are placed with carbon tape on the stubs which are made by aluminum. A final process was coated with Platinum in a sputter coater and observe in SEM.

Results and discussion

The results of electricity generation

In **Figure 4**, it showed the OCV that was generated by each surface roughness (0.0858, 0.3662, 0.6601 and 0.9562 Ra respectively) in 24 h. From the graph, the anode with surface roughness 0.0858 Ra (smoothest surface) was generated voltage to 0.4211 V in the 1st h, then kept raising with the unstable trend to 0.6043 V at 24th h. For roughness 0.3662 Ra, the OCV was generated from 0 to 0.4211 V in the 1st h, increasing rapidly to 0.57 V and gradually increasing to 0.6418 V in 24th h. The OCV with roughness 0.6601 Ra was started at 0.4933 V at the beginning, then kept stable after at 8th h and a little went down at the 14th h, finally at the 24th h showed 0.6542 V. The anode with surface roughness 0.9562 Ra (roughest surface) was generated voltage to 0.4980 V from the start, then kept fluctuating rising to 0.7656 V at 24th h.

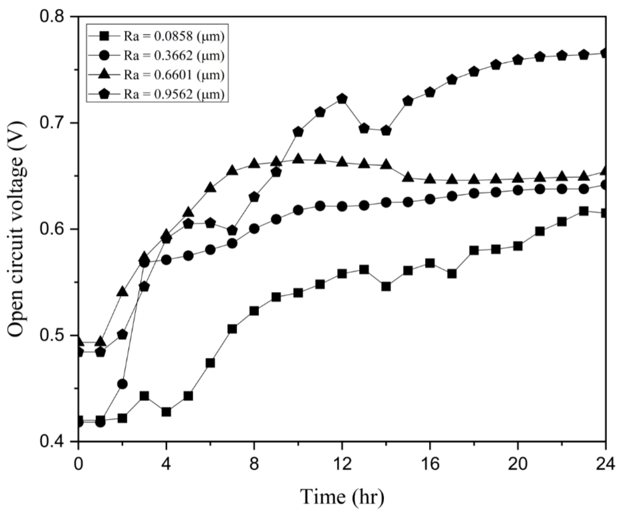
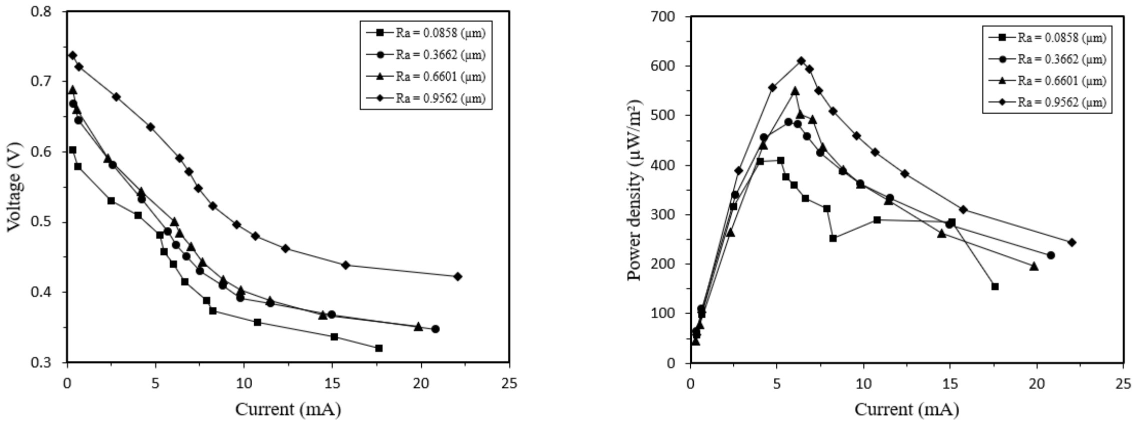


Figure 4 OCV with roughness 0.0858, 0.3662, 0.6601 and 0.9562 Ra respectively.

Polarization curves is a powerful tool to analyze and characterize microbial fuel cells. The polarization curve exhibits the voltage as a role of the current, as shown in **Figure 5(a)**. The power curves are calculated from the polarization curve and based on anode electrode's size when the MFC goes to a steady-state. **Figure 5(b)** compares the power densities of MFC with different roughness of anode surfaces. The maximum power densities of roughness 0.0858, 0.3662, 0.6601 and 0.9562 Ra were measured to be 409, 487, 550 and 611 µW/m^3, respectively.



(a) (b)

Figure 5 Polarization curve (a) and power curves (b) collected for a MFC with roughness 0.0858, 0.3662, 0.6601 and 0.9562 Ra respectively.

The surface inspection by SEM and ImageJ

From the last experiment, the researchers found that the roughness on the anode surface effect to the OCV generated. The investigation showed that the higher roughness on the anode surface, the higher the OCV generated. According to the result, the researchers assumed that the more roughness on the anode surface, the more microorganism adhered. This assumption brought us to inspect the anode surface by SEM method. To avoid the opportunity of human error in counting microorganism, the researchers used ImageJ software to differentiate the microorganism adhered in the samples.

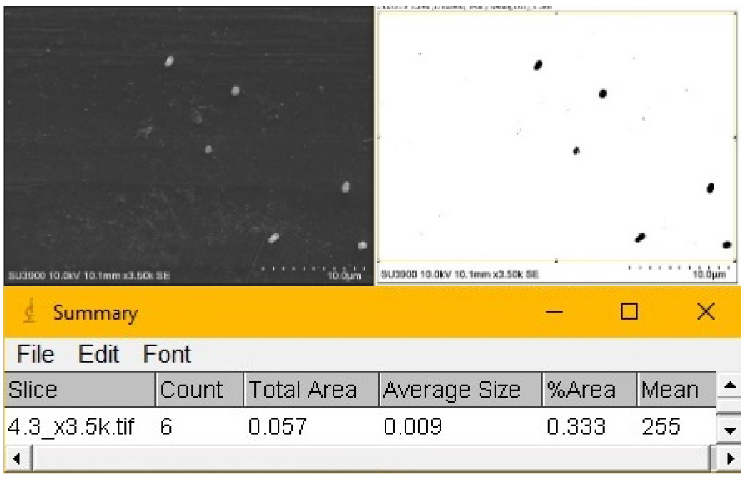


Figure 6 SEM image at 10 µm and the number of microbial counting by ImageJ on anode 0.0858 Ra.

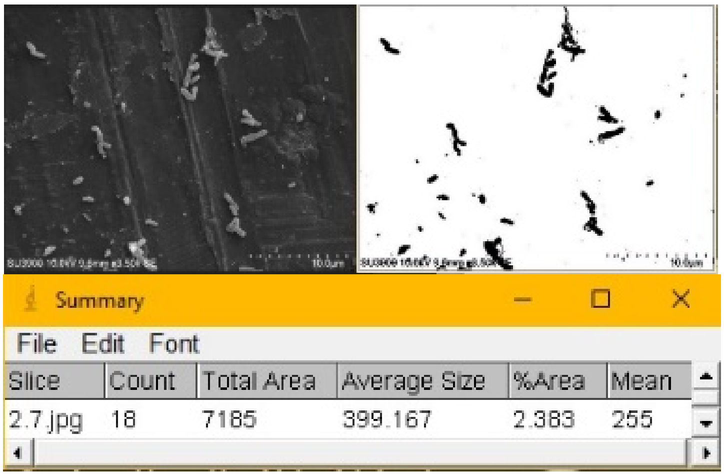


Figure 7 SEM image at 10 µm and the number of microbial counting by ImageJ on anode 0.3662 Ra.

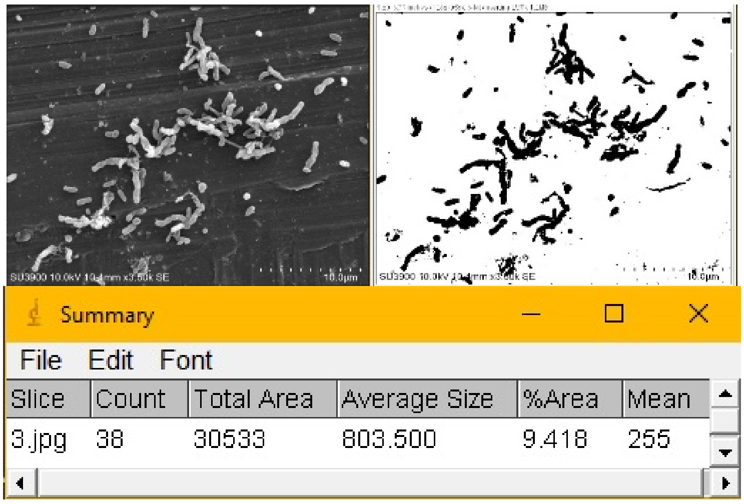


Figure 8 SEM image at 10 µm and the number of microbial counting by ImageJ on anode 0.6601 Ra.

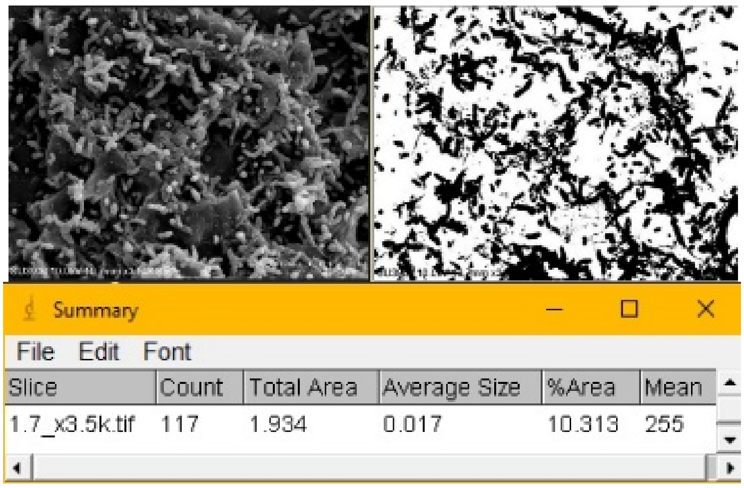


Figure 9 SEM image at 10 µm and the number of microbial counting by ImageJ on anode 0.9562 Ra.

Figures 6 - 9 showed the results of the surface inspection by SEM and the number of microbial counting by ImageJ of stainless-steel surfaces with roughness 0.0858, 0.3662, 0.6601 and 0.9562 Ra which the number of microbial counting 6, 18, 38 and 117 respectively.

The relationship of the number of microbial, electricity generation and anode roughness

From the **Figure 10**, the surface area of the anode is rough 0.0858 Ra found 6 microorganisms attached to the anode stage, which can produce voltage 0.6043 V. The roughness of 0.3662 Ra anode showed that, the number of microorganisms attached to the anode stage was 18, capable of producing voltage 0.6418 V. For the anode with the roughness of 0.6601 Ra, the number of microorganisms attached to the anode stage was 38 producing 0.6542 V. The roughest anode of 0.9562 Ra displayed 117 microorganisms attached to the anode surface that could generate electricity 0.7656 V.

It can be concluded that the anode region with more microbial adhesion. It is resulting in an increased production of OCV. The study shows that the electrochemical performance of MFCs. have got an effect from anode surface roughness. The biomass on a rougher anode surface growth is greater, effect to better efficiency of performance of the anode. We can use the study result towards the development of anodes, the optimal surface topographical features for a better electron transfer rate and find a better performance of power density.

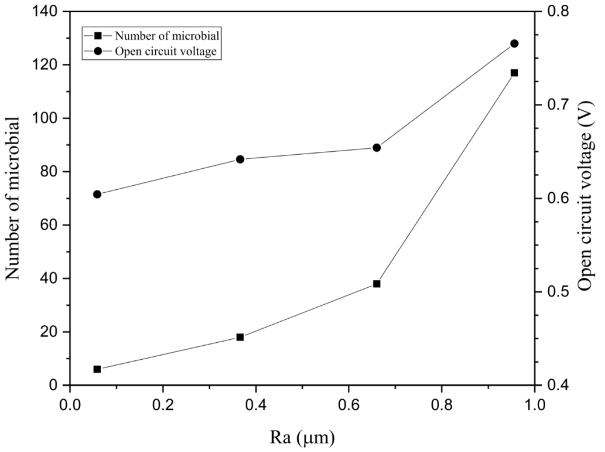


Figure 10 The relationship between the number of microbial, electricity generation and anode roughness.

Conclusions

The discovery of species of microorganisms is called Rhodopseudomonas palustris KU-EGAT 13. The experiments have been conducted with the production of electricity from this type of microorganism in a single chamber microbial fuel cell. In this study, all experiments were operated at room temperature. The experiments were conducted with 4 different surface roughness of the anode electrodes. It found that when it was in the highest anode surface roughness directed towards the highest OCV and power density. So, the anode surface roughness related to OCV in polynomial function. From the anode surface roughness experiments related to OCV. The researcher assumed that the number of microbes affects electricity generation. Therefore, all anodes were observed by SEM and found that when it is in the highest anode surface roughness directed towards the number of microbes stick on the surface. The SEM images also used the ImageJ software to count the number of microbial is in the SEM images, in which the collected data from this program found that the relationship between the number of microorganisms and surface roughness is an exponential function.

Electrodes constitute a major component of MFCs. For the anode, the main developments have been toward the surface treatment to improve the microbial attachment. At the cathode side, gas diffusion air cathodes which are low-cost and highly performing. The study explains that the electrochemical performance of MFCs has gotten an effect from anode surface roughness. The biomass growth is larger than a rougher anode surface, which contributes to anode's efficiency. Results from this research can be used towards the development of anodes electrode, which highly porous and conductive materials. Electrode materials should be highly stable in wastewater conditions for long-term MFC operation and should possess optimum pore size to avoid clogging related issue in wastewater treatment applications.

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