

MICROBIAL ELECTROLYSIS CELL CARBON ANODE WITH VOLTAGE VARIATION FOR HYDROGEN GAS PRODUCTION

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ABSTRAK

Krisis energi global dan dampak lingkungan dari penggunaan bahan bakar fosil telah mendorong pengembangan sumber energi terbarukan yang berkelanjutan. Hidrogen (H_2) menjadi salah satu kandidat utama karena sifatnya yang bersih dan nilai kalor yang tinggi. Penelitian ini bertujuan untuk mengembangkan dan mengoptimalkan sistem Microbial Electrolysis Cell (MEC) yang memanfaatkan limbah minyak kelapa sawit sebagai substrat dalam proses produksi hidrogen. Dengan memanfaatkan bakteri anaerob, MEC mampu mengubah senyawa organik dalam limbah menjadi elektron dan proton, yang kemudian dikonversi menjadi gas hidrogen melalui proses elektrolisis dengan bantuan listrik eksternal. Penelitian dilakukan dengan merancang sistem dua reaktor (anoda dan katoda) menggunakan elektroda karbon dan membran proton, serta mengamati volume gas hidrogen yang dihasilkan. Hasil penelitian diharapkan dapat meningkatkan efisiensi konversi energi, mengurangi limbah industri secara signifikan, dan mendukung pengembangan teknologi energi bersih yang aplikatif di sektor industri. Teknologi MEC menjadi solusi ganda yang inovatif, menggabungkan pengolahan limbah dan produksi energi terbarukan secara efisien.

Kata kunci: Microbial Electrolysis Cell (MEC); hidrogen; energi terbarukan; limbah kelapa sawit; bakteri anaerob.

ABSTRACT

The global energy crisis and environmental impacts of fossil fuel usage have accelerated the development of sustainable renewable energy sources. Hydrogen (H_2) has emerged as a promising clean energy carrier due to its high calorific value and zero carbon emissions. This study aims to develop and optimize a Microbial Electrolysis Cell (MEC) system that utilizes palm oil waste as a substrate for hydrogen production. Using anaerobic bacteria, MECs convert organic compounds in the waste into electrons and protons, which are then electrochemically transformed into hydrogen gas with the aid of an external power source. The research involves a dual-chamber reactor setup (anode and cathode) using carbon electrodes and a proton exchange membrane, monitoring the volume of hydrogen gas generated. The results are expected to improve energy conversion efficiency, significantly reduce industrial waste, and contribute to the advancement of applicable clean energy technologies. MEC technology presents an innovative dual-solution approach by integrating waste treatment with renewable energy production efficiently.

Keywords: Microbial Electrolysis Cell (MEC); hydrogen; renewable energy; palm oil waste; anaerobic bacteria.

INTRODUCTION

Renewable energy is an important solution in facing the challenges of the energy crisis and global climate change. Global energy demand is increasing, driven by the confluence of demographic growth, economic development, and urban expansion. Today, dependence on fossil fuels still dominates the world's energy supply, which not only threatens environmental sustainability but also poses economic problems due to price fluctuations and resource limitations. Hydrogen (H_2) has emerged as one of the promising clean energy alternatives because it has a high calorific value (142 MJ/kg) and its combustion results only produce water (H_2O)[1],

so it leaves no carbon footprint. The concept of a hydrogen economy means that hydrogen will be produced from a wide range of renewable sources in large quantities, and will be used to replace fossil-based fuels in the transportation, residential, commercial, and industrial sectors. Developing a successful hydrogen economy will mean benefits for a country's energy security, economy and environment, and ultimately consumers [2].

MFC is a combination of biotechnology and energy technology, which has great potential in renewable energy production as well as waste treatment. MFC is a combination of biotechnology and energy technology, which has great potential in renewable energy production as well as waste

treatment [3]. However, conventional hydrogen production, such as through the natural gas reform process, still relies on fossil fuels and produces significant carbon dioxide (CO₂) emissions [4]. Therefore, a more environmentally friendly and sustainable method of hydrogen production is needed.

One of the innovative technologies being developed is the Microbial Electrolysis Cell (MEC), which utilizes microorganisms to decompose organic matter and produce hydrogen through an electrolysis process with the help of additional electrical energy [5]. The main advantage of MEC is its ability to combine the treatment of organic waste with the production of hydrogen, thus offering a dual solution: reducing waste and generating clean energy. Palm oil waste, produced in large quantities by the palm oil industry, is one of the potential sources of organic matter to be utilized in the MEC system. This waste contains high levels of organic compounds, such as fatty acids and glycerol, which microorganisms can break down into electrons and protons for hydrogen production.

The palm oil industry is one of the most important sectors in the global economy, especially in producing countries such as Indonesia and Malaysia. However, behind its significant contribution to the economy, the industry also produces large amounts of waste, including liquid and solid waste from the palm oil processing process. Palm oil waste, such as Palm Oil Mill Effluent (POME), contains high levels of organic compounds, such as fatty acids, glycerol, and lignin-cellulose compounds, which can pollute the environment if not managed properly. At the end, the Microbial Electrolysis Cell (MEC) research with palm oil waste is to determine efficient waste treatment while producing renewable energy, especially hydrogen (H₂), as well as reducing environmental impact. Hydrogen is an environmentally friendly energy source that can be used for fuel or industry. MEC helps reduce Chemical Oxygen Demand (COD) and Biological Oxygen Demand (BOD) in waste, making it safer to dispose of into the environment, as well as reducing water and soil pollution due to untreated palm waste. The research aims to find optimal conditions (microbial selectivity, reactor design, or substrate) for MEC to be applied commercially in industry.

This research aims to develop and optimize the Microbial Cell Electrolysis (MEC) system as an innovative technology for environmentally friendly and sustainable hydrogen production.

RESEARCH METHODS

The waste used for this electrolysis process is oil palm liquid waste. The electrode used for this electrolysis process is carbon. The membrane used to transfer positive ions from a bottle filled with anaerobic bacteria with palm oil waste to another bottle filled with only water is proton burning. The MEC 2-tube bioreactor has been successfully built, as shown in Figure 3. This 2-tube bioreactor is made of thick Plastic material with a diameter of 67 mm, a height of 199 mm, and a thickness of 3 mm. These two reactor tubes are connected by acrylic pipes with a diameter of 21.7 mm and a length of pipe 78.5 mm connected by a union head in which a proton membrane has been added as a partition between the cathode tube (filled with water de minerale) and the anode (filled with anaerone bacteria and palm oil waste). This bioreactor has a capacity of 0.5 L, and is equipped with a monitoring system that measures Oxygen and H₂ gas. In addition, an additional power supply is used to regulate the voltage being conducted. The anode tube is coated in black so that light does not enter the tube to interfere with the process of bacteria digesting palm oil waste. With the first bottle filled with anaerobic bacteria along with oil palm liquid waste and flowed with lexicon (+) to the iron plate and carbon as the electrode, this first bottle acts as an anode. The second bottle that is connected to the first bottle with a transparent pipe and a proton membrane will be electrically supplied (-) also on an iron plate where this bottle contains water that produces hydrogen gas and oxygen that comes out of the release of positive ions from the membrane. The carbon fiber used in the construction of the object is a graphite carbon plate with a size of 100 x 20 mm which is connected with a Cu rod for good electrical conductivity as an electrode. Measurement of the level of hydrogen gas in the bioreactor is carried out using a gas sensor.

Before the study began, the carbon plate was soaked with a NaOH search for its activation for approximately 40 minutes so that the cavity on the surface of the plate opened. Then the plate is soaked and left with palm oil waste and anaerobic bacteria for 2 days.

RESULTS AND DISCUSSION

0.5 Volt Voltage Hydrogen Gas Production

The graph above shows the volume of gas (in ppm) against time (in seconds) for 5 hours (18,000 seconds) in the Microbial Electrolysis Cell (MEC) system with a working voltage of 0.5 V. The

sensors used are MQ-8 for Hydrogen (H_2) detection and MQ-131 for Oxygen (O_2) detection.

The graph shows a linear increase over time for both gases where hydrogen gas (H_2) (gray) increases more sharply than oxygen (O_2) (red). Hydrogen is produced more as compared to oxygen. At the end of 5 hours the volume of hydrogen gas almost reaches 400 ppm while oxygen reaches 190 ppm. This shows that the microbiological reactions that occur in the anode run efficiently. The anode and cathode work well in separating water into H_2 and O_2 . A voltage of 0.5 V is sufficient to produce both gases, although in MEC systems it is generally aided by bacterial activity in the anode.

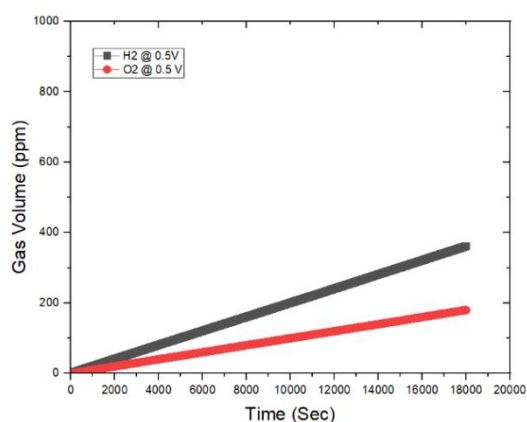


Figure 1. Graph of Hydrogen and oxygen gas at 0.5 Volt voltage

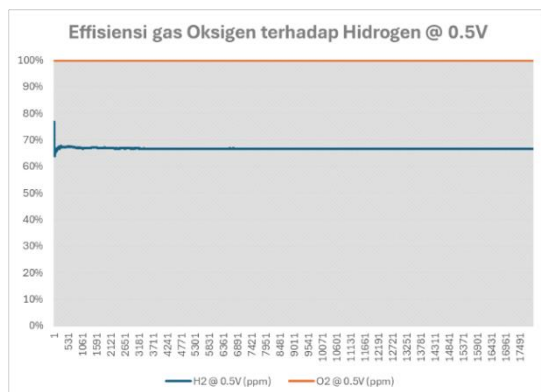


Figure 2. Graph of oxygen efficiency to hydrogen at a voltage of 0.5 Volts

Production of Hydrogen Gas Voltage 1 Volt

H_2 was relatively stable throughout the 5 hours although for the beginning of the experiment it fluctuated slightly, close to 67%. This value indicates that the system successfully converts the

organic substrate from palm oil waste into electrons and protons, which then form H_2 in the cathode when subjected to a voltage of 0.5V. Stability indicates that the conditions of the anode and cathode are stable, including bacterial activity and diffusion of protons through the membrane.

In gas, Oxygen production is lower than Hydrogen, because Oxygen is mainly produced from the oxidation of water in the anode (minor) or membrane leakage, so the trend tends to stabilize or rise slowly over time. At the end of 5 hours, the volume of hydrogen gas almost reached 900 ppm, while oxygen reached 420 ppm.

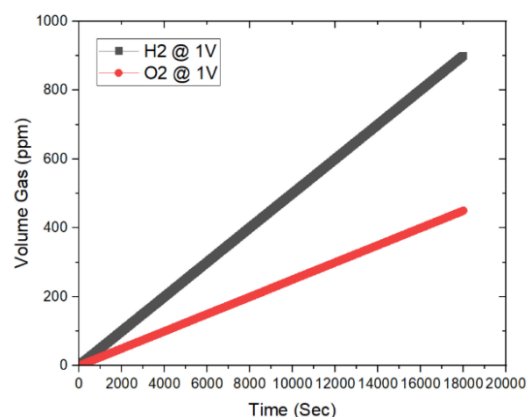


Figure 3. Graph of Hydrogen and oxygen gas at a voltage of 1 Volt.

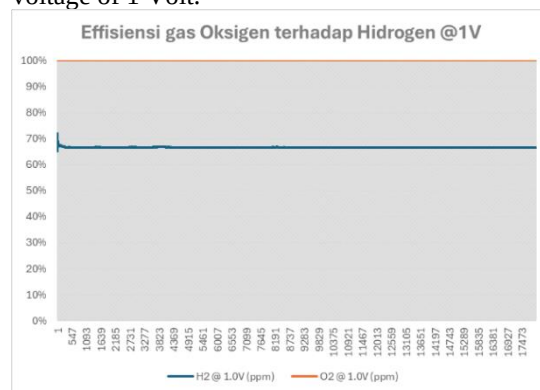


Figure 4. Graph of oxygen efficiency to hydrogen at a voltage of 1 V.

The H_2 concentration is stable in the range of 66–67% almost identical to the previous graph at 0.5V. This shows that the voltage increase from 0.5V to 1.0V does not significantly increase H_2 production.

This could indicate that the system has reached a kinetic or biological limit, where bacteria are unable to produce more electrons even if the voltage is increased. Another possibility is the

transport of protons through the membrane or the $H^+ \rightarrow H_2$ reduction reaction in the cathode has already reached saturation.

Production of 1.5 Volt Voltage Hydrogen Gas

The graph above shows the volume of gas (in ppm) against time (in seconds) for 5 hours (18,000 seconds) in a Microbial Electrolysis Cell (MEC) system with a working voltage of 1.5 V. The sensors used are MQ-8 for Hydrogen (H_2) detection and MQ-131 for Oxygen (O_2) detection.

The graph shows a linear increase over time for both gases where hydrogen gas (H_2) (gray) increases more sharply than oxygen (O_2) (red). Hydrogen is produced more compared to oxygen. At the end of 5 hours the volume of hydrogen gas almost reaches 1400 ppm while oxygen reaches 740 ppm. This shows that the microbiological reactions that occur in the anode run efficiently. The anode and cathode work well in separating water into H_2 and O_2 . A voltage of 1.5 V is sufficient to produce both gases, although in MEC systems it is generally aided by bacterial activity in the anode.

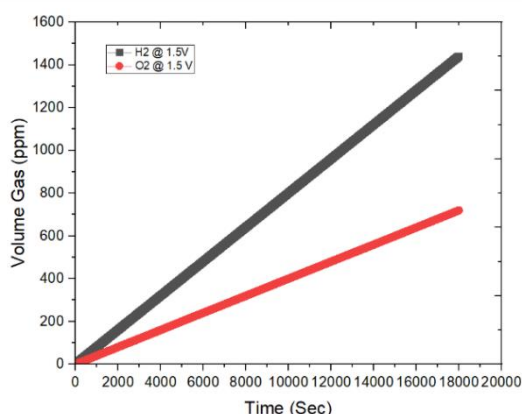


Figure 5. Graph of Hydrogen and oxygen gas at a voltage of 1.5V.

The H_2 concentration is more stable in the range of 66–67% almost identical to the previous graph at 0.5V and 1V. This suggests that the voltage increase does not significantly increase H_2 production, but for the initial reaction at 1 s to 1000 s it is much more balanced than in the previous two experiments.

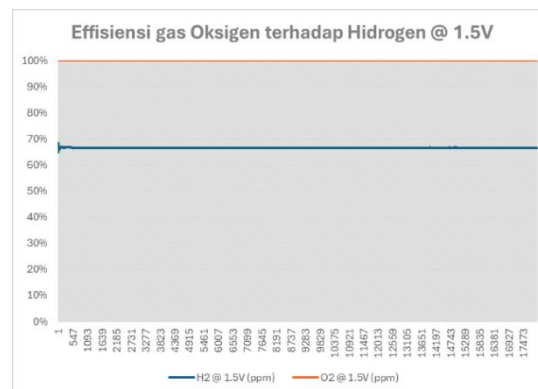


Figure 6. Graph of the efficiency of oxygen to hydrogen at a voltage of 1.5 V.

Figure 7. displays the volume of hydrogen (H_2) gas generated for 5 hours (18,000 seconds) in a Microbial Electrolysis Cell (MEC) system with three voltage variations: 0.5 V, 1.0 V, and 1.5 V. Data are taken using an MQ-8 sensor, which specifically detects H_2 gas. All lines show a linear rise over time, indicating a stable running reaction.

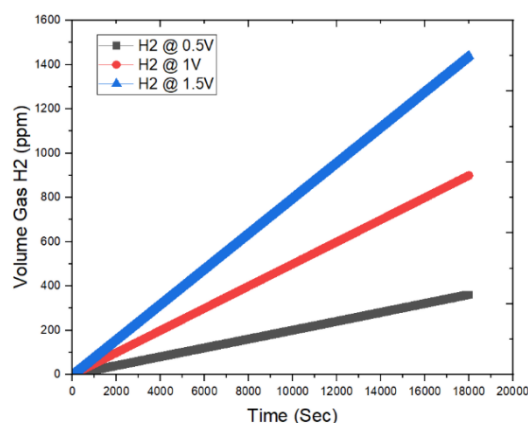


Figure 7. Graph of Hydrogen Gas at each voltage.

UV-Vis Results

Carbon is generally conductive, but depending on its shape (e.g., graphite, amorphous, or activated carbon), its bandgap value can vary. The curve shows a surge in absorbance after 1.8Nm, suggesting that the carbon plate begins to absorb significantly at this range. The slightly higher bandgap values of aquades and Fe indicate that carbon has mild semiconductor properties depending on its shape and cleanliness. And getting the energy value by using Tauc Relation is 1,866eV.

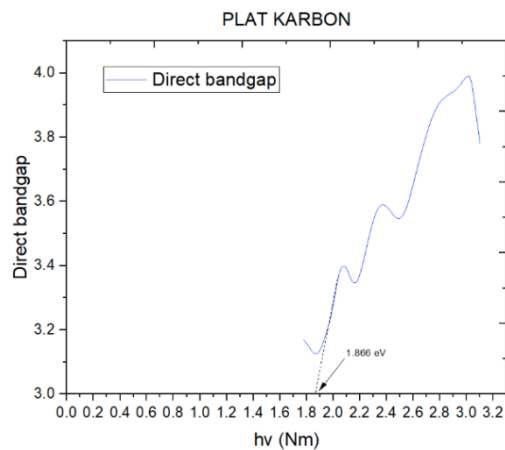


Figure 8. Carbon Plate UV-Vis Test Results

It can be seen that the ferrous metal material exhibits an energy transition quite similar to that of aquades in the early part, but the maximum value of the direct bandgap is much higher (>10). This could indicate the presence of oxides or contaminants on the surface that are causing higher absorption. The curve rises fluctuately and indicates the presence of several peaks that could be related to complex electronic structures or the presence of corrosion/oxidation influences. And getting the energy value by using Tauc Relation is 1.84eV.

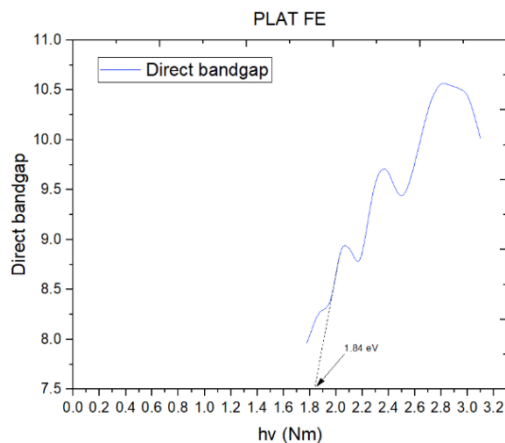


Figure 9. Results of UV-Vis Plate Fe.

CONCLUSION

A two-tube Microbial Electrolysis Cell (MEC) system with a proton membrane has been proven to be effective in producing hydrogen gas, using palm oil liquid waste (POME) and anaerobic bacteria as a substrate. The electrochemical reaction lasted stably for 5 hours at each voltage variation. The volume of hydrogen gas increases as voltage increases (0.5V, 1V, 1.5V). However, the energy conversion efficiency remained stable in the range of ~67% at all voltages, suggesting that

biological (microbial activity) and technical (membrane performance or ion diffusion) limits were the main limiting factors. The exothermic energy increases linearly as the voltage increases, from 385.94 kJ/mol at 0.5V to 1157.82 kJ/mol at 1.5V. The total output energy in the form of the calorific value of hydrogen gas shows a very large ratio to the input (up to $>14000\%$), indicating that most of the energy comes from the biological degradation of the substrate by microorganisms. The results of the UV-Vis test strengthen the character of the material: Aquades, POME, carbon and iron plates have relevant bandgaps and support the process of electrolysis and microbial activity.

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