The Performance of Types of Fuel Cell: Energy Generation

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Abstract- Today, a global energy crisis is a major challenge due to the high demand for energy and limited resources. Given the lack of energy and the lack of proper use of renewable energy sources, there is an urgent need to search alternative routes for energy production. The technology of microbial fuel cell is a promising alternative to energy production. The microbial fuel cell is a bioreactor that converts the chemical energy of organic or inorganic materials into electrical energy. In this fuel cell, various sources such as garbage, carbohydrates, proteins, sewage and cellulose are used as feeds by a variety of microbes. In this paper, the microbial fuel cell and the factors affecting it is investigated. Also, the advantages and disadvantages of microbial fuel cells over other fuel cells are studied. According to the studies, microbial fuel cells using microorganisms can be introduced as a new and efficient approach to generate energy.

Keywords Renewable energy, Microbial fuel cell, Microorganisms, Electrical energy.

1. Introduction

In recent decades, energy consumption has grown dramatically in the world. Energy sources are divided into two categories of renewable resources and non-renewable resources. Non-renewable resources can be divided into two major categories of nuclear or fossil energy. Fossil fuels have a negative impact on nature due to carbon dioxide emissions. As fossil fuels produce heat and contaminate the atmosphere, various countries in the world are struggling to solve the energy crisis by turning this energy into renewable sources such as solar energy, water and wind energy. The fuel cell is one of the alternative sources of energy that has recently been proposed. In a fuel cell during chemical processes, the energy contained in organic and inorganic compounds leads to electricity generation using bio-catalyst (Rahimnejad et. al., 2015). One type of fuel cell is a microbial fuel cell in which microorganisms act as biocatalysts. The system is remarkable for its benefits, such as limited moving parts and environmental compatibility. Fuel cell has higher efficiency than conventional fossil fuels such as petroleum and gasoline. Unlimited fuel feed and the possibility of generating high-quality electricity is another advantage of a microbial fuel cell. (Taghizadeh and Alaei, 2016). The microbial fuel cell is a chemical that converts chemical energy into electrical energy by the catalytic reaction of microorganisms. This cell usually consists of a cathode chamber and anode separated by a cationic membrane. The electrons are transmitted through an external circuit and proton through the membrane to the cathode compartment. The electrons and protons in the vicinity of oxygen in the cathode compartment become water (Isanlou et al., 2014). There are various combinations that can be used as fuel in microbial fuel cells from simple compounds such as glucose and acetate to more complex compounds such as starch, sewage and organic and inorganic sediments (Yawari et al., 2012). The purpose of this study is to investigate the microbial fuel cell, its effective factors and its applications, which will be further explained in the interpretation.

2. Literature Survey

Although, fuel cell has recently been introduced for electric power generation but, its history dated back to the nineteenth century. Serviliyam Gruber constructed the first fuel cell in 1839 with an example of the electrolysis reaction of water during a reverse reaction in the presence of platinum catalyst. The term "fuel cell" was used by Ludwick Mend and Charles Langer in 1889. They made a kind of fuel cell that consumed air and coal fuel. Interest in the use of fuel cells was diminished by the discovery of cheap fossil fuels and the propagation of steam engines. Another chapter from the history of fuel cell research was conducted by Francis Bacon of Cambridge University. In 1932 he made many modifications to the car made by Mend and Langer. These include replacing the expensive catalyst with platinum with nickel as well as the use of alkali hydroxide instead of sulfuric acid due to its non–corrosive property. The invention, which was the first alkaline fuel cell, was called Bacon Cell. He continued his research for 27 years to complete a full-fledged fuel cell (Renewable Energy and Energy Efficiency). New research in this field began in the early 1960s with the advancement of space occupation activities. The NASA Research Center was seeking to provide power for space shuttle flights. NASA chose fuel cell after rejecting options such as battery (due to heavy duty), solar energy (due to expensive) and nuclear energy (due to high risk). Research in this field led to the construction of a polymer-based fuel cell by General Electric. At the end of the last century, the idea of using microbial cells in an attempt to generate electricity was presented. As M.C. Potter, a professor of botany at Durham University was the first to start in 1911. In 1931, Branet Cohen continued his work by creating a series of semi-microbial cells that were connected in series, producing more than 35 V with a flow of just 2 mA. More work was done in this area by DelDuca et al. They used hydrogen produced by fermentation of glucose, which was used as the reactant in the aerial and hydrogen fuel cell anode. Unfortunately, even though the fuel cell was working, it was unreliable due to the unstable nature of hydrogen production through microorganisms (Renewable Energy Organization and Energy Efficiency). The findings now suggest that electricity can be generated directly from organic matter decomposition in a microbial cell. Like a conventional fuel cell, the microbial fuel cell also has an anode, cathode and an enclosure such that an anaerobic anodic chamber is separated from the cathode chamber by an ion exchange membrane and the circuit is completed with the help of an external wire (Renewable Energy Organization and Energy Productivity Electricity).

3. Types of fuel cell

A fuel cell is a unit that produces electricity through chemical reactions. Each fuel cell has two electrodes, one positive and one negative, which is generally called cathode and anode. The reactions that lead to the generation of electricity occur in electrodes. Also, each fuel cell has an electrolyte that transmits particles with an electric charge from one electrode to another. In addition, fuel cells need oxygen (Sharafabadi, 2014). One of the great advantages of fuel cells is the generation of electricity by minimizing pollution. Most of the oxygen and hydrogen used in generating electricity will eventually produce water by combining with each other. This can be seen in Figure 1. A simple fuel cell generates a small amount of electric current (DC). The basis of the work of a fuel cell is simple to explain, but it is really complicated to build at a low cost and high efficiency. Scientists have designed different types of fuel cells in different sizes to get more efficiency and to find technical details (Sharafabadi, 2014).

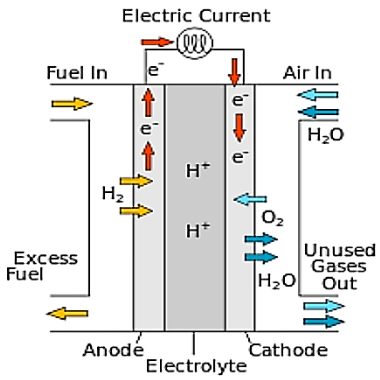

Figure 1. schematic of fuel cell.

Fuel cells are categorized depending on the type of electrolyte, each of which is suitable for a particular application. The fuel cells can be divided into two general types according to the type of electrolyte (Sharafabadi, 2014):

- Organic fuel cell
- Metal Fuel cell

Organic fuel cells are classified based on the organic electrolyte used in it into seven main types:

1. Phosphoric acid fuel cell (PAFC)
2. Alkaline fuel cell (AFC)
3. Molten carbonate fuel cell (MCFC)
4. Polymer fuel cell (PFC)
5. Solid oxide fuel cell (SOFC)
6. Direct methanol fuel cell (DMFC)
7. Microbial fuel cell (MFC)

Metal fuel cells can be divided into the following:

1. Zinc – air fuel cell (ZAFC)
2. Aluminum- air fuel cell (AAFC)
3. Magnesium- air fuel cell (MAFC)
4. Iron- air fuel cell (IAFC)
5. Lithium- air fuel (LAFC)
6. Calcium- air fuel cell (CAFC)

3.1. Phosphoric acid fuel cell

The electrolyte used in this fuel cell is pure phosphoric acid (about 100% concentration). The operating temperature range of this cell is between 150 and 220℃. Ionic conductivity in phosphoric acid is relatively weak, but this acid is more stable than other acids for use in this type of fuel cell. Phosphoric acid fuel cells are not sensitive to CO_2 and do not cause any problems in the presence of 1-2% of CO. The catalyst used in phosphoric acid fuel cell is platinum and the matrix used to store the acid is silicon carbide (SiC) (Sharafabadi, 2014).

3.2. Alkaline fuel cell

Potassium or sodium hydroxide is used as electrolyte in this cell. Hydrogen is used as fuel and oxygen as oxidants at temperatures of 70 ° C (Ormerod, 2003).

3.3. Methanol fuel cell

Methanol fuel cell is in fact a polymeric fuel cell, with the difference that the electrode structure is slightly different from that of a polymer fuel cell, and in this type, liquid methanol is consumed as fuel. The main problem with this fuel cell is the passage of methanol from a polymer membrane (Sharafabadi, 2014).

3.4. Molten carbonate fuel cell

The electrolyte of this type is the molten carbonate salt in a ceramic matrix (Sharafabadi, 2014).

3.5. Solid oxide fuel cell

This is a solid fuel cell which is used a ceramic as an electrolytic which is oxygen ions conductor. In the cathode, oxygen is reduced to oxygen ions and moves to the anode by electrolyte. In the anode, oxygen and hydrogen ions produce water (Ormerod, 2003).

3.6. Fuel cell with polymer oxide electrolyte

The polymer membrane is used as electrolyte in this type of fuel cell. The pure hydrogen in the anode turns into a positive ion of hydrogen and negative electrons. The electrons go from the external circuit to the cathode and the polymer electrolyte allows hydrogen ions to pass from the anode to the cathode. The oxygen cathode combines air with hydrogen ions and negative electrons to generate electricity and heat (Ormerod, 2003).

3.7. General comparison between organic fuel cells

In Table 1, types of fuel cell are compared by properties. Operating temperature, efficiency, and production power, are presented in the table which help us to select the best and most affordable fuel cell (Sharafabadi, 2014).

Table 1. Comparison of organic fuel cell (Sharafabadi, 1393).

Type / Property	Alkaline	Methanol	Molten carbonate	Phosphoric acid	Polimeric	Solid Oxide
Electrolyte	KOH	Polymeric membrane	Liquid molten carbonate (fixed)	Liquid phosphoric acid (fixed)	Ion exchanged membrane	ceramic
Operation temperature	60-90	60-130	650	200	80	1000
Efficiency	40-60%	40%	45-60%	35-40%	40-60%	50-65%
Power generation	<20 kW	<10 kW	>1 MW	>50 kW	< 250 kW	>200 kW
Application	Submrine and Spacecraft	Transportation	Power plants	Power plants	Power plants	Power plants

3.8. Microbial fuel cell

In this cell, bacteria are used as catalysts for the oxidation of organic and inorganic materials, (Logan et al., 2006). Materials such as acetate, glucose, ligno-cellulose, synthetic sewage, colored sewage, cellulose and mineral compounds, etc. can be used as feed in the cell (Pant et al., 2010). The electrons from these materials are transmitted by the bacteria from the anode to the cathode, which ultimately results in electricity generation (Logan et al., 2006).

4. The process of producing energy in a microbial fuel cell

The theory of electricity generation using a microbial fuel cell may not be a novel idea, but it is new as a practical way of generating electricity. As an economically competitive way of generating energy, making a microbial fuel cell is extremely urgent. Microbial fuel cells are so effective that less effort has been made to carry out practical architectures using less accessible materials. More information about this cell will be explained in the following sections. These include energy generation, oxidation and reduction reactions, and the advantages and disadvantages of microbial fuel cells (Logan, 2012).

4.1. Energy Production Method

Microbial fuel cell technology is the latest biodegradable method from bacteria. In a microbial fuel cell, microorganisms produce organic matter by oxide and electron. The electrons go to an electron receiver. The receiver takes and reduces electrons. Oxidants are oxygen, nitrate and sulfate. We now know that some bacteria are capable of transferring electrons to a receptor. So, bacteria can produce power in the microbial fuel cell. To illustrate the function of microbial fuel cells to generate electricity, we introduce the components of the machine to start producing power. This system has two cathode and anode compartments separated by a membrane. The fuel feed is a microbial, an organic matter, and an electron receptor (oxygen), and its product is water and electricity, and the bacterium plays a role as an electron transfer. The bacterium oxidizes the growth medium and organic matter, releasing the electron to the cathode and proton to the solution. Spread in the cathode to provide the oxygen needed in the cathode. Oxygen in anode compartment prevents electricity generation. Therefore, membranes are used to remove bacteria from oxygen. Basically, membrane is permeable to the proton. the proton enters the cathode and reacts with the electrons transmitted through the wire and the oxygen and the water is generated. The two electrodes are connected to one wire with resistance, and the current is calculated by measuring the voltage drop across the resistance using a multi meter electric. The steps in energy production are shown in Figure 2 (Logan, 2013).

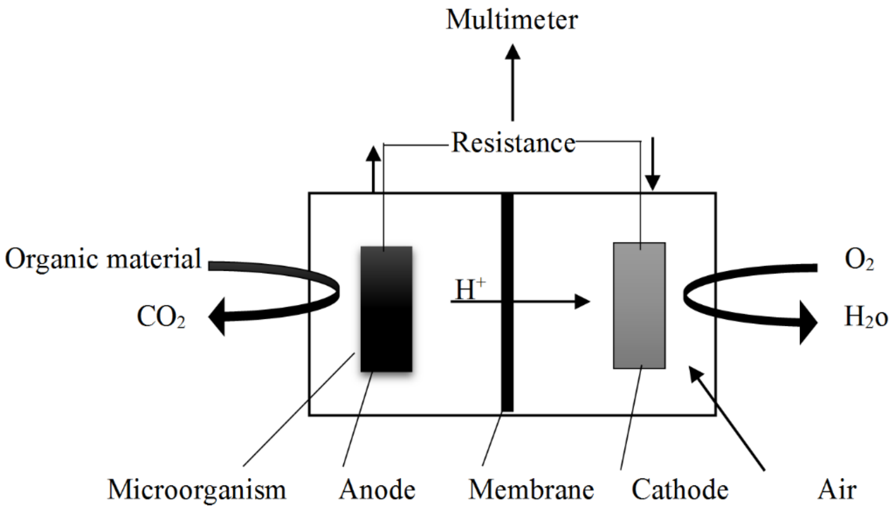

Figure 2. General view of the microbial fuel cell and its performance.

4.2. Oxidation and reduction reactions

As explained in the previous section, the microbial fuel cell has two compartments, one anode and one cathode. In anode,

$$C_6H_{12}O_6 + 6H_2O \longrightarrow 6CO_2 + 24H^+ + 24e^- \quad (1)$$

$$24H^+ + 24e^- + 6O_2 \longrightarrow 12H_2O \quad (2)$$

organic material is decomposed into carbon dioxide, hydrogen, and electrons by oxidation. The reaction of 4-1 occurs in this section (Daei et al., 2005).Hydrogen and electrons produced in the anode are transmitted to the cathode and with oxygen entering this section, reaction 4-2 occurs, and eventually the products will be produced by water and electricity (Dai et al., 2005).

4.3. Advantages and disadvantages of microbial fuel cells

In tables (2 and 3) some of the disadvantages and advantages of microbial fuel cells have been described (Taghizadeh and Alaei, 2016).

Table 3. Disadvantages of microbial fuel cells.

Advantages
1. Relatively calm and silent, due to lack of moving parts .
2. Simple maintenance.
3. Diversification in the use of fuel.
4. Higher efficiency over fossil fuels such as oil and gasoline.
5. Simple and cost effective installation and operation
6. The ability to generate electricity and heat simultaneously
7. Connect to microturbines
8. High-quality power generation

Table 2. Benefits of microbial fuel cells.

Disadvantages
1. Expensive because of lack of production line.
2. Heavier than normal batteries.
3. Limited products
4. Little information, due to the lack of development of microbial fuel cells.

5. Microorganisms used in microbial fuel cells

Fuel cells are capable of generating electricity using a variety of different chemicals, with oxidation of chemicals in the anode and reduction in the cathode. Microbial fuel cells do not need to use metallic catalysts in anode, instead, they use microorganisms.Some microorganisms are defined as Exoelectro-gens due to the ability to transfer electrons. Others describe microorganisms as electrochemical active bacteria and respiratory bacteria. Microorganisms used in fuel cell are available in marine sediments, soil, sewage and freshwater sediment or active sludge. A number of species, such as Geobacter, Shewanella, Clostridium, are often used in microbial cells to generate electricity and hydrogen, and are capable of oxidation of acetate and ethanol as substrates (Parkash, 2016). Therefore, the mechanism of electron transfer in the anode is a critical issue for studying the cell. So far, there are several known mechanisms of the transfer of bacterial electrons to electrode surfaces. The electrode potential is created when electrons are available. Some bacterial species are weak in transport electrons through the system to the electrode, because their surface structure is non-conductive. Therefore, electrochemical intermediates were introduced to transfer electrons from cells to electrodes.

Electrochemical intermediates place the bacteria in its oxidated form and interact with reducing agents in the cell. Once reduced, intermediates that are permeable can penetrate the cell to bond to the electrode surface. Then, the reduced intermediates are the same electrocatalytic oxidized by the transmission electrons. Oxidized intermediates are allowed to start this cycle again. However, intermediates are usually toxic compounds. In addition to the bacterial species that can be transmitted through the intermediaries to transmit electrons, some bacteria are able to transport electrons from oxidation of organic matter to non-intermediate electrodes. Bacteria that are involved in microbial fuel cells do not need an electron-mediated transmission. In most non-mediated microbial cells, anodes are often absorbed by different microorganisms, such as Shuanella, Geobacter, and Rhodoferax.

The function of the microbial fuel cell is not only influenced by the type of microorganism but also by the mechanism of electron transfer to the anode (Parkash, 2016).

Some bacteria can produce electrons through their intermediates. Electron transfer to nano-wires 2 is carried out by bacteria. In the absence of nano wires, electrons can also be transmitted through the surface of bacterial cells. For self-generated intermediate electron transfer, Pseudomonas aeruginosa 3 can generate electronic shuttles to increase electron transfer velocity. Geobacter and Shvanella species produce nanowires. The two have a good ability to produce electricity and hydrogen in a microbial fuel cell. Geobacter Sulfur 4 is an anticoagulant chemical that can oxidise organic substrates completely to transfer electrons to non-intermediate electrodes. This combination can generate electricity of about 2.15 kWh per cubic meter Parkash (2016) and (Tazicet et al. 2010). Research on yeast Saccharomyces cerevisiae 5 and bacteria such as Bacillus coli 6 (Escherichia coli) showed that these microorganisms can produce voltages and, therefore, electricity (Logan, 2012).

6. Factors affecting the production of microbial fuel cells

The power produced in a microbial fuel cell is dependent on biological and electrochemical factors, some of which will be described below (Najafi et al., 1394).

6.1. Substrate conversion speed

This factor depends on the amount of bacteria present in the cell, the mass transfer phenomena in the reactor, the kinetics of bacteria, the loading rate of biomass, the efficiency of the proton exchange membrane and, ultimately, the high potential of the microbial fuel cell (Rabaey et al., 2005).

6.2. High potential in the anode

Generally, when the open circuit potential of this type of cell is measured, this value is reported to be from 750 mv to 798 mv. Parameters that are affected by excessive power include: electrode surface, electrochemical characteristics of the electrode and kinetics with electron transfer mechanism (Rabaey et al., 2005).

6.3. High potential in the cathode

The high amounts of potential in the cathode damages the performance of fuel cell as does high anode potential. Several researchers used Hexacyanoferrate to solve it. However, *Hexacyanoferrate* are not completely oxidised by oxygen in the air and should be considered as an electron receptor. The cathodes of the microbial fuel cell, preferably, should be the open air cathodes to be stable (Rabaey et al., 2005).

6.4. Proton exchange membranes

Nafion membranes, for example, are susceptible to waste. The best result is obtained from the microbial fuel cell using the Altrex membrane. Using the compressed carbon paper as separator, the membrane was removed. Although this irregularity significantly reduced the internal resistance of the microbial fuel cell, it caused the cathode catalyst to be poisoned. There is currently no information on the stability of this system (Rabaey et al., 2005).

6.5. Internal resistance

The internal resistance of the microbial fuel cell depends on the electrolyte resistance between the electrodes and the membrane resistance. For optimal performance of the fuel cell, anode and cathode, convergence is required. Proton migration is also significantly affected by the loss of resistance, and appropriate mixing can minimize these losses (Rabaey et al., 2005).

7. Applications of microbial fuel cells

Fuel Cells have been used extensively in electricity generation, hydrogen production, and wastewater treatment (Rahimnejad et al., 2015). In the future, microbial fuel cells may have other uses besides sewage treatment and renewable energy. By placing an anode electrode in marine sediments and a cathode in the water on which it is located, it is possible to generate electricity from the decomposition of organic matter bacteria in sediments. In this way, enough electricity is not produced to make it economically feasible as a renewable energy production method, but it can be sufficient to operate machines in the offshore. Also, the microbial fuel cell could be changed and used as a bio-cleansing method. Based on these technologies, this cell can be used to remove nitrate and convert it into nitrite from water (Logan, 2012). The application of microbial cells in biosensors is based on the technology of the cell to analyze contaminants and monitor the process. Due to the limited battery life and need to be recharged, microbial cells are suitable for use as electrochemical sensors and can be used (Rahimnejad et al., 2015).

8. Conclusion

The benefits of producing electricity using a microbial fuel cell are presented in following results which are deduced from this study:

1- Today, electricity generation from micro-organisms as a relatively new method, attracts scientists.

a) Generate electricity and energy from waste materials such as sewage, food and agricultural waste.

b) Generate electricity without harm to the environment, or even help the environment.

c) Suitable for areas where electricity, light, water, and sun is not available.

2- Some of consideration during examining and building a microbial fuel cell are as follows:

a) Finding the right microorganism.

b) Using more efficient intermediates to improve electron transfer from microorganism to anode. In the sense that part of the organic matter is oxidized and the electrons are transferred to the electrode. The role of mediator is very evident in electron transfer to electrode.

3- Since the first energy producers are bacteria, it is necessary to recognize and utilize bacterial species that can produce more electricity. The power output of a microbial fuel cell is limited by several factors such as the efficiency of electron transfer from microorganisms to electrodes, electrode surface area, reactor shape, receiver electron and electron, and oxygen reaction kinetics in a cathode chamber. Microbial fuel cell technology has limitations for sewage treatment because the process has not yet been commercially feasible. Therefore, it is suggested in future studies to consider the industrial aspects of this process and its use as an economical and cost effective process for the treatment of urban and industrial wastewater.

4- In the direct connection of the bacterium to the anode, due to the limited number of bacteria capable of sticking to the anode level, the flow rate is low. The addition of electrolyte-soluble electrolyte leads to more bacteria accumulation around the anodes, and as a result, more bacteria can have electrochemical activity. Penetration resistance controls the process and the flow in this method is low. So, the intermediate concentration should be increased.

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