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Department of Mechanical Power Engineering

Renewable Energy

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Class: 4th
Stage Subject: Renewable Energy
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Experiments No. (5)

REVERSIBLE PEM FUEL CELLS

Fuel cells can be thought of as alternative energy devices. They convert chemical energy into electrical energy. Hydrogen fuel cells do this very **cleanly**, with no toxic emissions, and very **efficiently**. Fuel cells do not generate energy out of thin air. They use hydrogen. Hydrogen is an outstanding carrier of energy. Hydrogen is nontoxic, renewable, easily obtained, and packed with energy. When it combusts with oxygen, it turns into water. This water can again be split into hydrogen and oxygen via electrolysis. The generated hydrogen can be combusted once again, thus undergoing a limitless cycle without toxic emissions. With a fuel cell, you can very efficiently convert hydrogen into electric current without combustion.

Fossil fuels are converted into usable energy through combustion. The energy released during combustion is inherently difficult to capture and inefficient. It also produces carbon dioxide, which cannot easily be converted back into a usable fuel. A fossil fuel combustion engine at a power plant is only about 30 to 40% efficient. This means it covert only 30 to 40% of the energy in the fossil fuels to usable energy (electricity). Engines in a car are even less efficient, at about 15 to 20% efficient. **Where does the rest of the energy go**? It escapes as heat, vibration, and noise.

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On the other hand, fuel cells can operate at 40 to 65% efficiency. This means that they can convert 40 to 65% of the energy in hydrogen into electricity. Experts even think that with advance in materials science and design, an efficiency of more than 75% is possible. Figure (1) compares the efficiencies of different energy conversion devices.

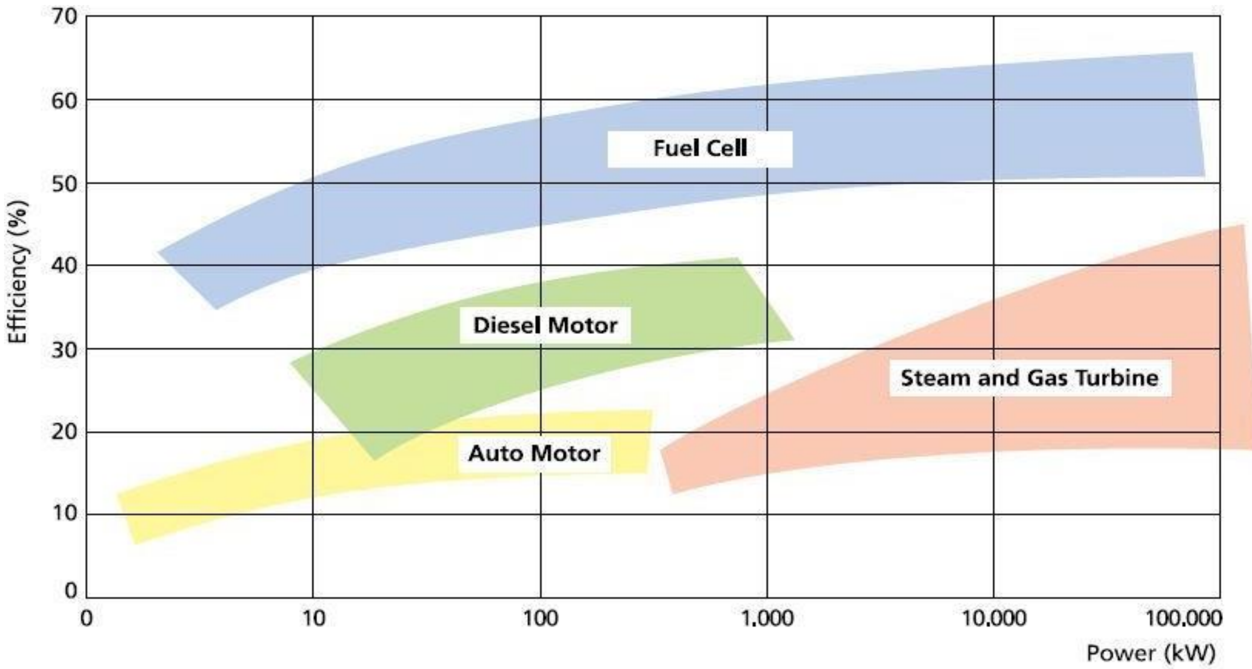

Figure (1)

One important consideration is the source of the hydrogen. Hydrogen can be obtained completely cleanly and renewably when it is generated via electrolysis of water powered by renewable electricity. This electricity could come from a solar cell.

There are many different types of fuel cells that use different chemicals.

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The fuel cell in this experiment kit converts hydrogen and oxygen into electricity and water, and vice versa. It is called a **reversible PEM fuel cell**. The abbreviation PEM refers to the membrane that separates the oxygen side from the hydrogen side of the cell. The letters PEM stand for **Proton Exchange Membrane**. A thin foil made of a special polymer serves as the membrane in your fuel cell, and it is located in the **MEA**, or **Membrane Electrode Assembly**, at the center of the cell. **Reversible** means that all processes can run in both directions. In other words, the cell can operate both as a fuel cell to combine hydrogen and oxygen into water, or as an electrolysis device to split water into hydrogen and oxygen.

In addition to the PEM, the MEA contains two **electrodes** on either side of the PEM. The MEA is sandwiched together with protective film, metal plates, and rubber gaskets in a clear plastic housing and held tightly together with four bolts (fig. 2).

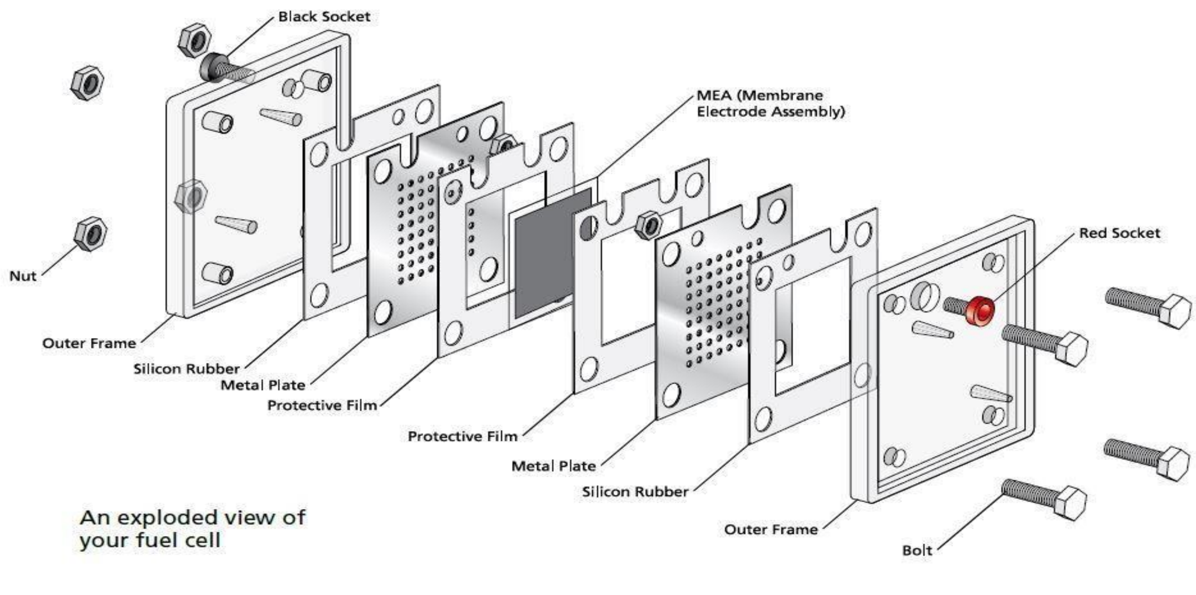

Figure (2)

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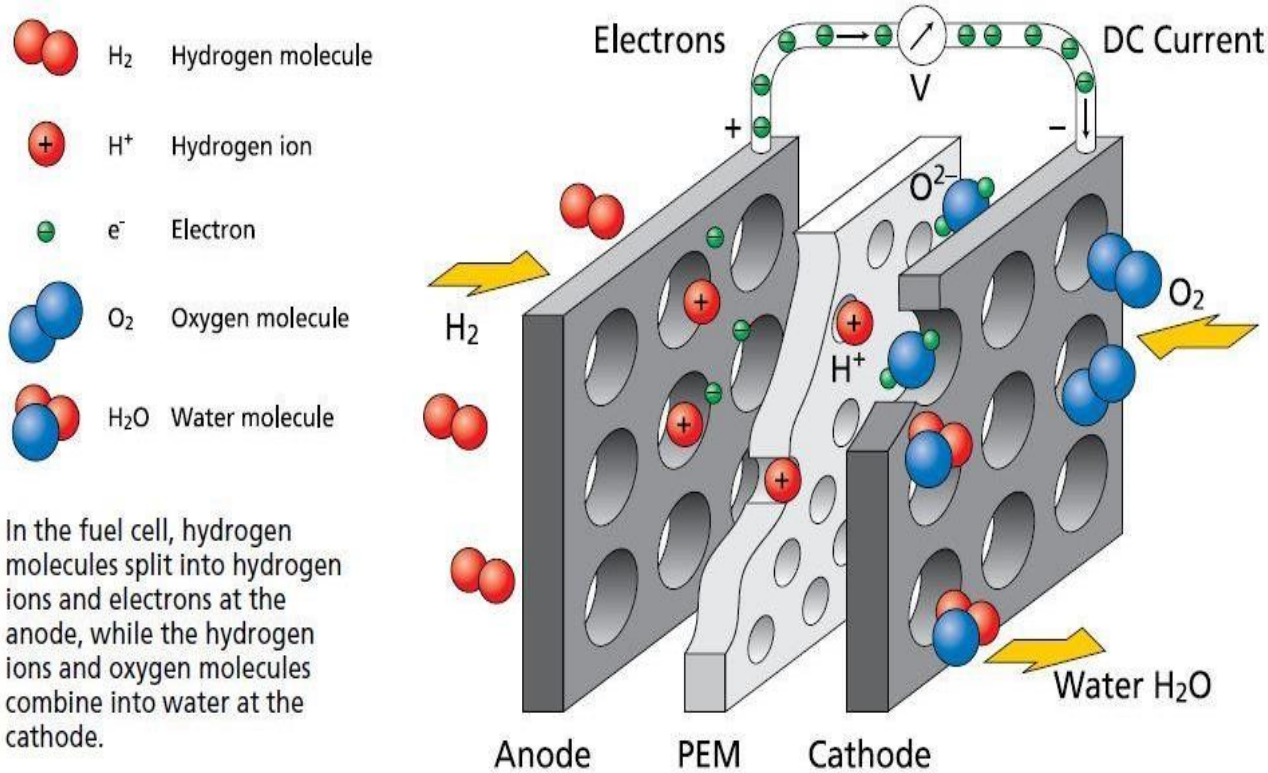
The two electrodes have different names since different things happen on them: the electrode on the hydrogen side is called the **anode(+)**, and the electrode on the oxygen side is called the **cathode(-)**. On the anode, electrically neutral hydrogen molecules (which come from the hydrogen tank) split into **electrons** and **hydrogen ions** with the help of a **catalyst**. A catalyst is a chemical that helps a reaction occur. The positively charged hydrogen ions migrate through the polymer membrane towards the negatively charged cathode, while the electrons travel

Through a circuit with an electrical load (for example, the motor) from the anode to the cathode. The hydrogen ions, also known as **protons**, are small enough to pass through the membrane's small holes, but the larger oxygen



ions cannot — hence the name Proton Exchange Membrane. The metal plates in the fuel cell conduct the electrons from the anode, through the circuit, to the cathode. On the cathode, the hydrogen ions react with the oxygen

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molecules (which come in from the oxygen tank) and the electrons that come through the external circuit to the cathode. The net result is the formation of water (fig. 3).

Figure (3)

In a sense, hydrogen and oxygen ions are being reassembled into water molecules. While it was necessary to put energy into the splitting of water molecules during electrolysis, now energy is released upon recombination of the ions. In this way, an electrical voltage is produced across the fuel cell. If you connect an electrical load (the electric motor) to the anode and cathode, electrons flow from the anode to cathode. In other words, an electric current flows and the motor runs. Since the conversion of hydrogen and oxygen takes place catalytically, the electrodes themselves do not change in these chemical reactions. The combustion is said to be ―cold‖ as no flames are involved. Nevertheless, heat is released in the process. Perhaps you can feel a warming of the fuel cell.

Chemically, the following reactions occur at the electrodes of the fuel cell:

Anode:

$$2\ H_2 \rightarrow 4\ H^+ + 4\ e^-$$

Electron Donation (Oxidation)

Cathode:

$$O_2 + 4\ H^+ + 4\ e^- \rightarrow 2\ H_2O$$

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Electron Uptake (Reduction)

Net Reaction: $2 H_2 + O_2 \rightarrow 2 H_2O$

The water production at the cathode (oxygen side) can be easily observed. Pay attention to it when the fuel cell generates current. The larger the current flow, the faster water is regenerated from the hydrogen and oxygen gases.

OBJECTIVES:

The purpose of this experiment is to demonstrate the use of fuel cell – electrolyzer system for the production of electricity.
The specific objectives of this experiment are;-

- In part (A) of this experiment (Electrolyzer):
1- Determine the relationship between irradiance intensity and the amount of hydrogen collected with time for each reading.
2- Determine the electrolyzer efficiency with different irradiance intensity.

$\%\eta$Electrolyzer = Hydrogen volume(m^3)* Hydrogen heating value($10.8*10^6$ J/ m^3) / Electrolyzer Operating Energy (J)

3. Plot the relationship between irradiance intensity and electrolyzer efficiency.

-In part (B) of this experiment (Fuel cell):
1. Determine the relationship between the amount of hydrogen supplied to a fuel cell and power generated from fuel cell.
2. Plot characteristic (energy-consumed time) curve for the fuel cell.

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3- Determine the fuel cell efficiency with different amount of hydrogen supplied.

$\%\eta$Fuel cell = Fuel Cell Generated Energy (J) / Hydrogen volume(m^3)* Hydrogen heating value($10.8*10^6$ J/ m^3)

4. Determine the overall efficiency of the system (fuel cell – electrolyzer) by using the following formula to estimate the efficiency:

Overall efficiency = Fuel Cell Generated Energy / Electrolyzer Operating Energy

MATERIALS:

1. Electrolyzer.

2. Fuel Cell.

3. Gas collecting columns.

4. Power supply (photovoltaic cell).

5. 2-wire leads with alligator clips.

6. Current and Voltage meter

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PRE-LAB QUESTIONS

1. In Part (A) of this experiment, you will change the irradiance intensity on the PV panel. What effect do you think this will have on the power supplied to electrolyzer?
2. In Part (B) of this experiment, you will change the amount of hydrogen supplied to fuel cell. What effect do you think this will have on the power output of the fuel cell and consumed time?

PROCEDURE

Part (A)

1. Fill the plastic basin about 2/3 full with distilled water.
2. Connect the solar panel wires to the electrolyzer. Make sure to connect the red wire to the red side of the cell and the black wire to the black side.
3. Set up the light on a ring stand. Turn on the light and position it about **10 cm** from the solar panel so that the light is shining directly onto it.
4. After a few seconds, you should start to see gas bubbles coming from the ends of the long tubes that are under the water in the basin.
5. Record the data(irradianc intensity, current, voltage, volume of hydrogen cullected and operating time)
6. Repeat step (3) with diferent irradiance intensity.

Part (B)

1. Turn off the light source.
2. Make sure the hydrogen plastic tube is connected to fuel cell.
3. Connect the electrical load wires to the fuel cell. Make sure to connect the red wire to the red side of the cell and the black wire to the black side.
4. Supply the hydrogen volume with the same amount for each step in part

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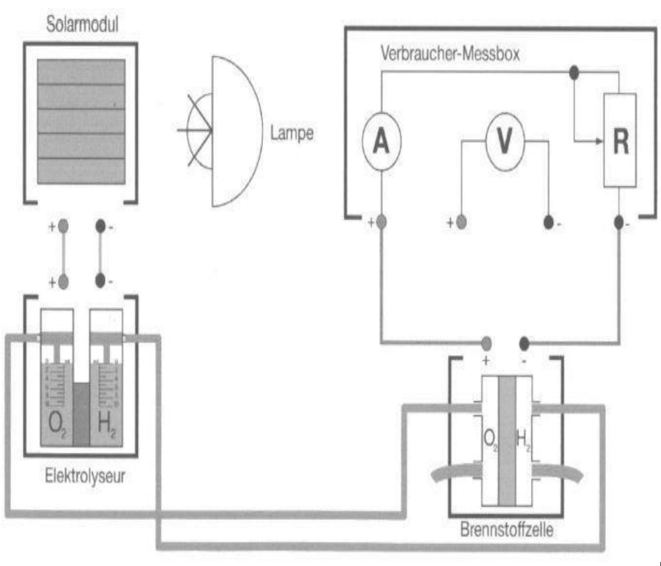
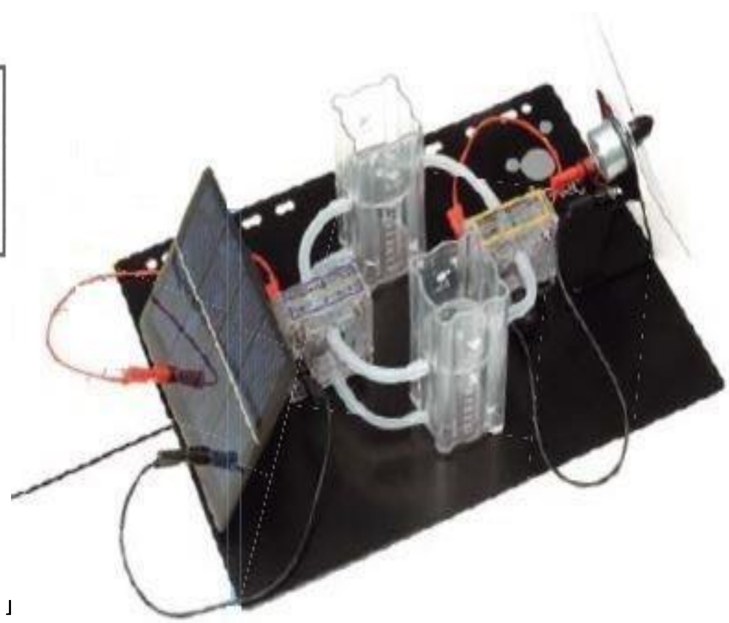
(A).

5. Record the data(volume of hydrogen supplied, current, voltage, and hydrogen consumed time)

6. Repeat step (4) with diferent hydrogen volume.





DATA

Part (A)

No.	Irradiance intensity(W/m^2)	Hydrogen volume(cm^3)	Source current(A)	Source Voltage(V)	operating time (Sec)	Source Energy(J)	$\%\eta_{Electrolyzer}$
1							
2							
3							
4							

Part (B)

No.	Hydrogen volume(cm^3)	current(A)	Voltage(V)	Consumed Time (Sec)	Energy(J)	$\%\eta_{Fuel\ cell}$
1						
2						

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3						
4						

PROCESSING THE DATA

1. Multiply current and voltage with time to determine the energy supplied to electrolyzer from solar panel in part (A).
2. Multiply current and voltage with time to determine the energy produced from fuel cell in part (B).
3. What is the relationship between energy supplied and the amount of hydrogen collected in part (A)?
4. What is the relationship between energy output and Consumed Time in part(B)?

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EXTENSIONS

1. Briefly explain how PEM fuel cell works and specify their advantages and disadvantages.
2. Plot the relationship between irradiance intensity and electrolyzer efficiency.
3. What is the effect of charging the electrolyzer at different power? Does it affect the discharge curves?
4. Plot characteristic (energy-consumed time) curve for the fuel cell.
5. Calculate the overall efficiency of the system .
6. Does the charging procedure affect the total efficiency of the system? Explain.