Application Area: Energy

Fuel Cells
Part 1 – What is a Fuel Cell?

Keywords

Fuel cell; Energy

Summary

A fuel cell is an electrochemical energy conversion device that produces electricity and heat by electrochemically combining a fuel (typically hydrogen) and an oxidant (typically oxygen). A fuel cell is able to convert chemical energy directly into electrical energy without the need for combustion, as long as fuel is supplied. As consequence, a fuel cell gives much higher conversion efficiencies than a conventional internal combustion engine, which is limited by the efficiency of the Carnot cycle.

A fuel cell does not necessarily need pure hydrogen for operation. A fuel cell system which includes a *fuel reformer* can use the hydrogen from any hydrocarbon fuel - from natural gas to methanol, and even gasoline. Since the fuel cells rely on electrochemical processes and not combustion, emissions from these types of a systems would still be much smaller than emissions from the cleanest fuel combustion processes.

The operation of a fuel cell results in much lower carbon dioxide emissions and negligible amounts of other pollutants like SO_x and NO_x, compared with fossil fuel-based technologies for the same power output.

Principle of a Fuel Cell

A fuel cell consists of two electrodes sandwiched around an electrolyte, as shown in Figure 1.

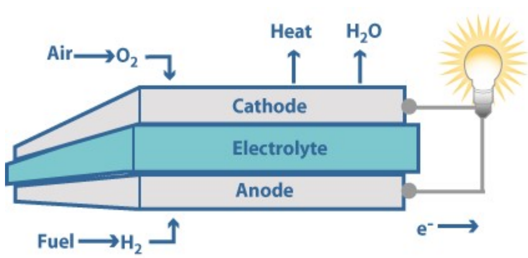

Figure 1 – Working principle of a fuel cell.

Hydrogen fuel is fed into the anode of the fuel cell. Oxygen (or air) enters the fuel cell through the cathode.

At the anode hydrogen is split into protons and electrons, Equation 1.

$$2H_2 \rightarrow 4H^+ + e^- \left(E^0_{anode} = 0\ V\ vs. SHE\right) \quad 1$$

The protons diffuse through the electrolyte to the cathode, and the electrons create a current flow in the circuit, which can be utilized before they reach the cathode.

Electrons recombine with protons and oxygen at the cathode, to form water (Equation 2).

$$O_2 + 4H^+ + 4e^- \rightarrow 2H_2O \left(E^0_{cathode} = 1.23\ V\ vs. SHE\right) \quad 2$$

The overall reaction is:

$$O_2 + 2H_2 \rightarrow 2H_2O \left(E^0_{cell} = 1.23\ V\ vs. SHE\right) \quad 3$$

From the equations above, one can see that the cell potential E^0_{cell} or open circuit potential (OCP) of a fuel cell under ideal conditions is 1.23 V.

In Figure 2, the performance (i-V characteristic) of a typical single fuel cell is shown, where the dashed line represents the ideal behavior and the solid line is the real behavior.

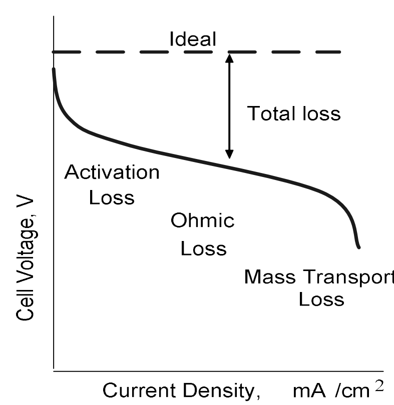

Figure 2 – i-V curve of a fuel cell showing the individual losses

From the curve it can be seen that the OCP is less than the ideal OCP and decreases (i.e., there is a voltage loss) with the increase in current density.

There are four major factors that contribute to these losses:

- Activation or kinetic loss, due to rate of the charge transfer reactions taking place at the surface of the electrodes.
- Ohmic or resistive loss, due to the resistance to the flow of electrons through the electrode materials, interconnects and the electrolyte and it is proportional to the current density.
- Mass transport, diffusion, or concentration loss, due to the change in concentration of the reactants at the surface of the electrodes as the reactants are consumed.
- Fuel crossover and internal currents. This type of loss (not shown Figure 2) is usually due to unused fuel passing through the electrolyte and stray currents due to electron conduction through the electrolyte. In principle, the electrolyte should transport only ions but sometimes, particularly in the case of direct methanol fuel cells (to be discussed in the next application note), fuel diffusion and electron conduction can result in significant losses

Fuel cell stack

As discussed in the previous section, a single fuel cell is only capable of producing a theoretical maximum of 1.23 V. After taking into account the various voltage losses in practice, the real voltage of a single fuel cell can be as low as 0.7 V. This voltage is not large enough for most applications. Therefore, to produce higher voltages in a fuel cell, more than one individual cells are linked together to form a fuel cell stack.

A fuel cell stack can be configured in various ways by connecting groups of cells in series and parallel thus providing the voltage, current, and power required for an application. The number of individual cells contained within one stack is typically greater than 50 and can vary significantly with the stack design. A schematic of a fuel cell stack is shown in Figure 3.

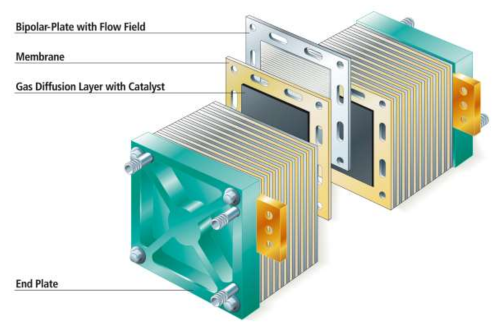

Figure 3 – Schematic overview of a fuel cell stack.

The basic building blocks of a fuel cell stack include the anode, the cathode and electrolyte with additional components required for electrical connections, insulation and the flow of fuel and oxidant. In addition, a fuel cell stack has current collectors and separator plates.

The current collectors conduct the electrons from the anode to the separator plate. The separator plates provide the electrical connection between cells and physically separate the oxidant flow of one cell from the fuel flow of the adjacent cell. Often, the two current collectors and the separator plate are combined into a single unit called a bipolar plate. The channels in the current collector serve as the distribution pathways for the fuel and oxidant.

Electrochemical characterization methods

Cyclic voltammetry (CV)

With CV, valuable information regarding the kinetics of the various components can be obtained. With the Metrohm Autolab potentiostats/galvanostats (pgstats), in combination with the SCAN250 and ADC10M modules, it is possible to perform analogue sweeps with scan rates up to 250 kV/s for measuring fast processes such as hydrogen adsorption.

Linear sweep voltammetry (LSV)

LSV can be used for determining the i-V characteristics of a fuel cell. It involves sweeping the potential of the working electrode and measuring the current response. With the Metrohm Autolab pgstats it is possible to achieve sweep rates down to a few V/s.

Electrochemical impedance spectroscopy (EIS)

Electrochemical impedance spectroscopy (EIS) has been successfully applied to the study of fuel cells. One of the advantages of EIS over DC techniques is the possibility of using very small amplitude signals without significantly disturbing the measured properties. With the Metrohm Autolab pgstats equipped with a FRA32M module and a Metrohm Autolab Booster10A or a Booster20A current booster, it is possible to perform EIS measurements at high current densities up to 20A.

For measurements at even higher current densities, external equipment like programmable electronic loads can be connected and controlled by the Autolab software.

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For more information

Additional information about this application note and the associated NOVA software procedure is available from your local **Metrohm distributor**. Additional instrument specification information can be found at **www.metrohm.com/en/products/electrochemistry**.