Autolab Application Note FC01

Fuel Cells
Part 1 – What is a Fuel Cell?

Keywords

Fuel cell;

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). As the fuel cell is able to convert chemical energy directly into electrical energy without the need for combustion as long as fuel is supplied, it gives much higher conversion efficiencies than a conventional combustion engine that is limited by the efficiency of the Carnot cycle. The higher efficiency also results in much lower carbon dioxide emissions and negligible amounts of SOx and NOx (when reformed fuel is used) 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. Hydrogen fuel is fed into the anode of the fuel cell. Oxygen (or air) enters the fuel cell through the cathode.

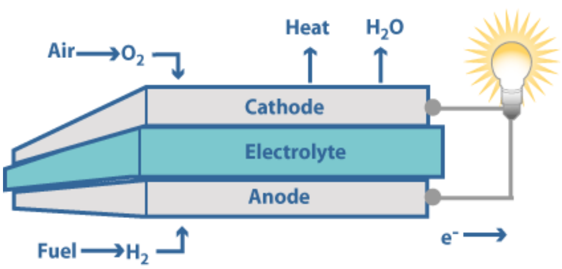

Figure 1 – Working principle of a fuel cell

At the anode hydrogen is split into protons and electrons. 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 return to the cathode. They recombine with protons and oxygen to form water.

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 cell relies on chemistry and not combustion, emissions from this type of a system would still be much smaller than emissions from the cleanest fuel combustion processes.

Basic reactions for a H_2/O_2 fuel cell

Anode reaction:

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

Cathode reaction:

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

Overall reaction:

$$O_2 + 2\,H_2 \rightarrow 2\,H_2O$$

From the equations above, one can see that the 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 cell is shown, where the dotted line represents the ideal and the solid line is the real behavior.

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

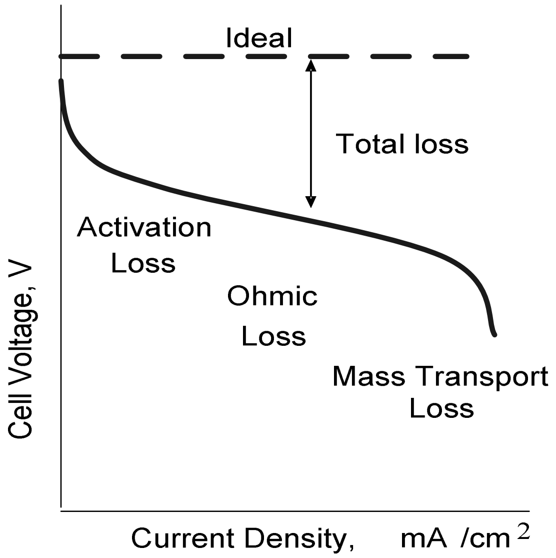

Figure 2 – i-V curve of a fuel cell showing the individual losses

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 used up
- Fuel crossover and internal currents: This type of loss (not shown in the above figure) 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.

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.

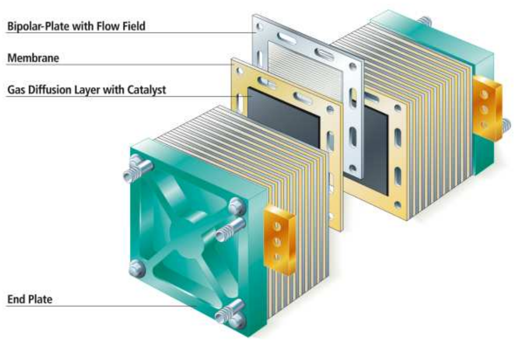

Figure 3 – Schematic overview of a fuel cell stack

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 characterrisation methods

Cyclic voltammetry (CV)

With CV, valuable information regarding the kinetics of the various components can be obtained. With the AUTOLAB potentiostat/galvanostat system in combination with the SCAN250 and ADC10M modules it is also 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 AUTOLAB system 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 AUTOLAB FRA2 system combined with the 10 A or 20 A current booster, it is possible to perform EIS measurements also at high current densities.

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

Date

1 July 2011