Autolab Application Note FC02

Fuel Cells
Part 2 – Types of Fuel Cells

Keywords

Fuel cell;

Summary

In the previous application note, the principle of a fuel cell was described and some of the problems in their use as viable technology were discussed. To overcome the various technical problems, many different fuel cell types have been developed. In this application note, proton exchange membrane, direct methanol and solid oxide fuel cells are discussed in more detail.

Proton Exchange Membrane (PEMFC)

Also known as the Polymer Electrolyte Membrane Fuel Cell, this type of fuel cell have as electrolyte a thin conductive plastic sheet (proton conducting membrane or a conducting polymer, such as perfluorosulphonic acid polymer), sandwiched between two porous electrodes impregnated with an active catalysts (a highly dispersed metal alloy particles, typically platinum based). The back of the electrodes are coated with a hydrophobic compound, such as Teflon, which provides a gas diffusion path to the catalyst layer.

Within the cell, the following electrochemical reactions take place:

Anode reaction (E_0 = 0.00 V):

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

Cathode reaction (E_0 = 1.23 V):

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

Overall reaction:

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

The protons produced at the anode will solvate with water molecules and diffuse through the membrane to the cathode.

PEMFC operates on hydrogen and, if a hydrocarbon such as natural gas is used as a fuel, it is reformed to form H_2 by the following reactions:

$$CH_4 + H_2O \rightarrow 3\,H_2 + CO$$

$$CO + H_2O \rightarrow H_2 + CO_2$$

The Pt catalyst at the anode can tolerate only a few ppm of CO at its operating temperature (80 °C). To prevent electrode poisoning, the unconverted CO needs to be removed to concentrations below 10 ppm before introducing it in the fuel cell.

PEMFC system advantages:

- Operation at high current densities
- Ability to start very quickly
- Compact and light weight design
- No corrosive fluid spillage hazard as the only liquid present in the cell is water

PEMFC system challenges:

- CO tolerance of the anode
- Improvement in cathode kinetics
- Need for higher temperature membranes
- Cheaper membranes and membrane electrode assemblies

Direct Methanol (DMFC)

These cells resemble the PEM cells as both use a polymer membrane as electrolyte. However, in the DMFC, liquid methanol is oxidized to form protons, eliminating the need for a fuel reformer.

Anode reaction:

$$CH_3OH + H_2O \rightarrow CO_2 + 6\,H^+ + 6\,e^-$$

Cathode reaction:

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

Overall reaction:

$2\,CH_3OH + 3\,O_2 \rightarrow 2\,CO_2 + 4\,H_2O$

DMFC can typically operate in a temperature range of 50-100 ℃, making it attractive for small to mid-sized applications such as cellular phones and laptops.

One of the main problems in the commercial application of the DMFC is the slow kinetics of the methanol oxidation reaction resulting a relatively low performance compared to the hydrogen fuelled PEMFC.

Another problem is the methanol crossover, the permeation of methanol through the polymer membrane to the cathode where it is oxidized reducing the cathode potential. This occurs because the cathode catalyst, typically Pt, is electro-active to methanol oxidation.

Direct Methanol System advantages:

- Liquid fuel results in high storage efficiency

Direct Methanol System challenges:

- Improvement in methanol oxidation kinetics
- Improvement in cathode kinetics
- Higher temperature membranes with lower crossover

Solid Oxide (SOFC)

The solid oxide fuel cells or SOFC are used in high-power applications such as large electricity generating stations.

Anode Reaction:

$H_2 + O^{2-} \rightarrow H_2O + 2\,e^-$

$CO + O^{2-} \rightarrow CO_2 + 2\,e^-$

Combined Anode Reaction:

$H_2 + CO + 2\,O^{2-} \rightarrow CO_2 + H_2O + 4\,e^-$

Cathode Reaction:

$O_2 + 4\,e^- \rightarrow 2\,O^{2-}$

Overall Reaction:

$H_2 + O_2 + CO \rightarrow H_2O + CO_2$

In a SOFC, a hard ceramic material is used as electrolyte, allowing operating temperatures up to 1000 ℃. The electrolyte consists of a solid, nonporous metal oxide, typically Y_2O_3 stabilized ZrO_2 with the anode made from $CoZrO_2$ or $NiZrO_2$, while the cathode is made from Sr doped $LaMnO_3$. The cell operates at 650 to 1000 ℃ allowing the conduction of oxygen ions through the electrolyte.

CO and hydrocarbons such as CH_4 can also be used as fuels in an SOFC. Because of the high temperatures within the cell, the water gas shift reaction and the steam reforming reaction will become possible:

$CO + H_2O \rightarrow H_2 + CO_2$

$CH_4 + H_2O \rightarrow 3\,H_2 + CO$

The resulting H_2 is easily oxidized at the anode.

SOFC advantages:

- Because of the solid state components, the SOFC can be, in principle constructed in any configuration
- No liquid electrolytes will eliminate the corrosion and electrolyte management problems
- Internal reforming can be achieved due to operating temperature greater 600 ℃
- High temperatures (1000 ℃) exhaust heat from the SOFC can be used for the generation of steam for cogeneration purposes
- The high temperature helps to achieve fast reaction kinetics without requiring any precious materials

SOFC system challenges:

- The high temperature of the SOFC places stringent requirements on the materials of construction
- The materials that can be used in the SOFC need to be chemically stable in extreme oxidizing and/or reducing conditions. They also require good thermo-mechanical properties at high temperatures
- The cell components must be capable of withstanding thermal cycling

Table 1 provides a summary of the most important properties of the different types of fuel cells.

Type	**Fuel**	**Charge carrying ion**	**Operating temperature (°C)**
Alkaline (AFC)	H_2 (pure)	OH^-	50-200
Polymer electrolyte (PEMFC)	H_2	H^+	30-100
Direct methanol (DMFC)	CH_3OH	H^+	20-90
Phosphoric acid (PAFC)	H_2	H^+	220
Molten carbonate (MCFC)	CH_4, H_2, CO	CO_3^{2-}	650
Solid oxide (SOFC)	CH_4, H_2, CO	O^{2-}	500-1000

Table 1 – Comparison table of common fuel cell types

Date

1 July 2011