Hydrogen fuel cells and photochemical etching

Introduction

In 1874, the French novelist Jules Verne wrote: “I am convinced that hydrogen and oxygen, the two elements that combine to form water, will one day – either together or as single entities – be an inexhaustible source of heat and light of an intensity of which coal is not capable.” A century and a half later, Verne’s vision is turning into reality.

The development of renewable energy sources and energy storage technologies has accelerated in recent years driven by the need to decarbonize the global economy and avoid the catastrophic effects of climate change. One technology in particular has the potential to drastically reduce our dependence on fossil fuels while also offering significant advances in mobile power. This technology is the hydrogen fuel cell.

The principle of fuel cells was invented in 1838 by the German scientist Christian Schönbein. In the following year, the use of hydrogen and oxygen in fuel cells was uncovered by the Welsh scientist Sir William Grove who in 1843 produced and demonstrated the first fuel cell unit. Progress in the development of fuel cells was very slow at the time due to the invention of the combustion engine. Interest in fuel cells was re-ignited in the 1950s leading to the development of proton exchange fuel cells in 1959 by General Electrics in the US for use by NASA. The oil crisis in the 1970s prompted further work to develop new types of fuel cells. Today, major car manufacturers such as Toyota, Honda and Hyundai are already making hydrogen cars available to the public.

While fuel cells can be an important element in achieving cleaner transportation, they can also be used in consumer electronic devices. Fuel cells can be scaled to a size that will allow them to be embedded in laptops, tablets and other electronic devices.

Hydrogen is considered a clean fuel because it can be produced from water using renewable energy or from fossil fuels combined with carbon capture and storage technology.

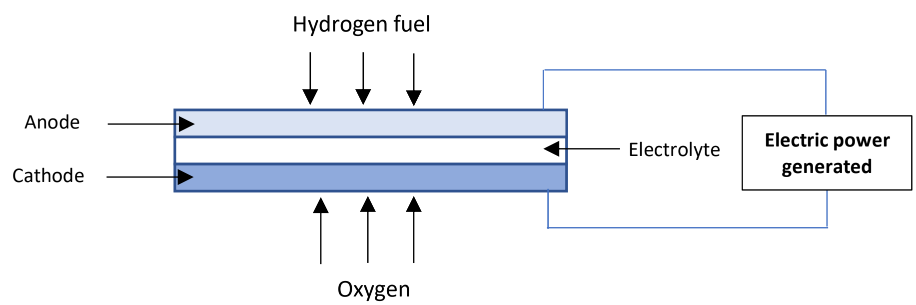
How does a fuel cell work?

In basic terms, a fuel is a chemical substance that releases a large amount of energy when reacted with oxygen. This energy can be harnessed by converting it into useful forms such as heat, movement or electricity. When a fuel reacts with oxygen, the existing chemical bonds within the fuel and oxygen molecules are broken in a process that requires energy (an endothermic process). Then, the atoms within these molecules are rearranged and new chemical bonds between the atoms are created in a process that releases energy in the form of heat (an exothermic process). The energy released in the second process is much larger than the energy consumed in the first process, so the net result is that a large amount of energy is generated.

In a conventional energy system such as the internal combustion engine, a carbon-based fuel is reacted with oxygen to generate heat and pressure, which in turn are converted into useful mechanical (movement) energy. The useful energy is only 30-40% of the potential chemical energy stored in the fuel and oxygen, so these systems are characterized by significant energy losses.

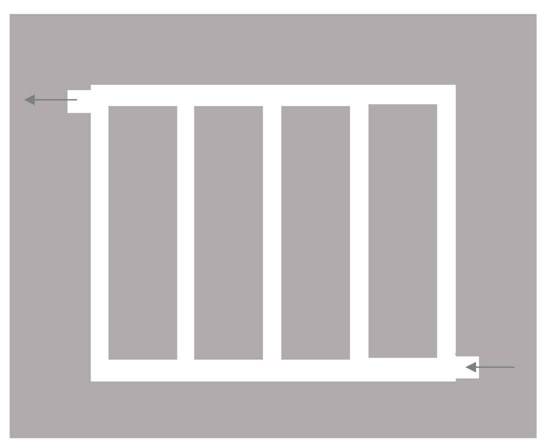
Fuel cells, on the other hand, convert the chemical energy of a fuel directly into useful electrical energy, thus achieving very high efficiencies. Moreover, if hydrogen is used as the fuel, the only waste emission is water vapour.

In a hydrogen fuel cell, hydrogen serves as the fuel and is reacted with oxygen to produce water, heat and electrical energy. The cell consists of two electrodes and an electrolyte sandwiched between the two electrodes, as shown in the figure below. Hydrogen reacts at the anode generating a proton and an electron. The proton travels through the electrolyte to the cathode while the electron travels through the external circuit to the cathode, thus creating an electric current. The proton and the electron then react with the oxygen at the cathode producing water vapour. Electric power is generated by the flow of electrons from the anode to the cathode.



The electrodes are usually made of small platinum particles (which act as a catalyst to promote the reaction) supported on porous carbon. However, due to a number of disadvantages including the high cost of platinum, other electrode materials are now being developed.

One of the main types of fuel cells is the Polymer Electrolyte Membrane (PEM) fuel cell, also known as the Proton Exchange Membrane fuel cell. As the name suggests, PEM fuel cells employ a polymer membrane as the electrolyte. The major potential application of PEM fuel cells is as replacement for internal combustion engines in light-duty vehicles.



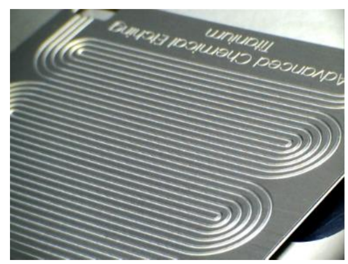
A fuel cell unit is made up of a series or stack of cells. Cell interconnection can be achieved using bipolar plates. In this method, a bipolar plate is used to make connections all over the surface of one cathode and the anode of the next cell. In addition to connecting adjacent cells, the bipolar plate serves as a means of feeding hydrogen to the anode and oxygen to the cathode. Grooves or channels on the surface of the bipolar plate allow the gases to flow over the surface of the electrodes. These channels are designed to offer a large surface area for adequate gas flow whilst at the same time maintaining a sufficient contact surface area between the bipolar plate and the electrodes to which it is connected.

Manufacturing fuel cell plates

While the potential offered by fuel cell technology is very promising, a number of challenges remain to be resolved. Research is accelerating to address these challenges and advances in manufacturing techniques will make it possible to produce fuel cells in a wide array of metals and sizes.

Bipolar plates are usually made of graphite, metal alloys, or composite materials. While graphite is lighter than any metal and is not prone to corrosion, it is also brittle and porous and has significantly lower electrical and thermal conductivities compared to metals. Metals, on the other hand, are characterized by very high conductivities. Their corrosion resistance can be enhanced using conductive coatings. For example, titanium is a light metal with very good corrosion resistance which can be further improved by coating the surface with a titanium nitride protective finish. Aluminium, which is another attractive metal for fuel cell plates due to its low density (40% lighter than titanium), can be coated with chromium nitride. Other metals can be used such as copper and stainless steel and various surface treatment and coating techniques are also available to deposit a wide range of coating materials on metal plates.

Photochemical etching is an important fabrication process that can be used to produce flow channels on metallic fuel cell plates. Different flow patterns can be etched such as parallel, serpentine, or grid channels without affecting the physical and chemical properties of the base metal.



Advanced Chemical Etching (ACE) can manufacture photochemically etched fuel cell flow plates in a range of metals such as aluminium, titanium or stainless steel. The process can be used to produce different prototype designs for the purpose of optimizing the flow pattern. The process can accommodate low, medium or large volume production. Metal plates up to 2 mm in thickness can be etched. The channel width to depth ratio is typically 2-to-1. Metal plates can be etched from both sides simultaneously.

Photochemical etching can also be used to create micro-channels for miniaturized fuel cells. There is currently a great deal of interest in developing miniaturized fuel cell technology driven by advances in microfabrication technologies and also by the need to improve the performance of energy storage technologies for portable electronic devices. Photochemical etching of metal plates offers a cost-effective way of producing macro- or micro-channels for fuel cells.

Whilst it is possible to produce fuel cell plates in various stainless steel alloys using conventional photochemical etching, two innovative processes developed at ACE now enable the company to manufacture fuel cell plates in aluminium and titanium alloys. Aluminium and titanium are particularly difficult to etch, but the new etching processes allow ACE to achieve very high levels of quality and consistency putting ACE at the forefront of this exciting technology.

The future

On the 2nd of March 2020, the UK Parliament launched the UK Hydrogen Taskforce, a cross-industry coalition comprising of ten energy and engineering heavyweights including Arup, Baxi, BP, ITM Power, and Shell. The aim of the taskforce is to drive investment in hydrogen. The view is that hydrogen will have a major role in delivering the UK government's net zero target – a legislation to commit the UK to a legally binding target of achieving net zero carbon dioxide emissions by 2050.

At ACE, we recognize our role in enabling new technologies by working closely with the key players in the rapidly growing renewables industry. Through innovation and continuous improvement, ACE will continue to expand the boundaries of the photochemical etching industry, enabling further advances in technology and allowing ACE to contribute to solving society's biggest challenges.