

Fire and Explosion - General

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FUEL CELLS

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Introduction

1. The purpose of this note is to provide an introduction to fuel cells. It provides information on the principles of operation, the different types of fuel cell being developed and the associated fuels. It also provides information on current and future applications.

Basic principles of fuel cell operation

2. Water can be electrolysed into hydrogen and oxygen by passing an electric current through it. Conversely, when hydrogen and oxygen combine to produce water, a small electric current is produced. This is the basic principle of the fuel cell. The current production is small but can be enhanced by using catalysts, raising the temperature and increasing the electrode area and porosity. To increase the voltage many cells are connected in series to form a stack. Bipolar plates sit between the electrodes to connect the entire electrode surfaces while still allowing gas flow.

3. Fuel cell technology provides clean, efficient and quiet operation and is being promoted for a range of operations, particularly motor vehicles but also mobile phones, laptop computers, power stations, combined heat and power applications, including domestic-scale CHP. The hydrogen can be supplied either in liquid or gaseous form, or in a hydrogen rich fuel such as methanol or petrol. In most cases, the oxygen is taken directly from the air.

4. Many different manufacturers are developing fuel cell prototypes and many have reached the demonstration phase. Within the UK, Woking Borough Council installed a 200 kW fuel cell CHP at a leisure centre in October 2001 and Transport for London will be trialling three fuel cell buses in 2003. (Note these fuel cell vehicles should not be confused with prototype direct combustion engines which use hydrogen directly as fuel.)

Fuel cell types

5. The main types of fuel cells are shown in table 1 and are described in more detail below.

Alkaline Electrolyte Fuel Cells

6. Alkaline Electrolyte Fuel Cells were used in the Apollo space missions in the 1970's, when they were fuelled with pure hydrogen and oxygen. They have not been developed for wider use because of the problem of carbon dioxide reactions with the alkaline electrolyte. For an alkaline fuel cell to work over a long period it would be essential to remove the carbon dioxide from the air supply. This can be done but increases the size, complexity and the costs. So although the alkaline fuel cell is itself comparatively cheap, the fuel supply system makes it expensive. However, the alkaline fuel cell may become a more viable option in the future as electricity from renewable sources could be used to electrolyse water. The pure gases could then be fed into alkaline fuel cells to turn them back into electricity as needed.

Proton Exchange Membrane Fuel Cells (PEM)

7. The PEM Fuel cell has been widely developed for vehicle and mobile systems because it is compact, has a solid electrolyte and operates at comparatively low temperatures (with the aid of sophisticated electrodes and catalysts). The fuel for the cell is essentially limited to hydrogen. Other fuels such as methanol can be used but the reaction rate is slow and there are problems with CO poisoning of catalysts. Most mobile systems are currently run on hydrogen gas from cylinders. Air can be used for the oxygen supply.

Phosphoric acid fuel cells (PAFC)

8. These have found commercial application primarily as emergency power back-up systems in America, Japan and Europe. The reaction rate is boosted by means of platinum catalysts and a temperature of 200°C. The hydrogen feed problem is solved by 'reforming' natural gas to hydrogen and carbon dioxide but this adds to the costs, complexity and size of the cell. Nevertheless they are reported to be very reliable and require little maintenance. Some of the costs can be reclaimed by utilising the by-product heat energy.

Solid Oxide Fuel Cells (SOFC)

9. The Solid Oxide Fuel Cell operates in the region of 600 to 1000°C. This means that high reaction rates can be produced without the need for expensive catalysts, and that gases such as natural gas can be internally reformed within the fuel cell, without the need for a separate unit. The high temperatures solve some problems but create others. The ceramic materials used for the cell are expensive and extra heating and cooling plant is needed. However, the by-product heat energy can be utilised for other purposes (ie combined heat and power) which can offset some of the costs.

Molten carbonate fuel cell (MCFC)

10. The electrolyte consists of a molten mixture of hot, corrosive lithium, potassium and sodium carbonates. The interesting feature is that in contrast to the alkaline fuel cell, the molten carbonate fuel cell needs carbon dioxide to operate. The high temperature (650°C) means that a good reaction rate is obtained with a comparatively inexpensive nickel catalyst. Like the SOFC, it can use gases such as methane directly, without an external reformer. Again the by-product heat energy allows the system to be used for combined heat and power.

Fuelling fuel cells

11. Prototype (PEM) fuel cell vehicles operate at comparatively low temperatures and must have a pure hydrogen feed. They are currently fuelled by compressed hydrogen gas in cylinders or small tanks. Some PEM prototypes are fitted with an onboard reformer and can also be fuelled by methanol (or similar). Liquid hydrogen can also be used but a pre-heating system is needed.

12. SOFC and MCFC systems are being developed for stationary CHP type applications. These high temperature fuel cells can use practically any hydrocarbon based fuel as it is reformed in situ by the high temperatures. However, the fuels still require some pre-treatment such as desulphurisation to below 0.1 ppm sulphur to prevent catalyst poisoning.

Sources of hydrogen

13. Hydrogen gas in bulk is generally derived from hydrogen rich hydrocarbons such as methane, propane, butane, petroleum, methanol, ethanol etc. The standard method is steam reforming. Other methods include partial oxidation, direct hydrocarbon oxidation (dry

reforming) and pyrolysis or thermal cracking. Hydrogen is also produced as a by-product of other processes such as chlorine production.

14. The use of hydrocarbons to produce hydrogen or as a direct fuel for fuel cells is seen as a comparatively short term solution. Although the emissions from fuel cells are seen as environmentally acceptable, the production of hydrogen from other fuels is less so. Therefore, the aim is to use renewable energy technologies to produce hydrogen. For example, electricity generated by wind or solar power could be used to electrolyse water to produce hydrogen. The production of hydrogen in this way is seen as one method of storing surplus energy produced by renewable energy methods.

Hydrogen storage

Storage of hydrogen as a gas

15. Storing hydrogen gas in pressurised cylinders or tanks is the most technically straightforward method, and is widely used in industry and research. This method is also well suited for storing the hydrogen from electrolyzers. (There is a hydrogen generation and storage plant at Munich airport.)

16. Most hydrogen gas in cylinders is supplied at pressures of about 200 bar. However, if this pressure is used for on-board vehicle fuel tanks, then the weight and volume penalties are high. Consequently, higher storage pressures, potentially up to 600 bar are being investigated

Storage of hydrogen as a liquid

17. Hydrogen can be stored as a liquid at about 22K and 3 bar. The weight and volume penalties for on-board vehicle fuel tanks are far less than for gaseous hydrogen. Liquid hydrogen tanks have already been developed for cars, to fuel internal combustion engines (not fuel cells) and the first liquid hydrogen filling station was opened in Hamburg, Germany in 1999.

18. The main drawback associated with cryogenic hydrogen is that the liquefaction process is very energy intensive. The energy required to liquefy the gas is about 40% of the fuel value of the hydrogen. Therefore the use of liquid hydrogen storage is not generally regarded as an energy efficient option.

Metal hydride stores

19. Other methods of hydrogen storage are under development such as metal hydride storage. Certain metals, particularly alloys of titanium, iron, manganese, nickel, chromium can react with hydrogen to form a metal hydride in a controlled easily reversible reaction. The main advantage is safety as the gas is held at a comparatively low pressure of 2 bar but it is suitable for applications where only small quantities of hydrogen are needed. With larger systems, heating during filling, and cooling during release of the hydrogen becomes a problem. Refill times are long (one hour for about 5 kg) and hydrogen of a very high purity is needed to avoid irreversible metal contamination.

20. An alternative to reversible metal hydrides are alkali metal hydrides which react with water to release hydrogen, and produce a metal hydroxide. This is a simple way of producing hydrogen and is not expensive. Unfortunately, a disposal route must be found for the metal hydroxide solution and the energy required to manufacture the hydride is greater than that released in the fuel cell.

Comments

21. As with many other power generation systems, the main fire and explosion hazards of fuel cells are those associated with the fuel supply. Fuels such as petrol, LPG and methane are widely and routinely used by the public. Their use is established and is well controlled and regulated by many standards and codes of practice.

22. The use of hydrogen as a fuel for fuel cells will require new safety standards. Work on several international standards has started. The International Standards Organisation (ISO) is developing standards for the storage of hydrogen on board vehicles through its ISO TC197 working group. The International Electrotechnical Commission working group IEC/TC105 has carried out some preliminary work on the preparation of standards for fuel cells. In Europe, the European Integrated Hydrogen Project (EIHP) has been set up to harmonise standards, codes of practice and filling procedures for refuelling stations. However, UK involvement in all these projects has been limited.

Table 1 The main types of fuel cells

Type	Electrolyte	Operating temperature (°C)	Development status	Applications
Alkaline fuel cell (AFC)	Potassium hydroxide	50-200	Fully developed for space systems. Transport systems available for initial demonstrations	Space, transport
Proton exchange membrane (PEM) also known as the solid polymer fuel cell (SPFC)	Sulphonic acid incorporated into a solid polymer membrane	50-100	250kW CHP systems and several cars and buses being demonstrated, but not yet commercial. Most car companies are investing in this technology.	Commercial and residential CHP, distributed power, portable power, transport.
Solid fuel oxide cells (SOFC)	Ceramic, solid oxide, zirconia (Ceria-gadolinia in research for lower operating temperatures.)	500-1000	Tubular systems available for demonstration; planar technology still under development.	Commercial and residential CHP, power generation, ship propulsion, trains.
Molten carbonate fuel cell (MCFC)	Molten lithium carbonate	630-650	250kW systems being demonstrated, but further R&D needed for higher powers.	CHP, power generation, ship propulsion, trains.
Phosphoric acid fuel cell (PAFC)	Phosphoric acid	190-220	200kW systems offered for sale, but not commercially competitive in the UK.	CHP, power generation

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