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Alkaline Fuel Cell Engineering and Testing

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Abstract

A fuel cell is a device that directly converts the chemical energy of reactants (a fuel and an oxidant) into low d. c. electricity [1]. Used in conjunction with other sustainable energy options, hydrogen and fuel cell technology can provide a realistic alternative to fossil fuels. Although research is continuing in many areas we are no closer now to commercialisation than ten to twenty years ago. This is due to a number of key reasons, some of which include efficiency, scale, accessories and power output.

This paper outlines the benefits that could be derived from switching to a hydrogen based economy and the commercialisation of hydrogen fuel cells as a clean and environmentally friendly alternative. It looks in general at the fuel cell, outlines its origin, how it operates, and the wide range of fuel cells available. The paper also compares the alkaline fuel cell (AFC) with the proton exchange membrane fuel cell (PEMFC) as options for low temperature applications. In particular, the paper focuses on the research being conducted by the Dublin Institute of Technology into alkaline fuel cell technology and outlines the systems capabilities and limitations.

Keywords:

1. Introduction

Peak oil means the end of cheap oil. In contrast to this, demand for oil is increasing as energy intensive industrialised economies are cornering available supplies and pushing up fuel prices. In the last four years the price of oil has jumped drastically from 20 dollars to over 70 dollars a barrel with no signs of a fall off in this rising trend. Another major economic concern centres on the fact that fossil fuel reserves are located in volatile areas of the world and oil is being used as a political and economic weapon that could result in world recession as demand increases and supplies decrease.

Environmentalists would suggest that economic problems with the carbon economy coupled with rising emissions concerns resulting in climate change, global warming and the greenhouse effect, should spell a new beginning for the hydrogen based economy and other alternative energy options for the production of electricity, such as wind, solar, wave, and renewable sustainable supplies.

It was with this in mind that the European Commission Research Directorate-General in March 2004 called for deeper co-operation between research groups through co-ordination of resources, cross fertilisation of ideas, and sharing of results in an effort to speed up commercialisation of hydrogen and fuel cell technology. It is recognised at European level that hydrogen and fuel cell technologies are core long-term technologies for realising global sustainable energy. Hydrogen compliments electricity and together they represent the most promising mass market energy sectors for delivering sustainable energy for stationary heat, power and transport in the long term [2].

1.1 Overview

William Groves invented the fuel cell in 1839, years before the internal combustion engine was invented. His experiments centred on the use of platinum electrodes connected in series, immersed in sulphuric acid and the process of reverse electrolysis.

In the 1960's one of Groves successors, Francis Bacon a pioneer of alkaline fuel cell development found prominence when NASA decided to use fuel cell technology to power its Apollo space program [1]. The alkaline fuel cell was selected because of its power generating efficiency that approached 70% [3]. A cell with a high efficiency uses less fuel to generate the same amount of electricity [4]. Another advantage was the cell's low cost (use of non-noble metal catalysts) and also by maintaining the pH of the water exiting the cell between 6 and 8 the water was drinkable, this was a major weight saving consideration [1]. As part of this program the alkaline fuel cell powered 106 missions and clocked up more than 82,000 service hours for NASA [5].

All this development should have spelt the beginning of the hydrogen economy but with cheap and abundant fossil fuel readily available and fuel cells still experiencing technical difficulties the opportunity to switch to a renewable, sustainable, and environmentally friendly energy alternative was set aside.

As the space program pioneered most investment into fuel cell research, when NASA switched allegiance from the alkaline fuel cells to the dry electrolyte Solid Polymer Fuel Cell (SPFC) developed by General Electric, American interest in alkaline fuel cell technology ceased. Later in the 1990's Ballard Technologies with its newly named Proton Exchange Membrane Fuel Cell (PEMFC) scored great success in financing its technology development program and attracting big automakers as strategic partners. This left only a few players remaining in the AFC field world wide, mainly based in Europe [6].

1.2 Fuel Cells

A fuel cell converts chemical energy into d.c. electrical energy [7]. This can be achieved by various ways and means depending on the fuel and oxidant, direct or indirect fuelling or type of electrolyte and temperature of operation [8]. Table 1. is a compilation of existing fuel cell solutions, and lists fuel type, electrolyte,

Fuel Cell Type	Electrolyte	Anode Gas	Cathode Gas	Electric Power	Efficiency	Applications
Proton Exchange Membrane, (PEM)	Ion Exchange Membrane	Hydrogen	Pure or Atmospheric Oxygen	50 to 250 kW	35-60%	Vehicle Applications
Direct Alcohol Fuel Cell, (DAFC)	Polymer Membrane	Methanol Solution in Water	Atmospheric Oxygen	Up to 10 kW	35-40%	Vehicle Applications and small Heat and Power
Alkaline Fuel Cell (AFC)	Potassium Hydroxide	Hydrogen	Pure Oxygen	5 to 20 kW	45-65%	Military, Space and Vehicle Applications
Phosphoric Acid Fuel Cell, (PAFC)	Immobilised liquid Phosphoric Acid	Hydrogen	Atmospheric oxygen	200 kW to 1 MW	35-50%	Medium combined Heat and Power
Solid Oxide Fuel Cell, (SOFC)	Ceramic	Hydrogen, Methane	Atmospheric oxygen	Up to 200kW	45-60%	Large and small combined Heat and Power. Vehicle Applications
Molten Carbonate Fuel Cell (MCFC)	Immobilised liquid Molten Carbonate	Hydrogen, Methane	Atmospheric oxygen	Up to 2 MW	40-55%	Large combined Heat and Power

Table 1. Range of Fuel Cells

efficiency and application. The efficiency stated is the percentage figure the fuel cell manages to convert of the fuel energy in the hydrogen to electrical energy.

Figure 1. illustrates the operating temperature ranges of the six fuel cells in common

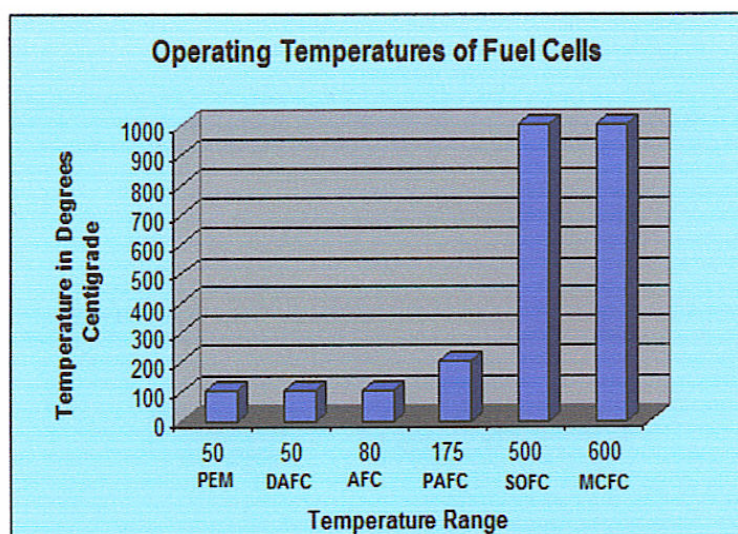


Figure 1. Operating temperatures of the six most common fuel cell.

use. Fuel cells are categorised as high or low temperature cells and this dictates their suitability for various applications, stationary, transport or heat/plant. The electrolyte used in a cell can be either solid or liquid. For temperatures below 100°C, aqueous acid, alkaline or a solid electrolyte may be used. Between 100 and 200°C it is necessary to use highly concentrated solutions of acids such as phosphoric acid. Between 200 and 400°C, one may use molten alkaline hydroxides and from 600 to 1000°C molten carbonate or salt mixtures may be used. Above 1000°C solid electrolytes can also be used [9].

The very popular Proton Exchange Membrane (PEM) cell employs a solid electrolyte that allows positively charged ions to travel unimpeded across the polymer membrane while rejecting negatively charged ions forcing them to flow through an external circuit in the form of electrical current. The preference for acidic or alkaline electrolytes is dependant on the desired application, for a mobile situation (e.g. buses, trucks, cars) alkaline electrolytes would be suitable but the acidic PEM cell is the one most vehicle manufacturers involved in fuel cell research prefer. Advantages of using an alkaline electrolyte compared to an acidic electrolyte are that electrode materials other than noble metals (platinum) can be utilised. Other cell materials that form part of the cells casing and construction can also be produced from inexpensive material with less risk of aggressive attack, these are important factors to the longevity and cost of the fuel cell. Also oxygen reduction reaction is faster in alkaline solutions than in acids.

1.3 Fuel Cell Type and Operation

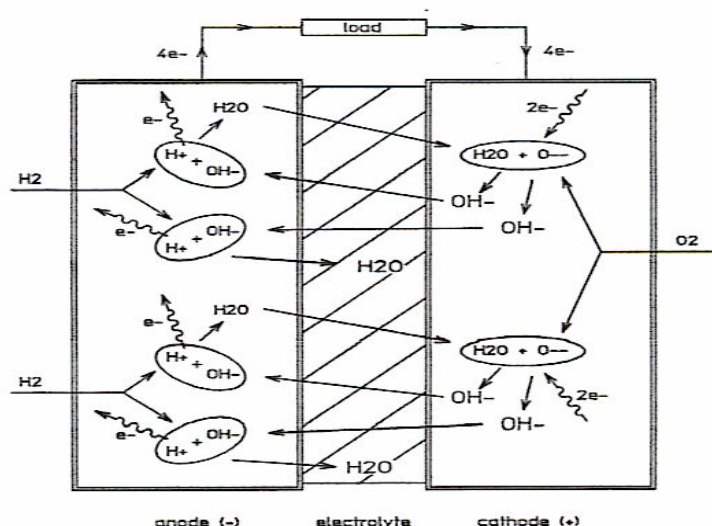
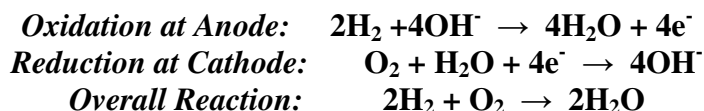


Figure 2. Alkaline Fuel Cell

The Alkaline Fuel Cell (AFC) is shown in Figure 2. this cell utilises the migration of Hydroxyl ions (OH^-) from the cathode to the anode to create a reaction. At the anode the hydrogen gas (H_2) combines with the hydroxyl ions (OH^-) to form water (H_2O) and electrons (e^-). Because the electrons cannot pass through the electrolyte they are forced out at the anode supplying current to external loads. Water formed at the anode then migrates back to the cathode where it joins up with oxygen (O_2) and

returning electrons to regenerate the hydroxyl ions (OH⁻) and the cycle repeats itself. Most reaction water leaves at the anode (H₂) side but a small amount is removed via the electrolyte causing the electrolyte's molar concentration to be weakened affecting the cell output. The remedy for this is to periodically replace the Potassium Hydroxide electrolyte.



The acronym PEM refers to **Polymer Electrolyte Membrane** or **Proton Exchange**

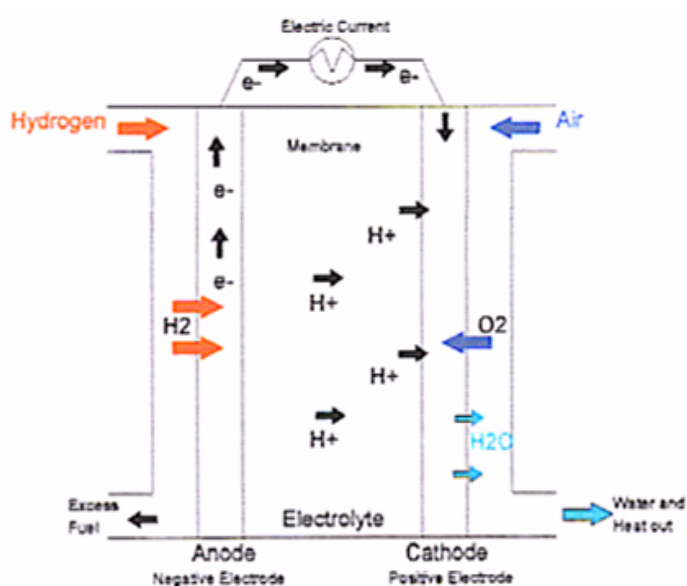
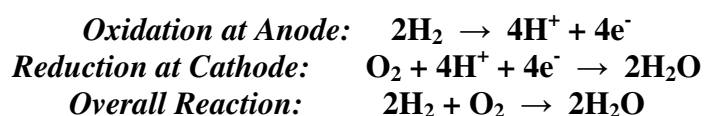


Figure 3. The PEM Fuel Cell

Membrane and refers to the solid acid electrolyte used by the PEM fuel cell illustrated in Figure 3. As hydrogen gas (H₂) enters the cell at the anode side it comes into contact with a precious metal catalyst and breaks down into protons (H⁺) and electrons (e⁻). The catalyst is a substance usually platinum that accelerates a chemical reaction. The protons can pass unimpeded through the thin plastic membrane while the electrons travel in the form of current to supply the external loads before returning to the cell at the cathode. The protons that have diffused through the membrane reunite with the electrons and react

with the oxygen fed in at the cathode to produce water (H₂O). This process produces no pollution and the only by-products are water and heat.



The PEM fuel cell is finding most favour with Motor Manufacturers and is believed in some quarters to be most suitable for transportation and small stationary applications. Compared to other types of cell the PEM generates more power for a given volume or weight of fuel cell. There is also the added advantage that it uses air as opposed to pure oxygen and does not require a corrosive fluid to operate [10]. The Canadian company Ballard Power Systems and the American company UTC Fuel Cells are acknowledged as two of the leading companies in the industry and both are developing PEM fuel cells for the mass market, especially the transportation sector. Other important US companies include Fuel Cell Energy, which is developing large-scale fuel cell power plants and Plug Power, which is developing smaller units to power residential and commercial premises, [11]. The commercial potential of the PEM fuel cell and the continued investment has lead to the development of ion conducting plastic film membranes that generate electric current more easily, operate across a broader

temperature range and cost less than incumbent materials, which are mainly sulfonated fluoropolymers [12]. This allows for a compact, low cost and quick responding cell technology more suited to the various application demands of industry. However some of the main problems that still impair the dominance of the PEM fuel cell are Carbon Monoxide poisoning, affecting the long-term performance of the membrane. The PEM fuel cell requires pure hydrogen as a fuel and therefore is not suited to on-board reforming of hydrocarbons (natural gas, gasoline etc.). Also it's use of precious metal catalysts especially platinum which is rare and costly. PEM fuel cell technology has been targeted for transportation applications because it operated efficiently on pure hydrogen with the result being zero emissions. But converting from a Carbon based economy to a Hydrogen economy is a future aspiration, and realistically reforming of fossil based fuels to extract hydrogen would be required in the interim to bridge the gap.

1.4 Direct Methanol fuel cells (DMFC) are relatively new and similar to the PEM cell in that it uses a polymer membrane as an electrolyte. However, in the DMFC the anode catalyst draws the hydrogen from the liquid methanol, eliminating the need for a fuel reformer. The liquid Methanol is oxidized in the presence of water at the anode and produces CO_2 , hydrogen ions and electrons. The hydrogen ions pass through the membrane and the electrons travel through the external circuit as current, reuniting to react with the oxygen from the air to form water at the anode and complete the circuit, [13]. Initially the DMFC was ignored because of its high catalyst costs (platinum), fuel crossover effect, poisonous fuel, low efficiency and power density problems. But it now seems that new technology has resolved these matters and interest in the DMFC has resurfaced for very small to mid size applications like laptops, cellular phones and motor vehicles, because it offers low temperature operation without the need for a reformer.

1.5 The Phosphoric Acid Fuel Cells (PAFC) is considered the first generation of modern fuel cells and was one of the first to be commercialised. Its typical use is stationary power generation and also to power large vehicles like city buses. As the name suggests the electrolyte is liquid phosphoric acid (H_3PO_4) at nearly 100% concentration and it is most conductive at a temperature of 150 to 200°C. It operates similar to a PEM fuel cell, as the hydrogen (H_2) enters the cell at the anode, the catalyst causes it to split into protons (H^+) and electrons (e^-). The protons migrate through the electrolyte to the cathode side where they combine with the electrons from the external circuit and oxygen (O_2) from the air to form water and another by-product, heat [14].

1.6 Solid Oxide Fuel Cells use a solid ceramic electrolyte and operate at very high temperatures. The high temperature operation is considered an advantage because of the cells flexibility to use more types of hydrocarbon fuel (natural gas, diesel, gasoline, alcohol, coal gas) be tolerant of impurities and use inexpensive catalysts, but a disadvantage in that high temperatures enhance the breakdown of cell components. Because of its high efficiency output, 60% approx., the SOFC is mainly used for power generation with a potential also to power vehicles [15]. The solid electrolyte structure of the SOFC is impervious to gas crossover from one electrode to another, with the charge carrier being the oxygen ion (O^{2-}). At the cathode the oxygen molecules from the air are split into oxygen ions with the addition of four electrons. The oxygen ions are conducted through the electrolyte and combine with the hydrogen at the anode, releasing four electrons. The electrons exit the cell as current to

supply the external circuits and return to the cathode to continue the cycle. The by-products are heat and water that exits the cell on the anode side.

1.7 Molten Carbonate Fuel Cells (MCFC) are high temperature fuel cells operating at temperatures in excess of 650° C. This implies high fuel to electricity efficiencies of up to 60%, increasing to 85% if the waste heat is utilised.

The MCFC uses a molten carbonate salt mixture as its electrolyte; the two commonly used compositions are lithium carbonate and potassium carbonate, or lithium carbonate and sodium carbonate. The mobility of the Carbon Trioxide ion is dependent on the conductive mobility of the melted salt (a liquid at 650°C). At the anode a reaction occurs between hydrogen and carbonate ions (CO_3^{2-}) that have migrated across the electrolyte from the cathode that produces water, carbon dioxide (CO_2) and electrons. The electrons are routed through the external system as current and return to the cathode to combine with oxygen (O_2) and carbon dioxide (CO_2) to produce carbonate ions to continue the process. The bi-products of producing electricity in this fashion are water and heat with carbon dioxide being collected at the anode exhaust and mixed with the cathode feed stream [16].

2.0 Alkaline Fuel Cell Research

Research at Dublin Institute of Technology (DIT) has centred on developing alkaline fuel cell engineering with a view to promoting this technology and steering it towards commercialisation. In conjunction with a German industrial partner, Gaskatel GmbH, DIT has built a single cell test bed for education and research purposes to enhance its research potential in this area and assist in refining Gaskatels alkaline fuel cell and system.

In an alkaline cell, fuel oxidation occurs at the anode. The single fuel cell unit, as shown in Figure 4. has two hydrogen electrodes made of Raney-nickel which have a high catalytic activity at low temperature for hydrogen oxidation and at the cathode oxidant reduction is accomplished by two oxygen electrodes made of silver. The supply for the gases and electrolyte are situated at the bottom of the cell and the exit for both gases and the electrolyte are at the top of the cell. This allows the cell to benefit from the fact that both hydrogen and oxygen will flow freely up through the cell of their own accord. The gases also move quicker through the cell on start-up, which helps to expel any trapped bubbles, inert gases and reaction water that may lodge in the cell on shutdown and re-start.

The cells output is most efficient at a constant temperature of 55° C. As part of the cells construction two heating elements are fitted between the positive and negative poles of the cell and connected in series (24 VDC, 1A) to speed up the heating process. This method of heating the cell is only effective if the electrolyte is immobile, when

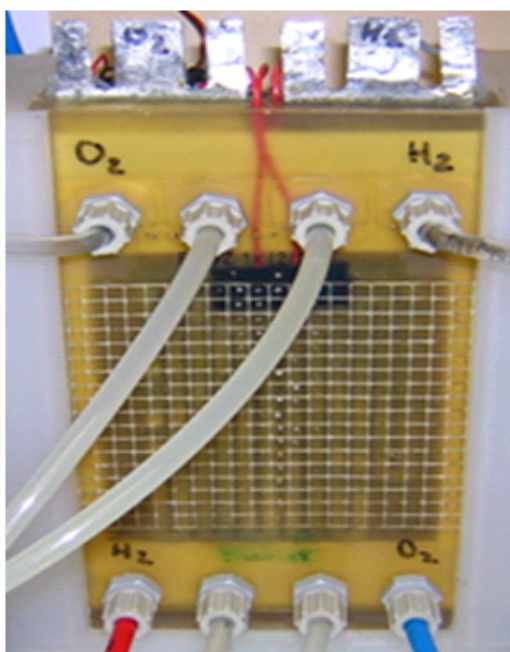


Figure 4. Alkaline Fuel Cell

electrolyte circulation commences the cell temperature drops quickly and drastically affecting the cells potential. The conclusion gathered from this is that the mobilisation of the electrolyte, although beneficial should be controlled, becoming more intermittent than constant. The temperature of the cell is monitored to prevent damage of overheating by a Pt. 100 resistor also positioned inside the cell in close proximity to each heating element.

The gas pressure within the cell also requires regulating and monitoring at a set 0.5 bar above atmospheric pressure to prevent cross-over between the electrolyte and the gas. When the electrodes are being constructed a two-pore system is created, the hydrophobic pores through which the gas flows and the hydrophilic pores through which the electrolyte flows. Capillary forces keep the electrolyte in the small pores when an over pressure of the gas with respect to the electrolyte is applied (as referred to above). In the alkaline fuel cell the gas diffused porous electrodes are very important and the contact zone where reactant, electrolyte and catalyst meet is called the three-phase zone [17].

The cell has one active separator and two passive separators. A thin porous plastic film or active separator is critically used to separate the anode and cathode electrodes from each other. This separator also facilitates the migration of the hydroxyl ion from the cathode to the anode and the water return in the opposite direction. The passive separators only separate the KOH and gas chambers from each other.

In alkaline fuel cell systems, the preferred electrolyte is usually the aqueous potassium hydroxide (KOH), which has a higher conductivity than most other alternatives. Sodium hydroxide (NaOH) was envisaged as a potential option but on balance its performance characteristics were less interesting than that of KOH, and the cost advantage was not really that important because the KOH electrolyte can be used for a longer time in the fuel cell so that its cost to the overall cost is almost negligible [18].

2.1 Testing

Automotive vehicles are the biggest users of oil and one of the major polluters so if a breakthrough is to be made in the development of the hydrogen economy and fuel cell technology it is they who will take the lead in developing this renewable and environmentally friendly energy source. The challenges facing the alkaline fuel cell being considered as a realistic option for automotive manufacturers is:

- Dispelling the suggestion that the cell requires pure oxygen as an oxidant and cannot operate on air. It has been quoted in many journals that the AFC needs its air supply virtually CO₂ free, as the ingress of CO₂ into the electrolyte reduces the electrolytes the current carrying capacity [19].
- Finding an electrolyte that is less aggressive and still has the very good conductivity that the alkaline solution provides [19].

As part of the research program conducted by DIT in collaboration with Gaskatel GmbH an alkaline fuel cell operating with air was tested under a variety of conditions. In order to facilitate these tests the cell was modified by increasing the size of the air intake compartment to suit the new conditions. Air contains approximately 77% nitrogen and only 21% oxygen with trace gases making up the remainder. Because the cell requires oxygen as an oxidant the air supply was adjusted to provide a higher gas flow through the cell [20]. The purpose of these tests was to simulate different electrolyte concentrations and observe the build up of potassium carbonate inside the cell. The general perception is that the formation of these carbonate particles will block

up the pores of the electrode, causing the cell to mal-function and that this will happen rather quickly.

The results were quite different, the cell operated for more than 5000 hours with unscrubbed air. With a constant current density of $100\text{mA}/\text{cm}^2$ there was a decrease of potential of approximately 10% and this was reversible by changing to a fresh electrolyte solution [20]. This would suggest that the perception that an alkaline fuel cell cannot operate with air is dated and if a suitable air scrubber (a type of air filter) were used as part of a systems construction the cell should operate efficiently.

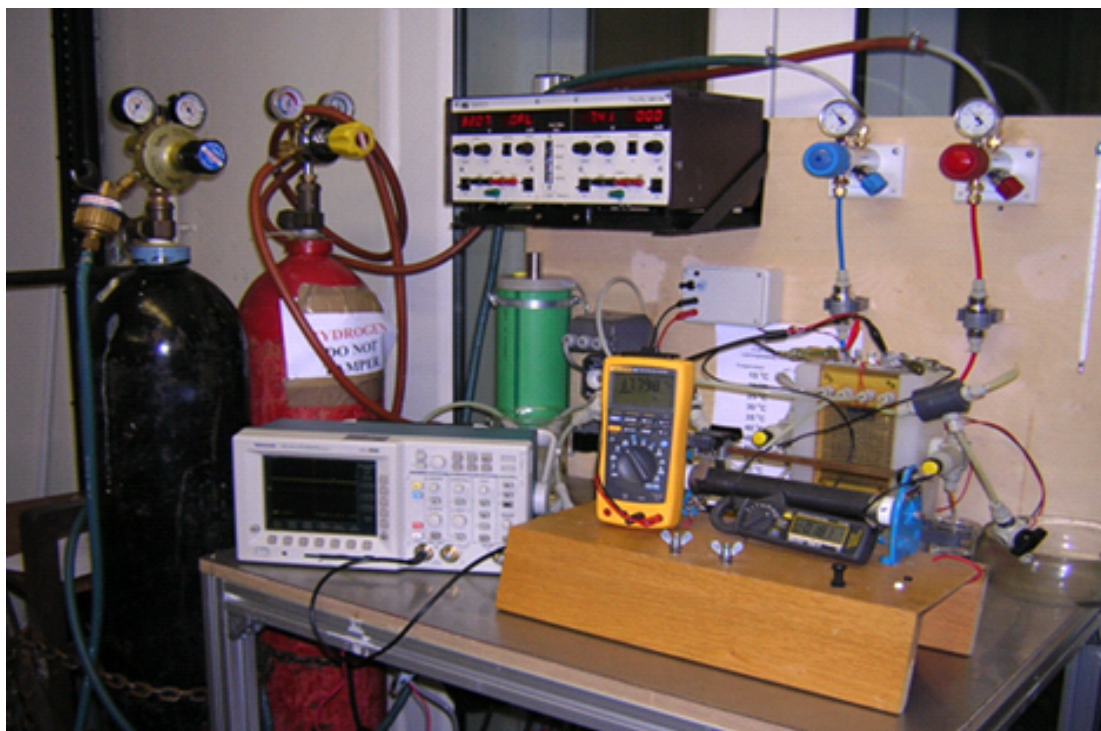


Figure 5. Single Alkaline Fuel Cell Test Bed.

Another part of the research program currently in progress at DIT involved the construction of a single alkaline fuel cell test bed, Figure 5. Constructing the system gave researchers at DIT a valued insight into the complexities of a basic fuel cell system. As a result of collaboration between researchers at DIT and Gaskatel GmbH a suggestion was made to change the gas and electrolyte supply from the top of the cell to the bottom of the cell and this has been incorporated into the new cells construction. The new configuration allows both the hydrogen (H_2) gas and the oxygen (O_2) gas to flow freely through the cell as opposed to being pushed. This has a positive effect on relieving the build up of inert gas and trapping of bubbles inside the cell, allowing them to rise by natural progression towards the exit lines.

Constructing the test bed also identified and solved another problem with the system involving the hydrogen and oxygen gas supply to the cell. It was reported to the researcher that the test bed required constant monitoring because the system pressure varied with the change in volume of gas in each cylinder. As the level of the gas dropped inside the external gas cylinder the system pressure also dropped and this affected the pressure balance inside the cell between the pores of the electrode resulting in crossover and cell malfunction. The solution was to fit a Multi-stage gas regulator to the external hydrogen and oxygen gas supply bottles.

At the anode of an AFC the hydrogen gas (H_2) combines with the hydroxyl ions (OH^-) to form water (H_2O) and electrons (e^-). As part of this process water builds up in the

electrolyte and also leaves the cell in the exiting hydrogen stream. As reported as part of the Apollo space missions this water having been treated (the pH of the water maintained at between 6 and 8) was used as drinking water for the mission [1]. One of the problems encountered with the operation of the single cell test bed was the build-up of water in the exit lines of the system after shutdown. This water was alkaline and corrosive and is undergoing various tests to establish if it is reaction or crossover water, (the results of these tests are not available for this paper). With the old cell configuration (gas and electrolyte supply at the top of the cell) water was building up at the supply side of the cell, interfered with the gas supply and corrosively attacking the gas regulator. To prevent this a one-way valve was incorporated into the system but because potassium hydroxide molecules are tiny corrosive water did get past this valve and attach the hydrogen gas regulator. In a system incorporating a multi cell stack this problem would be amplified tenfold. The new design puts the hydrogen gas stream water at the exit side of the cell, which is more beneficial and easier to rectify. In a fuel cell stack system the hydrogen gas can be re-circulated towards the inlet side of the stack and this H₂ gas could be run through a condenser to extract the water. The separated water would be gathered in a sedimenter (water separator), made ph neutral and could be drained off when full.

Tests have also being carried out to check the cells recovery time. Results to date have suggested that the single cell takes up to 4 minutes to reach its start-up open circuit potential of 1.05 volts depending on cell temperature conditions. If the cell is at 50°C it takes less time to reach 1.05 volts, but time is taken up warming the cell so the time



Figure 6. Single Alkaline Fuel Cell Test Bed.

factor evens out. When operating under load if the load is increased the cell voltage drops immediately but if the load is decreased the cell takes up to 6 ~ 8 seconds (depending on the load applied) to recover its voltage and even out as shown in Figure 6. This would suggest that the fuel cell is more suited to constant loads as opposed to snap load situations similar to those associated with driving an automotive vehicle. The tests suggest that fuel cells operated in an automotive environment

require a secondary power source to assist and smooth out vehicle start up and other periods of excessive loading on the cell, (acceleration etc). Hybrid situation were not available in the early years of fuel cell development but the results from these tests would suggest that their use in an automotive application are well justified. It should also be mentioned that when a fuel cell is on activated stand, without load, the fuel cell electrodes and catalysts degrade more than under load [21].

The performance of the single alkaline fuel cell fitted to the test bed is most efficient at 55°C but controlling the temperature of the cell with a circulating electrolyte requires constant monitoring and control. When initially heating the cell on start-up it is best to leave the KOH immobile until the operating temperature is reached. When the pump is activated (the pump in this situation is externally powered) and circulation begins the cells potential starts to drop off as the cell temperature decreases. If the electrolyte is left to circulate it takes a long time to bring the cell back to its most efficient operating temperature (55°C) and effects cell efficiency. A circulating electrolyte is very desirable for cooling the cell and replenishing the electrolyte concentration. But it is hard to maintain an accurate cell temperature with a continuous circulating electrolyte. The solution adopted for the single cell system (with internal cell heating coils) was to monitor the cell heating times and control the KOH circulation intervals, but other options, such as externally heating the KOH are being looked at as part of the process of refining the system.

Conclusions

In conclusion, tests have shown that an alkaline fuel cell can operate on un-scrubbed air for an extended period exceeding 5000 hours, with any decrease in it's potential being rectified by changing to fresh electrolyte. The cell and its operating system have also displayed enough reliability and durability during testing to suggest that the misconceptions relating to alkaline fuel cells and its use of a corrosive electrolyte (KOH) can be resolved using modern technology. The new cell configuration has also allowed for an easier passage through the cell for gas and electrolyte prompting trapped bubbles, water and inert gases to exit the cell making the system and external subsystems easier to operate and design. Constructing this test bed and conducting various tests to examine the system and the cells potential has highlighted the need for expertise across a wide range of disciplines if the refinements necessary to bring the alkaline fuel cell to commercialisation is ever to be realised.

Reference Material

- [1] Fuel Cell Technology Handbook. G. Hoogers, E. Chen
CRC Press 2003
- [2] Integrating and Strengthening the European Research Area. J. Metthey
European Commission Research Directorate-General. 2004
- [3] Hydrogen/oxygen (Air) fuel cells with alkaline electrolytes. 2003
M.Cifrain, K. Kordesch Handbook of Fuel Cells John Wiley & Sons Ltd.
- [4] Fuel Cell Comparisons K. Kordesch
http://www.electricauto.com/contents/fc_compare.html 2004
- [5] An Introduction to Fuel Cells and Hydrogen Technology. B. Cook
Heliocentris, Canada. 2001

- [6] Alkaline Fuel Cell Technology for the 21st Century. Jiri K.Nor
Astri Energi Website www.astri.ca 2000
- [7] Fuel Cell Technology for Vehicles. R. Stobart
Society of Automotive Engineers. 2001
- [8] Indian Strategy for Fuel Cell Development. N.K. Bansal
Forschungszentrum Julich GmbH 2003
- [9] Fuel Cells D.P. Gregory
Mills & Boon Ltd. 1972.
Library Ref. 621 . 359.
- [10] Proton Exchange Membrane Fuel Cells. Concurrent Technologies Corporation.
http://www.fctec.com/fctec_types_pem.asp 2003
- [11] The Future of Fuel Cells
<http://www.benwiens.com/energy4.html> 2004
- [12] Plastic Technology Online Article
<file://C:\Temp\4Q70Q96R.htm> 2004
- [13] Direct Methanol Fuel Cells (DMFC)
http://www.cfdrc.com/bizareas/power/fuel_cell/dmfc.html 2004
- [14] Phosphoric Acid Fuel Cells (PAFC)
<http://fuelcells.si.edu/phos/phos3.htm> 2004
- [15] Vision Engineer-Solid Oxide Fuel Cell Online Article
<http://www.visionengineer.com/env/so.shtml> 2004
- [16] Molton Carbonate Fuel Cells (MCFC) FCTec
http://www.fctec.com/fctec_types_mcfc.asp 2004
- [17] Stack materials and design. 2003
K. Kordesch, V.Hacker. Handbook of Fuel Cells John Wiley & Sons Ltd.
- [18] Fuel Cell Systems L.J. Blomen, M.N. Mugerwa
Plenum Press, New York 1993
- [19] Fuel Cells for Automotive Applications. R.H. Thring, G. Sauer, O. Carlisle
Professional Engineering Publishing. 2004
- [20] Long-Term Operation of an Alkaline Fuel Cell with Air. 2006
E.Coyle, D.Kennedy, H-J Kohnke, S. Schudt, G.Sauer, J.P. Hamilton, H.Smith-Walter.
- [21] Advantages of Alkaline Fuel Cell Systems for Mobile Applications.
Hacker et al