ISSN (Online) 2393-8021
ISSN (Print) 2394-1588
International Advanced Research Journal in Science, Engineering and Technology (IARJSET)
National Conference on Renewable Energy and Environment (NCREE-2015)
IMS Engineering College, Ghaziabad
Vol. 2, Special Issue 1, May 2015

INTRODUCTION TO FUEL CELL TECHNOLOGY : A REVIEW

Shilpa saxena, Anurag verma

IMS engineering college
Ghaziabad , India

Abstract—As we know that the 19th century was the century of the steam engine and the 20th century was the century of the internal combustion engine, it is likely that the 21st century will be the century of the fuel cell. Full cells are now on the verge of being introduced commercially, revolutionizing the way we presently produce power. Fuel cells can use hydrogen as a fuel, offering the prospect of supplying the world with clean, sustainable electrical power. This paper discusses the history of fuel cells, fuel cells for NASA, alkaline fuel cells for terrestrial applications and PEM fuel cells. Fuel cell applications in transportation, distributed power generation, residential and portable power are discussed. The science of the PEM fuel cell and the direct methanol fuel cell are discussed. Benefits of fuel cells and obstacles to their widespread introduction are briefly outlined.

Keywords - Fuel cell, energy conversion, efficiency.

I. Introduction

Fuel cells are commonly known for their direct conversion from chemical energy into electrical energy and it's efficient in nature. On the other hand fuel cells are more efficient than other conventional power sources because their efficiencies are not limited by Carnot cycle. A fuel cell act as a battery but it does not need to be recharged; when these fuel cells are supplied with fuel and oxidant these cells give continuous power. Mostly all the type of fuel cells are consist of anode as negative side, cathode as positive side and an electrolyte which allows the charges to move between the two side of the fuel cell that are positive and negative.This paper describes the type of fuel cells which further classified into sub-categories on the basis of their use and power. Fuel cells are one of the most promising renewable energy sources of world. In principle, the fuel cell produces continuous power for as long as fuel cell is supplied.

In addition, because combustion is avoided, fuel cells produce power with minimal pollutant.

In fact, some fuel cell operate in reverse as electrolyzes, yielding are reversible fuel cell that can be used for energy storage.

On the basis of principle a wide variety of fuels and oxidant are based fuel cells. But mostly interested fuel cells are that which use common fuel (or derivatives) or hydrogen as reluctant, and ambient air as the oxidant.

Most fuel cell power systems comprise a number of components:

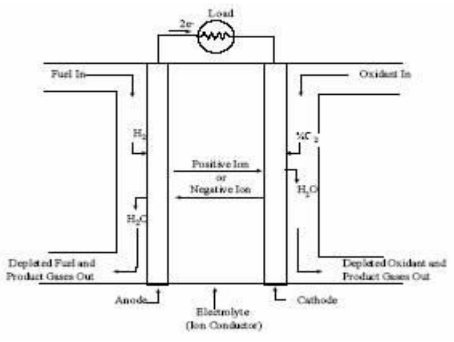
- Unit cells, in which the electrochemical reaction takes place
- Stacks, in which individual cells are combined by electrically connecting the cells to form units with the desired output capacity
- Balance of plant which comprises components that provide feed stream conditioning (including a fuel processor if needed), thermal management, and electric power conditioning among other ancillary and interface functions.

In the following, an overview of fuel cell technology is given according to each of these categories, followed by brief review of key potential applications of fuel cells.

2. UNIT CELLS:

Basic structure

Unit cells form the core of a fuel cell. Conversion of chemical energy contained in a fuel electrochemically into electrically energy. The basic building block, of a fuel cell consists of an electrolyte layer in contact with an anode and a cathode on either side. A schematic representation of unit cell with the reactant / product gases and the ion conduction flow directions through the cells is shown in figure.1.1



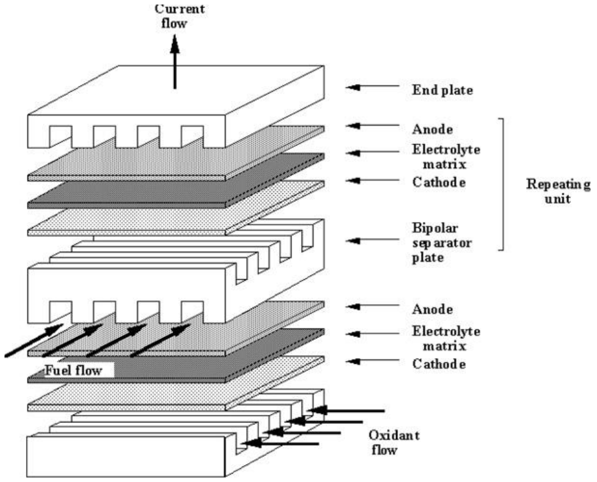
ISSN (Online) 2393-8021
ISSN (Print) 2394-1588
International Advanced Research Journal in Science, Engineering and Technology (IARJSET)
National Conference on Renewable Energy and Environment (NCREE-2015)
IMS Engineering College, Ghaziabad
Vol. 2, Special Issue 1, May 2015

In a typical fuel cell, fuel is fed continuously to the anode (negative electrode) and an oxidant (often oxygen from air) is fed continuously to the cathode (positive electrode). The electrochemical reactions take place at the electrodes to produce an electric current through the electrolyte.

1.2 fuel cell stacking:

For the most practical fuel cell application, unit cells should be combined in a modular way into a cell stack for achieving the voltage and power output level required for an application.

Generally, the stacking involves connecting more than one unit cells in series via an electrically conductive interconnection as shown in figure:



Various stacking arrangements are:

1. planar-bipolar stacking
2. stacks with tubular cells

2.2 fuel cell type

Fuel cells are classified on the basis of electrolyte and the type of fuel used, which determines the electrode reaction and the type of ions that carry the current across the electrolyte.

Most fuel cells underdevelopment today use gaseous hydrogen, or a synthesis gas rich in hydrogen, as a fuel.

Hydrogen has a high reactivity for anode reactions, and can be produced chemically from a wide range of fossil and renewable fuels, as well as via an electrolysis for similar practical regions, the most common oxidant is gaseous oxygen, which is available from air.

For space applications, both hydrogen and oxygen can be stored compactly in cryogenic form, while the reaction product is only water.

Most common classification fuel cells is on the basis of type of electrolyte used in the fuel cells are:

- PEFC(polymer electrolyte fuel cell)
- AFC(alkaline fuel cell)
- PAFC(phosphoric acid fuel cell)
- MCFC(molten carbonate fuel cell)
- SOFC(solid oxide fuel cell)

In accordance with the classification by electrolyte, some fuel cells are classified by the type of fuel used:

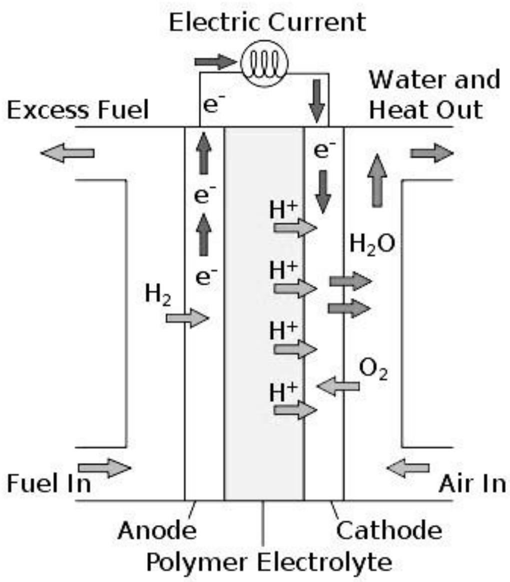
- Direct alcohol fuel cell (DAFC). DAFC (or most commonly, direct methanol fuel cells or DMFC) use alcohol without reforming.
- Direct carbon fuel cells (DCFC). In direct carbon fuel cell, solid carbon (from coal, pet coke or biomass) is used directly in the anode, without an intermediate gasification step.

The thermodynamics of the reactions in a DCFC allow very high efficiency conversion.

Therefore, if the technology can be developed into practical systems, it could ultimately have a significant impact on coal based power generation.

2.2.1 PEFC(POLYMER ELECTROLYTE FUEL CELL)

In this fuel cell, the electrolyte is an ion exchange membrane (fluorinated sulfonic acid polymer of other similar polymer) which is an excellent proton conductor. In this fuel cell, only the liquid is water, thus problems of corrosion are minimum. Typically, carbon electrodes with platinum electro – catalyst are used for both anode and cathode, and with either carbon or metal interconnection



Water management in the membrane is critical for efficient performance; the fuel cell must operate under conditions where the by-product water does not evaporate faster than it is produced because the membrane must be hydrated. Because of the limitation of the operating temperature imposed by the polymer, usually less than 100Oc, but more typically around 60 to 80 degree centigrade and because of problems with water balance, a

ISSN (Online) 2393-8021
ISSN (Print) 2394-1588
International Advanced Research Journal in Science, Engineering and Technology (IARJSET)
National Conference on Renewable Energy and Environment (NCREE-2015)
IMS Engineering College, Ghaziabad
Vol. 2, Special Issue 1, May 2015

H_2 rich gas with minimal or no CO (a poison at low temperature) is used. Higher catalyst loading (Pt in most cases) than that used in PAFC`s is required for both the anode and cathode. Extensive fuel processing is required with other fuels, as the anode is easily poisoned by even trace levels of CO, sulphur species, and halogens.

Applications of PEF`s:

- Used for prime mover for fuel cell vehicles(FCV`s)
- Used in automotive and portable applications.

Advantages of PEF`s:

- The PEFC`s has a solid electrolyte which provide excellent resistance to gas crossover.
- According to tests and on the basis of test result PEFC`s are capable of high current densities of over 2kw /l and 2 w/cm2.
- The PEFC lends itself particularly to situations where pure hydrogen can be used as a fuel.
- Due to the PEFC`s low operating temperature, it allows rapid start-up.

Disadvantages of PEFC`s:

- Thermal management is difficult due to the low and narrow operating temperature.
- PEFC`s are quite sensitive to poisoning by trace levels of contaminants including CO, sulphur species, and ammonia.

2.2.2 AFC(alkaline fuel cell):

Alkaline fuel cells also known as the bacon fuel cell as the electrolyte, potassium hydroxide (KOH) or some other alkaline aqueous solution and usually operates at temperature below 100 oc and its operating principle shown in figure (1.3.2.1). Electrodes reaction takes place upon supplying hydrogen to the fuel electrode and oxygen to the air electrode, and thus an electric current can be obtained.

The fuel used is hydrogen, and the oxidizing agent is either pure oxygen, or air. Since the pressure of carbon dioxide results in deterioration of the aqueous electrolyte, reactant gases should not have carbon di oxide as a component.

Higher the electrolyte concentration, greater the activity of water is reduced, and reaction becomes easier, so that the electrolyte characteristics are improved.

However, the water vapor pressure is also lowered, and it becomes difficult to evaporate and remove the water produced in the reaction; hence the actual concentration used is determined according to the operating conditions and cell characteristics.

Applications of AFC`s:

- Fuel cell taxi and boat.
- Generator and golf car.
- Electric vehicles, fork lift vehicles.

Advantages of AFC`s:

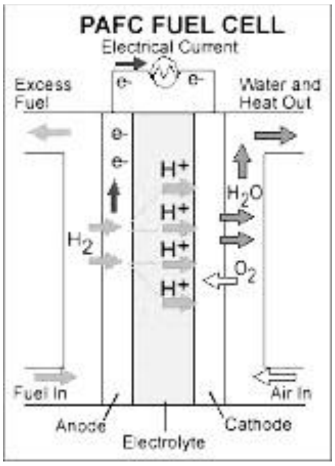
- Alkaline technology is the longest established technology for both space and submarine applications over other available cell.
- Electrically efficient.
- Over the last few years AFC energy has re-engineered this proven alkaline fuel cell technology to give a low lifetime cost of ownership.

Disadvantages of AFC`s:

- The sensitivity of the electrolyte to co2 required the use of highly pure H2 as a fuel.
- If ambient air is used as the oxidant, the CO2 in the air must be removed.

2.2.3 Phosphoric acid fuel cell (PAFC):

In PAFC; the electrolyte consists of concentrated phosphoric acid and a silicon carbide matrix is used to retain the acid while the functioning catalyst are made of Pt or its alloys. The operating temperature is maintained between 150 to 220 Oc , at lower temperature phosphoric acid tends to be a poor ionic conductor and CO poisoning of the Pt electro catalyst in the anode becomes severe.



The porous electrodes used in PAFC`s contain a mixture of the electro catalyst supported on carbon black and a polymeric binder to bind the carbon black particles together forming an integral structure . A porous carbon paper substrate acts as a strong support for the electro catalyst layer and as the current collector.

During cell operation generated heat is removed by either liquid or gas coolants which are routed through cooling channels in the cell stack.

Copyright to IARJSET
DOI 10.17148/IARJSET

ISSN (Online) 2393-8021
ISSN (Print) 2394-1588
International Advanced Research Journal in Science, Engineering and Technology (IARJSET)
National Conference on Renewable Energy and Environment (NCREE-2015)
IMS Engineering College, Ghaziabad
Vol. 2, Special Issue 1, May 2015

Efficiency of PAFC is typically 40 to 47% on a fuel (natural gas) LHV basis.

Applications of PAFC`s:

- PAFC have been used for stationary power generators with output in the range of 100 kW to 400 kW.
- Also used in large vehicles such as buses.
- Major manufacturers of PAFC technology include clear edge power (formerly UTC power) and Fuji electric.
- India`s DRDO is developing PAFC for air independent propulsion in their scorpene class submarines, and the Indian navy have requested a fully engineered system by 2014.

Advantages of PAFC`s:

- Fuel cells provide high quality DC power.
- Impure hydrogen can be used as a fuel, removing the need of pretreatment of the fuel supply.
- PAFC`s are emission free as it can tolerant to CO than PEMC.
- In PAFC the electrolyte is distributed in a porous layer of silicon carbide (Sic) which separates anode and cathode which reduce the corrosion.

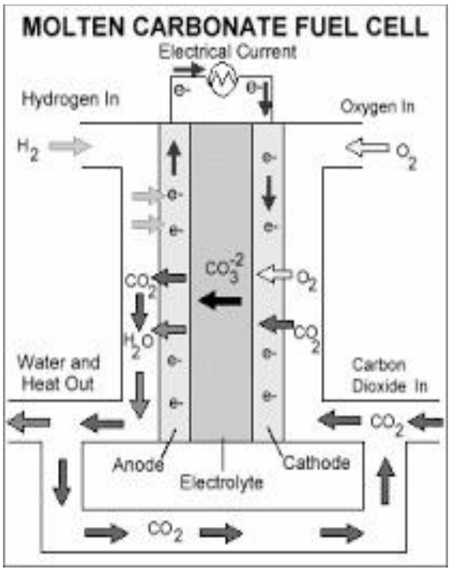
Disadvantages of PAFC`S:

- The larger weight of the PAFC`s usually 40,000 lbs. (10*10*18) in fact and cooling module of 1700 lbs.(4*14*4 in feet).
- Slow start up time: Because of high operating temperature PAFC`s take long time to start so they are mostly limited to stationary applications.
- Expensive because of catalyst used is platinum (Pt.) which raises the cost of the fuel cell.

2.2.4 MOLTEN CARBONATE FUEL CELL(MCFC):

MCFC is a high temperature fuel cell which operates nearby at 650`0c. These type of fuel cell uses natural gas directly required temperature is so high to reach enough conductivity of the carbonate electrolyte which enables to use low cost parts.

The efficiency MCFC`s can reach 60 to 80 %. The output of units can reach 2MW and designs exist for units up to 100 MW. MCFC`s are high – temperature fuel cells that use an electrolyte composed of a molten carbonate salt mixture. When the temperature comes ot 650`0 c, the electrolyte used as a molten mixture of carbonate salt melts and becomes conductive to carbonate ions.



These ions combine with hydrogen to form water on the cathode side. During the reaction co2 and electrons are released.

The reaction equation of the MCFC is:-

Anode: $2H2 {}_{+}2CO_3^{2-}$-------$2CO_2+2H_2O+4e^-$

Cathode: $O_{2+}2CO_{2+}4e^-_-$----------$2CO_3^{2-}$

Reaction equation O_2+2H_2----------$2H_2O$

Applications of MCFC:

- Mainly the focus of MCFC development has been larger stationary and marine applications.
- Molten carbonate fuel cells (MCFC`s) are currently being developed for natural gas and coal based power plant for electrical utility industrial, and military applications

Advantages of MCFC:

- In this type of fuel cell non-expensive catalysts can be used in conjunction with a number of fuel to provide sufficient activity.
- Moreover, carbon monoxide and even certain hydrocarbons are the fuels for MCFC.
- Main advantage is this, when the reaction works in the device, the high temperature waste heat enables the use of bottom cycle to further boost the system efficiency to 50 to 60%.

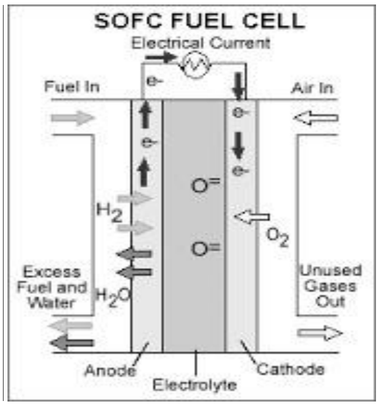
Disadvantages of MCFC:

- MCFC needs a high temperature near about 650`o c , which about promotes material problems .
- The main problem of MCFC is that how to avoid the electrolyte being corroded.

ISSN (Online) 2393-8021
ISSN (Print) 2394-1588
International Advanced Research Journal in Science, Engineering and Technology (IARJSET)
National Conference on Renewable Energy and Environment (NCREE-2015)
IMS Engineering College, Ghaziabad
Vol. 2, Special Issue 1, May 2015

2.2.5 SOLID OXIDE FUEL CELL (SOFC):

Solid oxide fuel cells (SOFC`) use a solid material, commonly a ceramic material called yttria -stabilized zirconia (YSZ), as the electrolyte. These cells have flat plane configuration and are often designed as rolled tubes.



Operating temperatures of these cells are (800-1000 degree centigrade).they run on a variety of fuels including natural gas.

SOFC`s have efficiencies of the order of 50-60% during conversion of fuel to electricity.

The electrochemical reactions involves are as follows:

Anode reaction: $2H_2 + 2O^{2-}$------------$2H_2O + 4e^-$

Cathode reaction: $O_2 + 4e^-$--------$2O^{2-}$

Overall cell reaction: $2H_2 + O_2$----------$2H_2O$

Applications of SOFC:

- SOFC has a large numbers of applications from use an auxiliary power in vehicles to stationary generation with outputs from 100 W to 2MW.
- SOFC is often used in the transportation sector, such as trucks and automobiles.
- SOFC can probably be used as the auxiliary power units to run electrical systems like air conditioning.

Advantages of SOFC`s:

- High efficiency is the main advantages of the SOFC.
- SOFC uses the natural gas directly.
- The heat produced by SOFC can be utilized in co-generation.
- Used electrolyte is solid, which avoids the electrolyte movement or flooding in the electrode.

Disadvantages of SOFC`s:

- They operate at high temperature. Due to this high temperature many conditions occurred on materials options and results difficulties in production processes because there are many materials that cannot bear so high temperature.
- The corrosion of metal stack components is another problems of SOFC`s
- Manufacturing cost is a huge issue for SOFC`s.

3. EFFICIENCY OF A FUEL CELL:

Efficiency can be defined in many ways actually it is based on the maximum energy that could be gained from a fuel by burning. It is called the heating or calorific value. The efficiency of a fuel cells is focused on the amount of power that could be obtained from the fuel.

4. CONCLUSION:

The recent thrust in development of clean and renewable energy sources has brought the fuel cell technology in the limelight. now being looked upon as clean energy sources , fuel cells have the potential to revolutionize the domain of energy generation . Provided electrochemical technology advances, the overall catalyst and electrode prices decrease, fuel cell technology may qualify as a new core technology for conversion of chemical energy to electricity and open up new vistas for utilization of previously untapped sources for electricity generation.

REFERENCES:

[1] Andrea, E.; Ma˜nana, M.; Ortiz, A.; Renedo, C.; Egu´ıluz, L.I.; P´erez, S.; Delgado, "A simplified electrical model of small PEM fuel cell," University of Cantabria, Spain.
[2] S.P.S. Badwal, K. Foger, "Solid Oxide Electrolyte Fuel Cell Review," Ceramics international, vol. 22, pp.257–265, 1996
[3] Nice, Karim and Strickland, Jonathan. "How Fuel Cells Work: Polymer Exchange Membrane Fuel Cells," [Online]. Available: http://auto.howstuffworks.com/fuelefficiency/alternative-fuels/fuel-cell2.htm
[4] B. Kakati, V. Mohan, "Development of low cost advanced composite bipolar plate for P.E.M. fuel cell", Fuel Cells, vol. 08(1), pp. 45–51, 2008.
[5] L. Carrette, K. Friedrich, U. Stimming, "Fuel cells-fundamentals and applications," Fuel Cells, vol. 1(1), pp. 5–39, 2001.
[6] D Friedman, R Moore, "PEM fuel cell system optimization," in: Proc Electrochem Soc, 1998, paper 27, pp 407–423.
[7] EG & G Technical Services, Inc. Science Applications International Corporation (2002) IN: U.S. Department of Energy, Fuel Cell Handbook, 6th edition, Morgantown, West Virginia, USA.
[8] Phosphoric acid fuel cell technology (Accessed 4 January 2014) [Online], Available: http://americanhistory.si.edu/fuelcells/phos/pafcmain.htm
[9] Solid Oxide Fuel Cell (SOFC) (Accessed 4 January 2014) [Online], Available: http://www.fctec.com/fctec_types_sofc.asp
[10] A. B. Stambouli, E. Traversa, "Solid oxide fuel cells (SOFCs): a review of an environmentally clean and efficient source of energy," Renewable and Sustainable Energy Reviews, vol. 6, pp. 433–455, 2002.
[11] A. Dicks, "Molten carbonate fuel cells," in: Curr Opin Solid State Mater Sci, vol. 8, pp.379–383, 2004.
[12] "Molten Carbonate Fuel Cell Technology". U.S. Department of Energy, (Accessed 5 January 2014) [Online], Available: http://www1.eere.energy.gov/hydrogenandfuelcells/fuelcells/fc_types.html
[13] Fuel Cell Energy Inc, USA, (Accessed 5 January 2014) [Online], Available: www.fce.com
[14] W. Habermann and E-H Pommer, "Biological fuel cells with sulphide storage capacity," in: Appl. Microbiol. Biotechnol. Vol. 35, pp. 128–133
[15] K. Rabae and V. Willy "Microbial fuel cells: novel biotechnology for energy generation," in:TRENDS in Biotechnology, Vol.23 No.6. June 2005.
[16] Microbial Fuel Cells Q&A, Penn state College of Engineering, USA. [17] Comparison of fuel cell technologies, Study Report, US Dept. of Energy