International Journal of Scientific Engineering and Research (IJSER)
www.ijser.in
ISSN (Online): 2347-3878
Volume 2 Issue 8, August 2014

Fuel Cell Types and Factors Affecting Them

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Abstract: ***Fuel cell is an excellent power generation source where electric current is generated with no environmental or noise pollution as the end product of the process is heat and water. This technology in which about six fuel cell types evolved in the pasted decade was base on the electrolyte used in each, and has a major limitation in competing with other contemporary power technology sources due to the high capital cost of the various fuel cells that arises mainly from the use of platinum or nickel as catalyst. The high cost of fuel cell is by far the largest factor contributing to the limited market penetration of the technology. This paper examines the components of the fuel cell types that gives rise to the various features exhibited by each fuel cell type and concluded that proton exchange membrane fuel cell [PEMFC] is the most favourite and most likely to be developed easily in other to compete with other contemporary energy source in terms of price and efficiency.***

Keywords: fuel cell, temperature, electrolyte, efficiency, catalyst, power density.

1. Introduction

Fuel cell [FC] is an electrochemical device which generate electricity via a chemical reaction that convert the chemical energy stored in fuels like hydrogen into an electric energy [1]. FC operates by a reverse principle of electrolysis whereby water is formed from hydrogen and oxygen as current is being generated. FC comes in different sizes and a particular FC is defined by the type of electrolyte used in it hence, about six types of FCs have evolved in the past decade. [8] The various FC types all operate by the same principle with a slide difference which arises due to the difference in electrolyte used by each. Proton exchange membrane fuel cell [PEMFC], Direct methanol fuel cell [DMFC] and Phosphoric acid [PAFC] have the same principle with electrolyte moving hydrogen ions from anode to cathode, in Alkaline fuel cell [AFC], hydroxyl ions moves from cathode to anode, in Molten carbonic fuel cell [MCFC] the carboxyl ions moves from cathode to anode and in the Solid oxide fuel cell [SOFC], oxygen ions moves from cathode to anode.[5][7][12] One great advantage of fuel cell among others is the fact that it generates electricity with very little pollution as it forms harmless waste products of water and heat. Although FC technology is an excellent technology, it is face with a major challenge of cost where it is very expensive to set up. It is therefore important to comparatively study the various fuel cells types with a view to come out with the best in terms of cost, operational principle and uses. This study compares the operation, uses and working principle of the various fuel cells using the following parameters;

- Operating temperature.
- Electrolyte used.
- Efficiency of the cell.
- Catalyst.

Each fuel cell has different characteristic influenced by the parameters above making it suitable for specific application. These characteristics are seen in the table below;

Table 1: Features of the fuel cell types

	PEM water - cooled	PEM air cooled	DMFC	AFC	HT PEM	PAFC	MCFC	SOFC
Typical output range	1 - 100 Kw	mW - 1 kW	mW - 1 kW	1 - 5 kW	100 W - 10kW	25 kW - 125 Kw	50 kW - 125kW	mW - 125 kW
State of development	Pr	Pr	Pr	Pr	D	Pr	Pr	D
Scalability	E	Li	Li	P	U	Li	P	P
Turndown dynamics	E	Mo	Mo	P	Mo	Mo	P	P
Power density	E	Mo	P	P	Mo	P	P	Mo
Quality of heat	L	N	L	L	M	M	H	H
Variety of fuels	P	P	P	P	Mo	Mo	Mo	G
Sensitivity to contaminants	H	H	H	H	M	M	L	L
Start-up time	F	F	F	F	M	M	S	S
Robustness	E	E	Mo	Mo	U	E	P	P
Lifetime	G	Mo	Mo	Mo	U	E	G	P

Pr=Proven; D=Development; E=Excellent; Li=Limited; P=Poor; U=Unknown; Mo=Moderate; L=Low; N=Nil; M=Medium; H=High; G=Good; F=Fast; S=Slow

Source: www.nedstack.com/technology/fuel-cell-comparis

2. Basic Component of Fuel Cell

2.1 Operating Temperature

For electrolyte to conduct ions or reactants from one electrode to another in the FC, it must be heated to a particular temperature unique to each electrolyte. This temperature range is known as temperature window. base on the operating temperature of a fuel cell, the various fuel cells are classified into two i.e. low temperature fuel cell

[PEMFC, PAFC DMFC AND AFC] with temperature between 40-200°C, and high temperature fuel cell [MCFC AND SOFC] with temperature between 400-1000°C. [5][2]

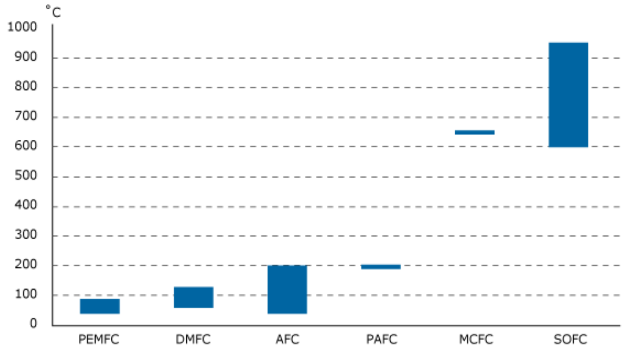


Figure 1: Fuel cells and their temperature window
Source: www.nedstack.com/technology/fuel-cell-comparis

The variation in operating temperature of the various fuel cells is largely due to the physical property of the electrolyte which defines the cell. E.g. the physical state and ionic conductivity of the electrolyte plays a vital role in the operating temperature of the fuel cell. The low temperature FC has mostly liquid state electrolyte which require low temperature for ionic conductivity while the high temperature FC with solid and molten state electrolyte require a high temperature for its ionic conductivity. E.g. SOFC with an operating temperature of 950° C has an electrolyte consisting of asolid material yttria-stabilized zirconia [ysz] which requires a very high temperature for ionic conductivity in other to move ions from one electrode to another. [6] The FC reaction is an exothermic reaction where heat is generated as bi product and the operating temperatures of the FC usually affect some features of the FC which includes;

- Start up time
- Life time
- Variety of fuel used
- Sensitivity to contaminant
- Output range
- Robustness
- Pressure variation etc.

This is explained in table 1 above.

Basically, the low temperature FCs do not require the cooling and thermal shielding necessary for high temperature FCs hence the additional cost incurs for that is saved. Application of the high temperatures FC is mostly limited to stationary appliances because they are mostly robust whereas the low temperature FC has wider application where they can be used in both mobile and stationary appliances. [2][4][5]

2.2 Electrolyte

Electrolyte in fuel cells are chemical compounds in liquid, molten or solid forms which are design or selected base on ability to transmit a specific ion or reactant from one electrode to another while preventing the protons from passing through. [11][13] The electrolyte of a FC determines the operating temperature and the catalyst of the cell and these two factors [operating temperature and catalyst] determine the overall cost of the FC. The various electrolytes are seen in the table below

	Operating temp. (°C)	Fuel	Electrolyte
PEMFC	40-90	H_2 (/CO_2)	Polymer
AFC	40-200	H_2	KOH
DMFC	60-130	Methanol	Polymer
PAFC	200	H_2 (/CO_2)	Phosphoric Acid
MCFC	650	CH_4, H_2, CO	Molten Carbonate
SOFC	600-950	CH_4, H_2, CO	Solid Oxide

Noble metals Noble metals/non-noble metals Non-noble metals

Figure 2: Electrolytes used in the various fuel cells.
Source: www.nedstack.com/technology/fuel-cell-types

2.3 Efficiency

This refers to the efficiency of a process that converts chemical potential energy contained in the fuel into kinetic energy or work. The efficiency of a FC is measured by the ratio of the amount of useful energy put out by the cell [energy output] to the total amount of energy put in [energy input].

$$\text{Energy efficiency} = \frac{\text{Energy output}}{\text{Total energy input}}$$

Energy output = electric energy produced by the cell
Energy input = energy stored in the fuel.

The efficiency of a fuel cell stack [system where numbers of cells are put in series to increase voltage] is given by;

$$\mathbf{Eff_{el,\,sys} = Eff_{FC} * Util_{H2} * [1-[Power_{BOC} / Power_{Fuel\ cell\ system}]]}$$

Whereby Eff_{FC} = efficiency of the fuel cell stack, $Util_{H2}$ = utilization of the hydrogen and PowerBOC = power consumed by the balance of plant components. [9][11]

One key factor under which FC is marked is their efficiency and some of the factors that influence the efficiency of a FC are;

- **Operating at a high cell voltage**; systems that offer high power densities at high cell voltages are clearly to be preferred: The fuel cell efficiency for hydrogen/oxygen fuel cells can be obtained by dividing the cell voltage at operation by 1.23 V. Hydrogen/oxygen fuel cells operated at 0.7 V thus have an electrical efficiency of 0.57. This energy efficiency number is based on the lower heating value of hydrogen.
- **Maximizing the utilization of hydrogen.** Open systems with low hydrogen stoichiometries, or closed systems with low purging frequencies, lead to less waste of hydrogen and thus to an increased efficiency.
- **Minimizing the flow of air.** As the flow of air is generally a factor of 4 higher than the flow of

hydrogen, the energy needed for supplying this air can pose a significant parasitic loss.

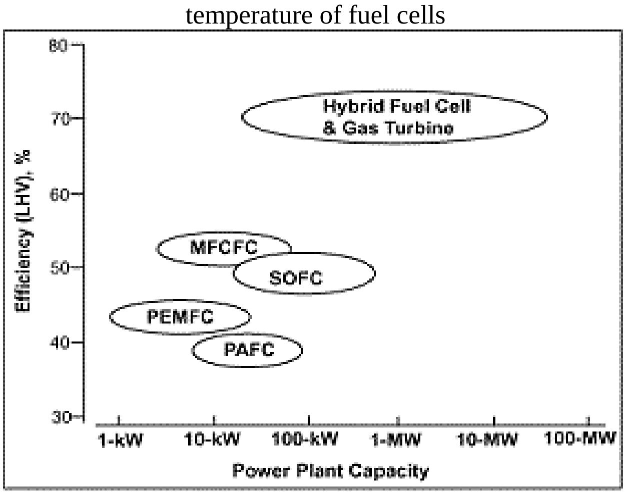
- **Minimizing the pressure drop at anode and cathode.** The pressure drop of the flow field and manifolds requires an increase of the reactant pressure at the inlet that directly leads to an increase in parasitic energy consumption.

Generally, FCs has efficiency of about 40 – 60% which is higher than some internal combustion engine. For a combine heat and power [CHP] system, the heat produce by FC is captured and put to use hence increase the efficiency of the system up to 75 – 90%, this is responsible for higher efficiency in most high temperature FC. [1][3]

Theoretically, FC operating at low power density and using pure hydrogen and oxygen as reactant with no heat recaptured and used, has an efficiency of 83%. This is rarely reached in practice and is not ideal for the various FC types as each FC type has unique electrolyte and hence catalyst that define it. Other factors such as electric production, transportation and storage also play a role in reducing overall efficiency of a system hence in practice, the maximum efficiency of a system using pure hydrogen and oxygen is between 35 – 50%.

Low temperature FC has lower efficiency than the high temperature FC as shown in the diagram below.

Figure 3: Relationship between efficiency and temperature of fuel cells



Fuel Cell System Efficiencies

Source; http://www.nfcrc.uci.edu/3/FUEL_CELL_INFORMATION/FCexplained/FC_benefits.aspx

2.4 Catalyst

In a chemical reaction, the action of catalyst lowers the activation energy required for a reaction to proceed faster or at a lower temperature. So far, the most excellent catalyst of the hydrogen FC is the platinum catalyst where it catalyses the oxidation reaction that separates electrons [e^-] from protons [H^+]. Platinum is a very expensive and scarce metal hence account for almost 35% of the cost of a FC. [1] The high capital cost for FCs is by far the largest factor contributing to the limited market penetration of FC technology. In order for FC to compete realistically with contemporary power generation technology, they must become more competitive from the standpoint of both capital and installed cost [the cost per kilowatt required to purchase and install a power system]. Aside the expensive nature of this metal, it is sensitive to carbon monoxide poisoning requiring a system to prevent it thus can only be use in pure hydrogen FC. Several techniques are being developed to replace the use of precious metals like platinum and ruthenium thereby reducing the cost of the FC. E.g, in PEMFC, the cost of production can be reduced by a modification that eliminates the use of platinum. It deploys the use of solid polymer electrolyte as catalyst hence the name platinum free membrane fuel cell [PFMFC]. This is possible because polymer electrolyte conduct hydroxyl ion [OH^-] rather than protons. This means the proton free membrane is midly alkaline thereby enabling the use of low cost transition metal rather than platinum and because the midly alkaline environment is non-corrosive, light weight aluminium infrastructure can be used for the PRMFC. [11]

3. Discussion

Table 1 shows the characteristics of the various FC types. Each characteristics exhibited by the FC is influenced by either of the parameters i.e. operating temperature, electrolyte, efficiency and catalyst. Ideally, none of the FC types satisfy all the characteristics hence are not competing realistically with other contemporary power generation technology. To develop a FC type that must meet up with other contemporary power generation technology, it must satisfy but not limited to the following characteristics;

3.1 Cost effectiveness

In a step toward eliminating what industries regard as the largest obstacle to large-scale commercialization of fuel cell technology, is the discovery of a metal-free catalysts using an affordable and scalable process making it more stable than platinum catalysts and tolerate carbon monoxide poisoning and methanol crossover. An efficient FC type with additional technology that reduce greatly the overall market cost of a fuel cell will make it compete realistically with other contemporary power technology sources. The low temperature FC tends to cost less that the high temperature FC.

3.2 Fast or early start up time

This refers to the time taken for a FC to attain the temperature window at which it becomes operational. As the operation temperature of a FC increases, the start up time also increases hence the characteristic favours the low temperature FC as they operate at a low temperature. Even the low temperature FC still requires an appreciable high temperature making FC generally to have a delay start up time there by limiting the general application of the FCs.

3.3 Robustness

An efficient FC that is less robust in size is required mostly for mobile application. The electrolyte hence its mode of operation result to the robustness of a particular

FC. High temperature FC such as SOFC and MCFC requires heavy metal material like ion for infrastructure making them robust hence are mostly used for stationery applications; also the cooling and thermal shielding system of the FC increases its robustness hence the cost.

3.3 Life time

FC with an excellent life time has additional market advantage due to its potential durability. The electrolyte and catalyst used in a FC determines to a large extend its life time. Where the electrolyte turns corrosive in the process of transporting H^+, it courses the metal component to erode hence life time of such FC is reduced. When the catalyst used at the electrodes gets depleted in the process, the life time of such a FC tends to reduced. From table 1 above, most low temperature FC such as PEMFC has excellent life time while the high temperature FC such as SOFC has poor life time. Although ceramics used in some SOFC are suitable to provide the strength, electrical, thermal and corrosive resistant properties needed, they also increase the cost of production to a large extend.

3.4 Power density

This refers to the amount of power [time rate of energy transfer] per unit volume. Power density varies from one FC type to the other e.g. PEMFC has a rated power density of $0.7W.cm^{-2}$ depending on operating conditions which is accounted for by the catalyst and electrolyte used. The action of the catalyst on H_2, facilitate the release of electrons which are passed through wire outside the cell thereby generating electric current. The effectiveness of the catalyst used and ability of the electrolyte to move ions from anode to cathode very fast, determines the power density of a FC. FC type that will compete realistically in the energy market must be of excellent power density and this is achieved by careful selection of the catalyst and electrolyte used.

4. Conclusion

FCs varies in their application and the characteristic of a particular FC determines the suitability of its application. Efficiency, cost advantage, Fast start up time and less robustness of a FC will gives it a clear advantage for market penetration. This characteristic favours mostly the PEMFC with a fast start up time, less robust and high power density. FC for Stationary applications used for powering a commercial, industrial or residential building and those used for combine heat and power generation may not necessarily require having a fast start up time, or being less robust however possessing these characteristics may be of great importance in marketing the FC. This shows that PEMFC is the most outstanding of all the FC types and can best be manipulated to compete realistically with other contemporary energy generation technologies.

5. Recommendations

In the light of the above listed problems of the FC technology and their possible solutions, the following recommendation is hereby offered:

1. More attention should be given to the development of PEMFC by way of research to develop more possible way of replacing platinum as catalyst.
2. More effort should be put into research to come up with more alternative fuel sources other than pure H_2 for the PEMFC.

Reference

[1] Anne-Claire Dupuis, Progress in Materials Science, Volume 56, Issue 3, March 2011, pp. 289–327; Measuring the relative efficiency of hydrogen energy
[2] Comparision of fuel cell technology. US department of energy, energy efficiency and fuel cell technology program, February 2011.
[3] J. Han, J. Charpentier, T. Tang. An energy management system of a fuel cell/Battery hybrid boat. Energies 2014, 7, 2799-2820; doi:10.3390/en7052799
[4] J. Milewski, A. Miller, K. Badyda. The Control Strategy for high temperature
[5] Fuel Cell Hybrid Systems. Online Journal on Electronics and Electrical Engineering [OJEEE] Vol. [2] – No. [4]Reference Number: W10-0034 331
[6] J. Ugartemendia, J.X. Ostolaza, I. Zubia. Operating point optimization of a hydrogen fueled hybrid Solid Oxide Fuel Cell-Steam Turbine [SOFC-ST] Plant Energies 2013, 6, 5046-5068; doi:10.3390/en6105046
[7] http://americanhistory.si.edu/fuelcells/basics.htm
[8] http://www.nedstack.com/technology/fuel-cell-comparison
[9] http://www.nedstack.com/technology/fuel-cell-type
[10] http://www.nfcrc.uci.edu/3/FUEL_CELL_INFORMATION/FCexplained/FC_benefits.aspx
[11] http://www.nfcrc.uci.edu/3/FUEL_CELL_INFORMATION/FCexplained/FC_Types.aspx
[12] http://www.statemaster.com/encyclopedia/Fuel-cell
[13] http://www.thefullwiki.org/Stationary_fuel_cell_applications
[14] http://en.wikipedia.org/wiki/Fuel_cell