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Fuel Cell and Its Applications: A Review

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Abstract **- Energy is the most fundamental requirement of today's era. Energy is consumed very rapidly. The energy requirements are very increasing. Our population, abundant energy resources and industrial diversity make our self proficient enough in producing and consuming energy. This will definitely leads in contributing to the national economy. It is the fact that initially there is a cost issue with every new technology but gradually developing mind we can cope up with it. The need for optimization in cost and efficiency can create systems which are cost effective, non- hazardous in nature, commercially available, clean fuel, compete with regular ongoing systems, inherently safe in handling, having renewable power and sustainable to nature.**

We envision a future where industries can fulfil the growing demands in an environmentally sustainable way. Hydrogen fuel cells have the real potential to be the future technology in terms of applicability. This technology has the solution to the problem of increasing requirements in an environmentally viable option.

This review article presents the working operation of Hydrogen Fuel Cell, Classification of fuel cell in a comparable way, applications, new developments, future technologies and economic growth.

Fuel cell is very much similar to the electrochemical cell or an ordinary dry cell. There are basically three components in each and every fuel cell. They are cathode, anode and electrolyte. They are connected with the electrical circuit. This construction has no rotating parts in its design. Hence, they are pretty simple and efficient in design. The classification is based on the type of electrolyte used.

Keywords: Fuel cell, Efficiency, electrolyte, cathode, anode and energy conversion.

I. INTRODUCTION

Fuel cell is an energy conversion based device. This will harness the power of hydrogen. Hydrogen is a handy fuel, which have the potential to power anything. It s versatility can produce clean and sustainable power in nature. A fuel Load cell is simple in its operation. It is nothing but electrochemical cell that converts the chemical energy from fuel into electricity. It occurs through the electrochemical reaction of hydrogen and oxygen. There occurs the flow of electrons from one electrode to another through the electrolyte. There are classifications based on types of electrolyte. Its working is very easy to understand. It is clean and environmentally viable option. Here, the energy is liberated by the chemical reaction by the flow of electrons and electrical energy is produced. The very first demonstration of simple basic fuel cell was given by Lawyer and Scientist William Grove in 1839, in his experiment the water was electrolysed into hydrogen and oxygen by passing an electric current by the help of battery, then after it was replaced by multi meter, and a small current is obtained through it. Here, the products are neither pollutants nor harmful in nature. The electrolysis is being reversed by recombining and the products are water. Hence, the electric current is generated. The hydrogen fuel is being burnt or combustion takes place in simple reaction, which is represented as follows:

$$2H_2 + O_2 \rightarrow 2H_2O \quad \text{---------- (1)}$$

There are three components in the structure of fuel cell. They are anode, cathode and electrolyte. The reaction takes place at anode and cathode.

At the anode of electrolyte in the fuel cell, the hydrogen gas get ionises which leads to release of electrons and creating H+ ions (or protons).

Anode:

$$2H_2 \rightarrow 4H^+ + 4e^- \quad \text{---------- (2)}$$

This reaction releases energy.

At the cathode, the oxygen gets reacted with the electrons released from electrode and H^+ ions from the electrolyte. This results in the formation of water.

Cathode:

$$O_2 + 4e^- + 4H^+ \rightarrow 2H_20 \quad \text{--------- (3)}$$

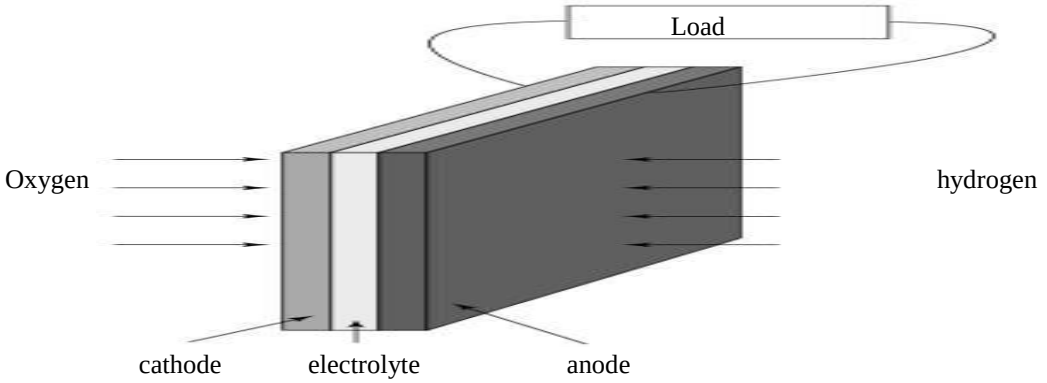

Fig.1 Construction of Fuel cell

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Generally, there are three segments of any type of fuel cell. They are as follows:
1) Anode,
2) Cathode and
3) Electrolyte
The main segment of any fuel cell is electrolyte. The type of the electrolyte tells about the nature, characteristics and its operation. Hence, it is said that type of electrolyte used describes the type of fuel used. Whatever may be the fuel cell type used, their principle of working will always be the same.
Considering these three segments in combination, the chemical reaction takes place in such a manner of generating electric power without giving harm to environment.
There may be the catalyst at anode. Catalyst can be platinum powder. Or there may be the arrangements where platinum electrodes are used. The catalyst is used to oxidize the hydrogen fuel. The hydrogen gas turns into ions and electrons. The ions make their way through electrolyte to the cathode. After reaching the cathode, they get combines with the cathode and starts reacting with the oxidant, which results in producing water. The ions pass which leads to production of electricity. Nickel is also mainly as cathode catalyst. This process results in formation of electricity at the load and the by-products formed in the reactions is water.
The fuel cell at the full load can produce the electricity up to 0.7 volt, the desired voltage electricity can be obtained by connecting the fuel cells in series and desirable amount of current can be procured by connecting the fuel cells in parallel arrangements.
There is no harm to the atmosphere in this technology. But there are losses involved in the mechanism. These loses can be minimized to a certain extent. These losses undergo to have lesser amount of voltage at higher current rate. The losses involved are ohmic losses, activation losses and also due to the mass depletion of reacting species, which is known as mass transport loss.

II. CLASSIFICATION OF FUEL CELL

Fuel cell is classified based on the type of electrolyte they is used in the operation. This employs to the chemical characteristic of the type of fuel cell. The kind of electro chemical reaction in the operation defines its type. There are certain factors like the fuel required which directly tends toward the type of electrolyte used that is the type of chemical reaction occurring in the mechanism. Addition to these the characteristics mentioned will obviously affect the application of fuel cell. There are certain fuel cells designed for a particular usage. Each fuel cell has its own characteristic, advantages and limitations. There potential is defined by these. Depending upon this their applicability is decided. There are still ongoing researches, which gives birth to the newer fuel cell. Every type of fuel cell has its own electrolyte, operating temperature, anode reactions, cathode reactions, applications, advantages and disadvantages. They are distinguished as following in the table:

TABLE1. CLASSIFICATION OF FUEL CELL

FUEL CELL TYPES	Polymer Electrolyte Membrane (PEM)	Alkaline (AFC)	Phosphoric Acid (PAFC)	Molten Carbonate (MCFC	Solid Oxide (SOFC)	Microbial Fuel Cell
Common Electrolyte	Perfluoro sulfonic acid	Aqueous solution of potassium hydroxide soaked in a matrix	Phosphoric acid soaked in a matrix	Solution of lithium, sodium, and/ or potassium carbonates	Yttria stabilized zirconia	Microbes
Operating Temperature	50-100°C 122-212° typically 80°C	90-100°C 194-212°F	150-200°C 302-392°F	600-700°C 1112-1292°F	700-1000°C 1202-1832°F	Ambient Temperature
Anode reactions	$H_2 \rightarrow 2H^+ + 2e^-$	$H_2 + 2OH^- \rightarrow 2H_2O + 2e^-$	$H_2 \rightarrow 2H^+ + 2e^-$	$H_2 + CO_3^{2-} \rightarrow H_2O + CO_2 + 2e^-$	$H_2 + O^{2-} \rightarrow H_2O + 2e^-$	
Cathode Reactions	$'1/2O_2 + 2H^+ + 2e^- \rightarrow H_2O$	$1/2O_2 + H_2O + 2e^- \rightarrow 2OH^-$	$1/2O_2 + 2H^+ + 2e^- \rightarrow H_2O$	$'O_2 + CO_2 + 2e^- \rightarrow CO_3^{2-}$	$1/2O_2 + 2e^- \rightarrow O^{2-}$	
Efficiency	60 % transportation 35% stationary	60%	40%	45-50%	60%	50%
Applications	• Backup power • Portable power • Distributed generation • Transportation • Specialty vehicles	• Military • Space	• Distributed generation	• Electric utility • Distributed generation	• Auxiliary power • Electric utility • Distributed generation	Bio energy process

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Advantages	• Solid electrolyte reduces corrosion & electrolyte management problems • Low temperature • Quick start-up	• Cathode reaction faster in alkaline electrolyte, leads to high performance • Low cost components	• Higher temperature enables CHP • Increased tolerance to fuel impurities	• High efficiency • Fuel flexibility • Can use a variety of catalysts • Suitable for CHP	• High efficiency • Fuel flexibility • Can use a variety of catalysts • Solid electrolyte • Suitable for CHP & CHHP • Hybrid/GT cycle	Advantages of MFCs include use of wide variety of organic materials as fuels, as well as their efficient operation at ambient temperature
Disadvantage	• Expensive catalysts • Sensitive to fuel impurities • Low temperature waste heat	• Sensitive to CO2 in fuel and air • Electrolyte management	• Pt catalyst • Long start up time • Low current and power	• High temperature corrosion and breakdown of cell components • Long start up time • Low power density	• High temperature corrosion and breakdown of cell components • High temperature operation requires long start up time and limits	Low power densities as compared to other technologies put this technology at a slight disadvantages.
References	[3]	[4]	[3]	[3]	[5]	[3]

III. APPLICATIONS

The fuel cells are in the limelight due to its accountability of efficiency. It is very much simple in the operation. The fact of its low emission device and silence is the authentication that it creates the space to be used in today's era. It confirms strongly that this technology has such compatible features that it is much better in comparison to the ongoing combustion engines, pistons and turbine technologies. The feature of fuel cell not only makes it viable to be used on small scale but also at large scale. From potable power systems for mobile to the vehicle, electronic equipments to the major application in Apollo space station in NASA's space shuttle the fuel cell technology has made its presence so powerful. The applications of major areas are presented in the following table:

TABLE2. Application of Fuel cell Technology

Attribute	Description Of the Attribute
Stationary Power	The fuel cells have found the major applications in power generation because of its higher efficiency. The low and high temperature fuel cell both are potential enough to be utilized in this area of application. The fuel cells like PEM, SOFC AND PAFC are generally employed for small power systems. The low temperature and high temperature fuel cell both have their own applicability. Generally the low temperature fuel cells have the advantage of giving faster start up time. The operating time needed is 40000 hours for the stationary applications. This start up operating time is a major obstacle in the fuel cell operation. There are fuel cells like SOFC and MCFC which are high temperature fuel cell. These type of fuel cell can directly be applied in place of heat cycle or can be used in an indirect way into combined systems of cycles.
Transportation	In today's era the means of transport plays a vital role. The ongoing technologies are not environmentally sustaining in nature. So there is need to change the technology. The scientists have realized that they can demonstrate the vehicles with PEMFC technology. This technology can replace the older complicated technology. PEMFCs have its own advantage of low operating temperature range. The PEM techniques are suitable for the transporting devices. The main favouring point to consider is these technologies don't require pure hydrogen used as fuel, can be operated without any rotating parts. Also, it doesn't exhibit any significant poisoning systems. There are benefits recognized recently in several companies like BMW, Delphi automotive systems, etc. They have developed SOFCs as auxiliary power unit and companies implementing PEM fuel cells replacing hydrogen combustion engine. It is implemented in BMW7series and was found successful.
Portable Devices	This will be the widely used major applications of fuel cell in the equipments such as portable computers, mobile phones, telephones and one of the important applications is military application. This area will include sustainability in terms of expansion.
Space Applications	Space applications have proved that this technology is the most viable option for conventional energy resource. It can produce 1.5 kilowatts of continuous electrical supply. It was exemplary seen in the Apollo missions. The powerful alkaline fuel cells were highly reliable. The fuel cell is capable for supplying almost 12 KW continual periods and 16 KW for short period. The shuttle program in itself is the major and outstanding reliability. This in space not only provided electrical power but also was used by astronauts for the drinking purposes.

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IV. NEW DEVELOPMENT AND FUTURE TECHNOLOGY

The Direct Methanol Membrane was earlier invented and initially developed at the Jet Propulsion Laboratory in Pasadena, California. It is the ongoing development. They were initially used in the application in the armed forces and the in NASA space applications. But then after it was found that they were capable of playing an essential role in transportation and portable devices application. Ballard Power, Motorola, the Los Alamos National Laboratory and Manhattan Scientific are all actively pursuing the development of the direct methanol fuel cell. Motorola claims that a portable cell phone will be able to remain fully charged on standby for a month rather than days. The company has also announced that it plans to have its version commercially available in three to five years.[7]

Also, in Microbial fuel cell the electricity is generated from human waste. The technology is so much developed that demonstrations are going and results are analysed in laboratories. Electrons are released in the process because bacteria utilizes enzyme to oxidize the matter.

There are many industries which uses low grade high ash graded coal through fluidized bed gasification to power the solid oxide fuel cells.[8]

India is a developing country, many rural areas suffers in lack of electricity. Looking forward to this loophole which is needed to be filled as soon as possible, considering the growing technology in the world. For enlightening our technical part, we can consider the Fuel cell as the best cost effective clean, non-polluted, non-hazardous, sustainable and environmentally safe.[9]

Many reviews and researches have been done recently over the fuel cell. Introduction to fuel cell technology : a review which explained fuel cell technology. 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.[10]

Another review Fuel cell Technology : A Review. This review talks about the different types of fuel cells and their fundamentals. Various characteristics of the different fuel cell types such as operating temperatures, efficiencies, are compared.[3] Their main considerations were Different types of fuel cell and their fundamentals like operating temperature and efficiencies are compared. More over the review: Applications of proton exchange membrane fuel cell systems was done. They introduced and discussed the remaining challenges and some of the latest research on the application test of PEMFC to real systems such as transportation, residential power generation and portable computers. Many researches are on going on this technology.

TABLE3 Number of journal papers for various year ranges.

Query keyword	Year range	Number of journal papers
Hydrogen energy	1900-2007	52,576
Fuel cell	1900-2007	14,711
Hydrogen energy	2000-2007	28,258
Fuel cell	2000-2007	11,165

TABLE3. Number of patents for various year ranges.

Query keyword	Year range	Number of patents
Hydrogen energy	1963-2007	10,576
Fuel cell	1963-2007	47,120
Hydrogen energy	2000-2007	5,228
Fuel cell	2000-2007	34,756

V. EFFICIENCY OF FUEL CELL

Since fuel cells use materials that are typically burnt in order to release their energy, the fuel cell efficiency is defined as the ratio of the electrical energy produced to the heat that is produced by burning the fuel (its enthalpy of formation or Δhf). In simple words the efficiency of fuel cell can be explained on the basis of amount of power that could be gained from the fuel. Other words can be defined as ratio of output to input.

VI. CONCLUSION

Fuel cells are simple, environmentally clean, efficient, and low emission device. These factors in itself makes fuel cell to hold wide range of applications. There is thrust to find the way mankind can generate as much as electricity in an sustainable way. Fuel cells have real potential to qualify as technology from which electricity can be generated with harmless by products.

As our demand for electrical power grows, it becomes increasingly urgent to find new ways of meeting it both responsibly and safely.

In the past, the limiting factors of renewable energy have been the storage and transport of that energy. With the use of fuel cells and hydrogen technology, electrical power from renewable energy sources can be delivered where and when required, cleanly, efficiently and sustainably.[10]

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