Hydrogen Fuel Cells- Space Application

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***Abstract*—Since the dawn of space age, hydrogen has been vastly used as a fuel, predominantly by NASA for rockets utilized in space exploration. Liquid hydrogen is the most obvious choice for liquid bi-propellant rockets where hydrogen burns in the presence of an oxidizer, to generate thrust. Till now bi-propellant rockets have the highest specific impulse (total impulse generated per unit weight of propellant) & the most efficient in the category of chemical rockets. But due to certain limitations, they are a hindrance to realize deep space missions where tremendous quantity of fuel is an absolute necessity. So why not tackle this situation where the rocket never runs out of the propellant. A possible solution could be "Hydrogen Fuel Cells". With the purpose of generating an electric current which could power any outside equipment either by using electricity or heat along with they could be a viable replacement for existing propulsion systems. A fuel cell is an electrochemical device that combines hydrogen and oxygen and generates electricity, with water and heat as its by-product. In its simplest form, a single fuel cell consists of two electrodes - an anode and a cathode - with an electrolyte between them. As per the working of fuel cell, it never runs out of fuel which could be a crucial factor in deciding the future propulsion techniques. But there are certain challenges as well which need to be mitigated in order to achieve complete utilization of fuel cells in the space applications.**

Keywords—Hydrogen, Fuel Cell, NASA

I. INTRODUCTION

Hydrogen is the first element in the periodic table of elements. It is the lightest element which is never found alone in existence and is even lighter than the air. It has the highest energy content per unit weight of all the fuels. It has no smell, no color and no taste. NASA has been harnessing these unique characteristics of Hydrogen to conduct missions. [1]

A. The Problem

In the present scenario based on the energy source, chemical rockets are the most obvious choice for space propulsion technologies. Among this category, Bi-propellant rockets have been the most common type of rockets in the utility until today. They imply the use of an oxidizer along with a fuel to burn and provide thrust as per the demands. Bi-propellant rockets generate the highest specific impulse (total impulse generated per unit weight of propellant). In other words, they can carry a heavier payload for a lesser quantity of propellant, making them the most efficient in the category of chemical rockets. They have the capability of achieving higher performance and versatility. Also, they provide the aspects of throttling as well as control for a wide range of thrust. But there are certain drawbacks. For instance, the liquid propellant as well as the oxidizer needs to be fed at a high pressure for ignition to generate thrust, for which there is a requirement of either pump feed or pressure feed system. This not only contributes to the increment of the dead weight of the rocket but it also causes an increment in the complexity of the system.

This could result in the failure of the entire system. Also, once the propellant is burned off, it is over. We cannot get any extra propellant in the space to resume the mission. So, there is a limit as to how much propellant could be carried on the rocket. And as per the needs of the future space missions, it is necessary to have a subsequent plan of action. Also, a significant amount of propellant is lost due to storage boil off and while transferring the propellant. To meet the future mission demands and to make deep space missions a reality, it is need of the hour to find a suitable replacement which could help realize deep space exploration missions.

B. The Solution

Why not tackle this situation where the rocket never runs out of the propellant? A possible solution could be "Hydrogen Fuel Cells". Their aim is to generate an electric current which could power any outside equipment either by using electricity or heat. Hydrogen Fuel Cells eliminate the concern of exhaustion of the propellant. Also, it helps in alleviating the complexity of propulsion system, thereby reducing the overall weight of the system. And since the electricity generation involves purely chemical process, there is an increment in the overall efficiency.

II. FUEL CELLS

A fuel cell is an electrochemical device that combines hydrogen and oxygen and generates electricity, with water and heat as its by-product. In its simplest form, a single fuel cell consists of two electrodes - an anode and a cathode - with an electrolyte between them.

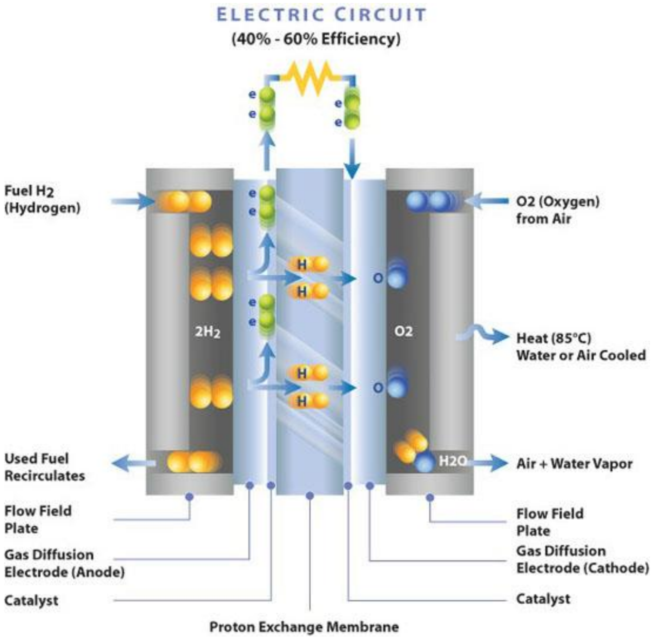

Figure 1: Fuel Cell Circuit diagram [2]

The working principle of hydrogen fuel cells is that hydrogen atoms lose their electrons due to a chemical reaction which takes place at an electrode known as anode. The electrons provide the current to fulfill the demands. The oxygen then enters at the other electrode, known as cathode and it combines with the electrons and the positively charged hydrogen ions pass through the electrolyte (solid or liquid), which serves as a membrane for proton exchange to form water, which could be again dissociated into hydrogen and oxygen and supplied to the fuel cell in order to maintain the continuous reaction.[3]

III. ADVANTAGES & DISADVANTAGES

A. Advantages of Fuel Cells

1.Near-to- Zero Emissions:

Fuel Cells operating purely on hydrogen have zero emission levels. Some of the fuel cells which utilize natural gas or other hydrocarbons as a source of hydrogen emit few emissions but even those are very low as compared to the emission levels of conventional power plants. Thus, fuel cells bring a decrement in the already existing pollution.

2.High Efficiency:

Since fuel cells operate electrochemically and they do not burn the fuel to produce energy, they have higher efficiency compared to conventional power generation methods which mainly work on the principles of combustion. Because there are always energy losses in terms of heat in the process of combustion.

3.Flexibility of Fuel Choice:

To operate hydrogen is a requisite for the fuel cells and the energy generation would continue to take place as long as the fuel supply is uninterrupted. So, there is a flexibility in the choice of fuel or the source of hydrogen. A fuel cell system can incorporate a hydrogen reformer which has the capability to generate hydrogen from diverse range of sources such as fossil fuels, hydrocarbons etc.

4.Scalability:

Pertaining to the power needs, the fuel cells can be scaled since they are modular. So higher power consumption needs could also be met with the fuel cells as they only must be linked together while the lower energy demands could be met with individual modules itself.

5.Reliability:

Fuel cells are highly reliable sources of energy as they can provide uninterrupted power supply thus catering to the energy demands whenever necessary. Fuel cells already provide the backup power in few of the existing power generation systems. But they have the capability of being configured as the primary power source.

6.Silent operation:

Since fuel cells function on the principles of electrochemical reactions, there is no involvement of either combustion or any moving parts which are the primary sources of emanating noise, thus they are a whole lot silent while operating when compared to most of the conventional technologies.

7.Technological Compatibility:

Fuel cells tend to complement and not just compete with the already existing power generation methods. Most of the technologies, especially renewable ones have implied the use of fuel cells to maintain a stable running condition and ensure operational continuity.

8.Lightweight:

Fuel cells tend to be lighter than an equivalent battery system since they have higher energy density thus making redundant the problems pertaining to the excess of weight in the system. Also, if the fuel doesn’t run out, the system will continuously generate power thus eliminating the need of recharging the system.

B. Disadvantages of Fuel Cells

1.Exceedingly High Costs:

The manufacturing cost of the fuel cells is quite high pertaining to the need for a catalyst, preferably platinum which is a very expensive metal. A viable replacement has still not been found to bring down the cost of fuel cell production.

2.Improving the output efficiency:

Fuel cells no doubt is a whole lot efficient than combustion based energy production methods, yet the amount of output being generated doesn’t make it a viable replacement for widely used technologies. Even with the aid of scaling the fuel cells, it might prove to be insufficient to satisfy the needs of energy consumption of a facility.

3.Extreme operating conditions:

Few of the fuel cells do not have a favorable working condition pertaining to the need of the electrochemical reaction to take place such as very high operating temperature, large size of the fuel cell setup, limitation of the material choice, leakage of the liquid electrolyte etc. Thus, it is extremely difficult to incorporate the existing fuel cell technology in other power generation facilities.

Table 1: Types of Fuel Cells [4]

Name	Electrolyte	Catalyst	Operating Temperature	Efficiency
Alkaline Fuel Cell	Potassium hydroxide solution in water	Low-cost metal catalysts	225-475ºF	60-70 %
Molten Carbonate Fuel Cell	Typically consists of alkali (Na & K) carbonates retained in a ceramic matrix of $LiHO_2$	Low-cost, non-platinum group catalysts	1,200 ºF	60-80 %
Phosphoric Acid Fuel Cell	Liquid phosphoric acid ceramic in a lithium aluminum oxide matrix	Carbon-supported platinum catalyst	350-400ºF	40-80 %
Proton Exchange Membrane Fuel Cell	Solid polymer membrane	Platinum	175-200ºF	40-60 %
Direct Methanol Fuel Cell	Solid polymer membrane	Platinum	125-250ºF	Up to 40 %
Solid Oxide Fuel Cell	Solid ceramic (Calcium or Zirconium oxides)	Low-cost, non-platinum group catalysts	1,800ºF	50-60 %

IV. CONCLUSION

Hydrogen Fuel Cells offer a promising future as is evident form the above-mentioned points but they have their own complications as well which unless eased is going to nullify the chance of hydrogen fuel cells to become a viable replacement of current power generation or propulsion technologies. Scientists are continuously iterating with various methods and designs to achieve the greater efficiency. As per the present scenario, NASA is keen on implementing Proton Exchange Membrane (PEM) Fuel Cells & Solid Oxide Fuel Cells (SOFC) to witness a dramatic advancement which would be able to provide reliable, compact and high energy power supply which is renewable as well for applications in the field of aerospace. Mitigating the challenges seems to have the utmost importance.

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