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A Review on Hydrogen as an Alternative Fuel

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ABSTRACT

In order to reduce the atmospheric pollution emitted by automobiles, control devices are being incorporated in the vehicles in many countries. This has resulted in a reduced vehicle mileage to the extent of about fifteen percent. Without the introduction of new technology, any further reduction in emission levels would be expected to extract payment in the form of further fuel economy losses. It is, therefore, worthwhile to look into the suitability of "clean" burning fuels for use in internal combustion engines and assess their potential for reducing engine exhaust emissions. So the investigation of alternative fuels becomes very necessary.

Hydrogen powered vehicles have been in development for the past decade. Hydrogen internal combustion engines may prove to be the most effective solution for the immediate future. This project explores the feasibility of making hydrogen internal combustion engines in mass produced vehicles. We researched the different methods for producing hydrogen, storing it in vehicles and converting traditional internal combustion to burn hydrogen instead of gasoline. Through this research we investigated the advantages of hydrogen internal combustion engines over hydrogen fuel cells. Though this technology shows the promising future, it has long way to go with further R & D, experimentation work for further betterment and efficient technological advancement in future.

Keyword: *reduced emission, fuel economy, new technology, alternative fuel, hydrogen ICE.*

1. INTRODUCTION

The very first hydrogen powered automobile technology which was developed in year 1806. Though hydrogen as a fuel is popularly known in propelling rockets, the very idea to power an on road automobile is not new. It is believed that lack of technology back proved to be a bane to carry forward the idea. The advancements in present day engine technology have enabled us to use alternate fuels like hydrogen to power our locomotives.

Hydrogen is the most abundant element present on earth. The ever increasing demands for fossil fuels have left us with very miniscule reservoirs. Increase in global warming due to the emission of carbonaceous matter to the atmosphere. Need to develop efficient engines in order to improve transportation. Hydrogen has a very high calorific value compared hydrocarbons. It is not a pollutant and also does not contaminate the ground water.

2. PROPERTIES OF HYDROGEN

- **Wide Range of Flammability**

Hydrogen has a wide flammability range in comparison with all other fuels. As a result, hydrogen can be combusted in an internal combustion engine over a wide range of fuel-air mixtures. A significant advantage of this is that hydrogen can run on a lean mixture. Generally, fuel economy is greater and the combustion reaction is more complete when a vehicle is run on a lean mixture [1].

- **Low Ignition Energy**

Hydrogen has very low ignition energy. The amount of energy needed to ignite hydrogen is about one order of magnitude less than that required for gasoline. This enables hydrogen engines to ignite lean mixtures and ensures prompt ignition [1].

- **Small Quenching Distance**

Hydrogen has a small quenching distance, smaller than gasoline. Consequently, hydrogen flames travel closer to the cylinder wall than other fuels before they extinguish. Thus, it is more difficult to quench a hydrogen flame than a gasoline flame [1].

- **High Auto-Ignition Temperature**

Hydrogen has a relatively high auto ignition temperature. This has important implications when a hydrogen-air mixture is compressed. In fact, the auto ignition temperature is an important factor in determining what compression ratio an engine can use, since the temperature rise during compress ion is related to the compression ratio [1].

- **High Flame Speed**

Hydrogen has a high flame speed at stoichiometric ratios. Under these conditions, the hydrogen flame speed is nearly an order of magnitude higher than that of gasoline. This means that hydrogen engines can more closely approach the thermodynamically ideal engine cycle [1].

- **High Diffusivity**

Hydrogen has very high diffusivity. This ability to disperse in air is considerably greater than gasoline and is advantageous for two main reasons. Firstly, it facilitates the formation of a uniform mixture of fuel and air. Secondly, if a hydrogen leak develops, the hydrogen disperses rapidly. Thus, unsafe conditions can either be avoided or minimized [1].

3. HYDROGEN AS A FUEL

Hydrogen produces only water after combustion. It is a non-toxic, non-odorant gaseous matter and also can be burn completely. When hydrogen is burned, hydrogen combustion does not produce toxic products such as hydrocarbons, carbon monoxide, and oxide of sulphur, organic acids or carbon except for the formation of NOx. Due to these characteristics, researchers are focusing their attention on hydrogen as an alternative fuel in internal combustion engines. Combustion of hydrogen is fundamentally different from the combustion of hydrocarbon [2].

Hydrogen has some peculiar features compared to hydrocarbon fuels, the most significant being the absence of carbon. The burning velocity is so high that very rapid combustion can be achieved. The limit of flammability of hydrogen varies from an equivalence ratio (φ) of 0.1 to 7.1 hence the engine can be operated with a wide range of air/fuel ratio. The minimum energy required for ignition of hydrogen–air mixture is 0.02 mJ only. This enables hydrogen engine to run well on lean mixtures and ensures prompt ignition. The density of hydrogen is 0.0838 kg/m3, which is lighter than air that it can disperse into the atmosphere easily. Hydrogen has the highest energy to weight ratio of all fuels. The flame speed of hydrogen is 270 cm/s that may cause a very high rate of cylinder pressure rise. The diffusivity of hydrogen is 0.63cm2/s. As the hydrogen self-ignition temperature is 858 K, compared to diesel of 453 K, it allows a larger compression ratio to be used for hydrogen in internal combustion engine. But it is not possible to achieve ignition of hydrogen by compression alone. Some sources of ignition have to be created inside the combustion chamber to ensure ignition.

TABLE I [2] PROPERTY COMPARISON

Properties	Diesel	Unleaded H2 gasoline
Formula	CnH1.8n	CnH1.87n -----
C8-C20	C4–C12	
Auto-ignition Temperature (K)	530	533–733 858
Min. ignition energy (mJ)	—	0.24 0.02
Flammability limits(vol. % in air)	0.7–5	1.4–7,6 4-75
Stoichiometric air fuel ratio on mass	14.5	14.6 34.3
Limits of flammability (equivalence ratio)	—	0.7–3,8 0.1-7.1
Density at 16 ◦C and 1.01 bar (kg/m3)	833–881	721–785 0.0838
Net heating valve (MJ/kg)	42.5	43.9 119.93
Flame velocity (cm/s)	30	37–43 265-325
Quenching gap in NTP air (cm)	—	0.2 0.064
Diffusivity in air (cm2/s)	—	0.08 0.63
Octane number	130	92–98
Cetane number	44-55	13–17 -----

4. HYDROGEN INTERNAL COMBUSTION ENGINES FUEL INDUCTION TECHNIQUES

As far as the development of a practical hydrogen engine system is concerned, the mode of fuel induction plays a very critical role. Three different fuel induction mechanisms are observed in the literature.

A. Fuel Carburetion Method (CMI)

B. Inlet Manifold and Inlet Port Injection

C. Direct Cylinder Injection (DI)

The engine was operated using all these fuelling modes.

- **Fuel carburetion method (CMI)**

Carburetion by the use of a gas carburetor has been the simplest and the oldest technique. This system has advantages for a hydrogen engine. Firstly, central injection does not require the hydrogen supply pressure to be as high as for other methods. Secondly, central injection or carburettors are used on gasoline engines, making it easy to convert a standard gasoline engine to hydrogen or a gasoline/hydrogen engine. The disadvantage of central injection in international combustion engine, the volume occupied by the fuel is about 1.7% of the mixture whereas a carbureted hydrogen engine, using gaseous hydrogen, results in a power output loss of 15% [3]. Thus, carburetion is not at all suitable for hydrogen engine, because it gives rise to uncontrolled combustion at unscheduled points in the engine cycle. Also the greater amount of hydrogen/air mixture within the intake manifold compounds the effects of pre-ignition. If pre-ignition occurs while the inlet valve is open in a premixed engine, the flame can propagate past the valve and the fuel-air mix in the inlet manifold can ignite or backfire. In a carbureted hydrogen engine, a considerable portion of the inlet manifold contains a combustible fuel-air mix and extreme care must be taken to ensure that ignition of this mix does not occur. Serious damage to the engine components can result when back fire occurs. A schematic diagram illustrating the operation of fuel carburetion method is indicated by Fig. 1. as below.

- **Inlet manifold and inlet port injection**

The port injection fuel delivery system injects fuel directly into the intake manifold at each intake port by using mechanically or electronically operated injector, rather than drawing fuel in at a central point. Typically, the hydrogen is injected into the manifold after the beginning of the intake stroke. Electronic injectors are robust in design with a greater control over the injection timing and injection duration with quicker response to operate under high speed conditions. In port injection, the air is injected separately at the beginning of the intake stroke to dilute the hot residual gases and cool any hot spots. Since less gas (hydrogen or air) is in the manifold at any one time, any pre-ignition is less severe. The inlet supply pressure for port injection tends to be higher than for carbureted or central injection systems, but less than for direct injection systems. A schematic diagram illustrating the operation of inlet port injection is indicated by Fig. 2. as below.

Inlet manifold or port injection methods of fuel induction, the inducted volume of air per cycle is kept constant and the power output can be controlled by the amount of fuel injected into the air stream, thus allowing lean operation. The fuel can either be metered by varying the injection pressure of the hydrogen, or by changing the injection duration by controlling the signal pulse to the injector.

- **Direct injection systems**

In direct in-cylinder injection, hydrogen is injected directly inside the combustion chamber with the required pressure at the end of compression stroke. As hydrogen diffuses quickly the mixing of hydrogen takes flame instantaneously. For ignition either diesel or spark plug is used as a source. The problem of drop in power output in manifold induction/injection can be completely eliminated by in-cylinder ignition. During idling or part load condition the efficiency of the engine may be reduced slightly. This method is the most efficient one compared to other methods of using hydrogen. The power output of a direct injected hydrogen engine was 20% more than for a gasoline engine and 42% more than a hydrogen engine using a carburetor. With hydrogen directly injected into the combustion chamber in a compression ignition (CI) engine, the power output would be approximately double that of the same engine operated in the pre-mixed mode. The power output of such an engine would also be higher than that of a conventionally fuelled engine, since the stoichiometric heat of combustion per standard kilogram of air is higher for hydrogen (approximately 3.37 MJ for hydrogen compared with 2.83 MJ for gasoline). While direct injection solves the problem of pre-ignition in the intake manifold, it does not necessarily prevent pre-ignition within the combustion chamber. In addition, due to the reduced mixing time of the air and fuel in a direct injection engine, the air/fuel mixture can be non-homogenous. A schematic diagram illustrating the operation of direct injection is indicated by Fig. 3. as shown below.

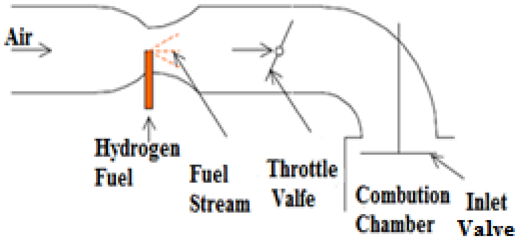

Fig.1 Fuel carburetion method (CMI)

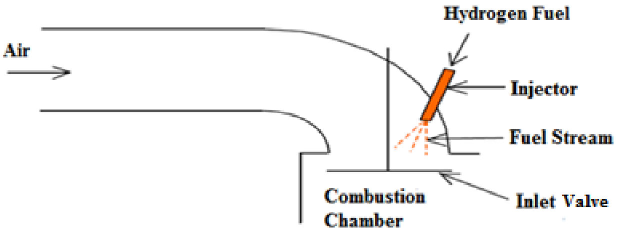

Fig.2 Inlet manifold and inlet port injection

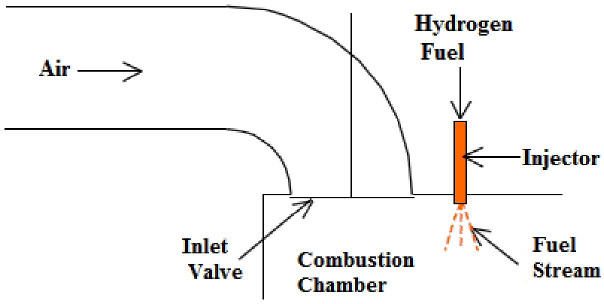

Fig.3 Direct injection system

- **Injector Specifications**

A fuel injection system performs two basic functions: fuel pressurization and fuel metering. When dealing with gaseous fuels, only the metering function is required to be carried out by the injection system as the pressurization is performed separately. Many different types of injector have been used in both inlet manifold and direct cylinder injection hydrogen internal combustion engines. As has already been indicated, the design of inlet manifold or inlet port injectors is less challenging as lower injection pressures are required. For direct cylinder injectors, not only must the design accommodate for higher injection pressure against the cylinder pressure, but the equipment must also be capable of withstanding the hostile environment of the combustion chamber. Lubrication between the injector moving parts also makes the design of direct injector more complicated. Typical injector construction is illustrated in Figure as shown below.

Two types of injectors are available for use in D.I. systems. One is a low-pressure direct injector (LPDI) and the other one is a high pressure direct injector (HPDI). Low-pressure direct injector injects the fuel as soon as the intake valve closes when the pressure is low inside the cylinder. The high-pressure direct injector injects the fuel at the end of the compression stroke.

5. HYDROGEN FUEL CELL VEHICLES (FCV)

- **Background**

Hydrogen FCVs are a potential option for reducing emissions from the transportation sector. Combusting fossil fuels to power conventional vehicles releases GHG emissions and other pollutants from the vehicle exhaust system (i.e., “tailpipe” emissions). In addition, there are also emissions associated with producing petroleum-based fuels (i.e., “upstream” emissions), notably emissions from oil refineries. FCVs emit no tailpipe GHGs or other pollutants during vehicle operation, and depending on how hydrogen is produced, there can be substantially lower upstream GHG emissions associated with producing hydrogen fuel [4].

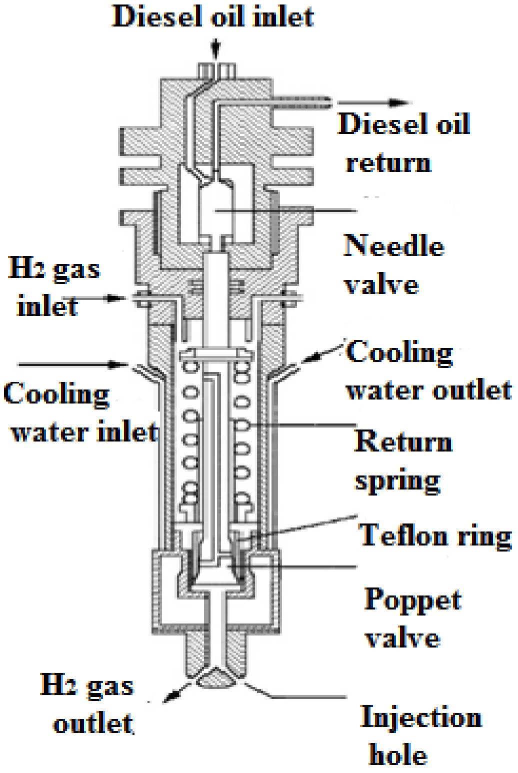

Fig. 4 Hydrogen fuel injector.

Fuel cells are already used to generate electricity for other applications, including in spacecraft and in stationary uses, such as emergency power generators. Although the concept of a fuel cell was developed in England in the 1800s, the first workable fuels cells were not produced until much later, in the 1950s. During this time, interest in fuel cells increased, as NASA began searching for ways to generate power for space flights. Hydrogen FCVs are considered one of several possible long-term pathways for low-carbon passenger transportation (other options include vehicles powered by electricity and/or biofuels). The benefits of hydrogen-powered vehicles include the following:

- High energy efficiency of fuel cell drivetrains, which use 40 to 60 percent of the energy available from hydrogen, compared to internal combustion engines, which currently use only about 20 percent of the energy from gasoline;
- Diverse methods by which hydrogen can be produced
- Unlike all-electric vehicles (EVs), comparable vehicle range and refueling time to gasoline vehicles;

- Similar to EVs, quick starts due to high torque from the electric motor and low operating noise; and Lack of any GHG emissions and few other air pollutants during vehicle operation and the potential for very low or no upstream GHG emissions associated with hydrogen fuel production.

Yet several key hurdles must be overcome before the introduction of FCVs on a large scale can become possible. These challenges include the production, distribution, and storage of hydrogen; fuel cell technology; and overall vehicle cost.

- **Description**

FCVs resemble normal gasoline or diesel-powered vehicles from the outside. Similar to EVs, they use electricity to power a motor that propels the vehicle. Yet unlike EVs, which are powered by a battery, FCVs use electricity produced from on-board fuel cells to power the vehicle.

An FCV includes four major components:

5.1 **Fuel cell stack**

The fuel cell is an electrochemical device that produces electricity using hydrogen and oxygen. In very simple terms, a fuel cell uses a catalyst to split hydrogen into protons and electrons, the electrons then travel through an external circuit (thus creating an electric current), and the hydrogen ions and electrons react with oxygen to create water.

To obtain enough electricity to power a vehicle, individual fuel cells, like the one described below, are combined in series to make a fuel cell stack. There are several different types of fuel cells, each of which is suited for a different application. Fuel cells are typically grouped according to their operating temperature and the type of electrolyte used. The amount of power generated by a fuel cell is determined by several factors including fuel cell type, size, operating temperature, and pressure at which the gases are supplied to the cell. The most common type of fuel cell used in FCVs is polymer electrolyte membrane (PEM).

A fuel cell is composed of an electrolyte, placed between an anode (a negative electrode) and a cathode (a positive electrode), with bipolar plates on either side. A fuel cell works as follows [5]:

- First, the hydrogen gas flows to the anode. Here, a platinum catalyst is used to separate the hydrogen molecule into positive hydrogen ions (protons) and negatively charged electrons.
- The PEM allows only the protons to pass through to the cathode, while the electrons travel through an external circuit to the cathode. The flow of electrons through this circuit creates the electric current (or electricity) used to power the vehicle motor.
- On the other side of the cell, oxygen gas, usually drawn from the outside air, flows to the cathode.
- When the electrons return from the external circuit, the positively charged hydrogen ions and electrons react with oxygen in the cathode to form water, which then flows out of the cell. The cathode also uses a platinum catalyst to enable this reaction.

5.2 **Hydrogen storage tank**

Instead of a gasoline or diesel tank, an FCV has a hydrogen storage tank. The hydrogen gas must be compressed at extremely high pressure at 5,000 to 10,000 pounds per square inch (psi) to store enough fuel to obtain adequate driving range. In comparison, compressed natural gas (CNG) vehicles use high-pressure tanks at only 3,000 to 3,600 psi.

FCVs can also be powered by a secondary fuel – e.g., methanol, ethanol, or natural gas – which is converted into hydrogen onboard the vehicle. Vehicles powered through a secondary fuel emit some air pollutants during operation due to the conversion process.

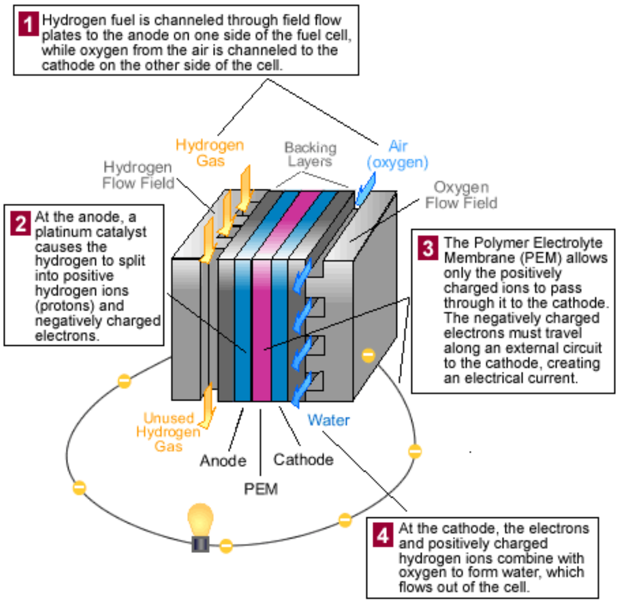

Fig.5 Fuel cell basics

5.3 **Electric motor and power control unit**

The power control unit governs flow of electricity in the vehicle. By drawing power from either the battery or the fuel cell stack, it delivers electric power to the motor, which then uses the electricity to propel the vehicle.

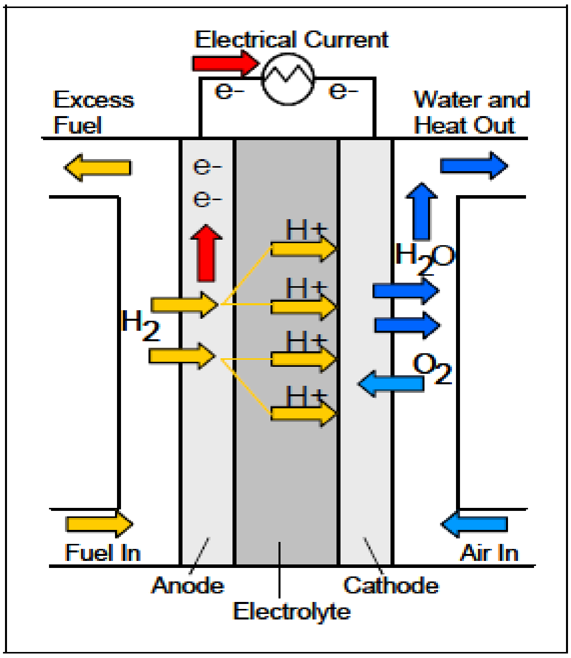

Fig.6 Fuel cell operation

5.4 **Battery**

Like HEVs, FCVs also have a battery that stores electricity generated from regenerative braking,13 increasing the overall efficiency of the vehicle.14 The size and type of these batteries, similar to those in HEVs, will depend on the "degree of hybridization" of the vehicle, i.e., how much of the power to propel the vehicle comes from the battery and how much comes from the fuel cell stack.

C. Environment benefit/ Emission reuction potential

Because FCVs are more energy efficient than vehicles powered by gasoline and because hydrogen as a transportation fuel can have much lower lifecycle GHG emissions than fossil fuels, FCVs have the potential to dramatically reduce GHG emissions and other air pollutants from the transportation sector [6].

FCVs are more energy efficient than gasoline-powered vehicles. A fuel cell uses about 40 to 60 percent of the available energy in hydrogen. Internal combustion engines use only about 20 percent of the energy available in gasoline, although this is expected to improve over the long term. EVs are more efficient than FCVs, using about 75 percent of available energy from the batteries.

In addition to being more energy efficient than gasoline-powered vehicles, FCVs can also have much lower lifecycle GHG emissions compared to vehicles fueled by petroleum-based fuels. FCVs emit only heat and water during operation (i.e., no tailpipe GHGs). Lifecycle GHG emissions from FCVs thus depend, mainly, on the process used to produce hydrogen. Hydrogen can be produced from fossil fuels (coal and natural gas), nuclear, renewable energy technologies (wind, solar, geothermal, biomass), and hydroelectric power.

6. **CONCLUSION**

As research progresses, the technologies used to produce the hydrogen are expected to shift toward those that produce no net greenhouse gas emissions. While some of the hydrogen production technologies now under development may be supplanted by competing or improved approaches, a variety of production technologies are likely to find long-term use in regions that offer an abundance of their required feedstock and renewable energy resource. Fuel costs to consumers will gradually decrease as these technologies and the delivery infrastructure are optimized and grow to maturity. Ultimately, hydrogen represents an important component of our national strategy to diversify energy resources. The use of hydrogen in IC engines can be realised by reducing the weight of the automobile and development of better auxiliary systems. The current technology uses petrol methane etc. in order to increase the range of the vehicle. Hence the goal of researchers is to develop automobiles which use only hydrogen as the only fuel.

The fuel cell is the heart of a hydrogen-powered vehicle. A fuel cell uses the combination of hydrogen and oxygen to generate electricity. The side effect of this process is the generation of water and heat. The electricity can then be used to power the car. The fuel cell is the primary device that turns ordinary electrical vehicles into a practical, competitive alternative. Though this technology shows promising future, it has long way to go. With further R & D, we hope for betterment of this technology.

REFERENCES

1. Chetan Patel, *Hydrogen fueled I. C. Engine*
2. N. Saravanan, C. Dhanasekaran, K. M. Kalaiselvan, Experimental investigation of hydrogen port fuel injection in D. I. Diesel engine, International journal of hydrogen energy 32 (2007) 4071-4080
3. Panayotis Christidis, Trends in vehicle & fuel technologies, overview of current research activities, European science & technology observatory, May 2003
4. Hydrogen & fuel cell technologies, The energy & resources institute, November 2007
5. Rahul Mahtani, Investigating the use of hydrogen as an alternative fuel, April 2010
6. Global strategy institute, Hydrogen: the fuel of future, october 2005.