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Hydrogen Powered Vehicles- An Overview

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Abstract: *Every day we come across headlines stating the increase in the usage of petroleum, diesel, or the drastic changes in the weather due to Global warming. Because of this very reason mankind has started looking for alternative fuels and energy sources. Strenuous efforts have been made over the past few decades finding if the simplest element i.e. Hydrogen can actually deliver, serve the purpose of an alternative fuel and reduce our reliance on oil. Is Hydrogen capable of replacing conventional fuels like gasoline/diesel? Our paper highlights the important aspects of hydrogen powered vehicles, their types, and imprints a notion of being in a pollution free state with negligible tailpipe emissions as well as shows the hindering pitfall of its usage.*
Keywords: *Automobiles, Emissions, Hydrogen, Hydrogen Powered Vehicles, Weather Changes.*

I. Introduction

Engine displacement, power output, fuel economy etc. have always been the most common factors when it comes to gauging a car for its “on-road” capabilities. But in the last few decades, “emissions”, a previously overlooked factor has become vital to building and buying “road-optimum” civilian automobiles. Car manufacturers across the world face a serious deadline to reduce the tailpipe emissions of their automobiles.

This has led to an array of alternative fuels being discovered and researched upon. The standout amongst these is Hydrogen. The vehicles derive their energy from the simplest element found on earth i.e. Hydrogen. The truly fascinating feature flaunted by these fuel cells is “ZERO HARMFUL EMISSIONS”. Moreover the only emissions are water vapor and heat.

II. Hydrogen as an Alternative Source of Energy

Hydrogen is the first element on the periodic table, making it the lightest element. Since hydrogen gas is so light, it rises in the atmosphere and is therefore rarely found in its pure form, H_2. In a flame of pure hydrogen gas, burning in air, the hydrogen (H_2) reacts with oxygen (O_2) to form water (H_2O) and releases energy. The energy released enables hydrogen to act as a fuel. Since there is very little free hydrogen gas, hydrogen is in practice only as an energy carrier, like electricity, not an energy resource. Thus, hydrogen gas must be produced separately. Therefore, we need to have an insight on its properties and production and storage in order to show its viability.

III. Characteristics of Hydrogen

There are several important characteristics of hydrogen that greatly influence the technological development of hydrogen ICE and FCVs. [1]

Wide Range of Flammability: Compared to nearly all other fuels, hydrogen has a wide flammability range (4-74% versus 1.4-7.6% volume in air for gasoline). This first leads to obvious concerns over the safe handling of hydrogen. But, it also implies that a wide range of fuel-air mixtures, including a lean mix of fuel to air, or, in other words, a fuel-air mix in which the amount of fuel is less than the stoichiometric, or chemically ideal, amount. Running an engine on a lean mix generally allows for greater fuel economy due to a more complete combustion of the fuel. In addition, it also allows for a lower combustion temperature, lowering emissions of criteria pollutants such as nitrous oxides (NO_X).

Low Ignition Energy: The amount of energy needed to ignite hydrogen is on the order of a magnitude lower than that needed to ignite gasoline (0.02 MJ for hydrogen versus 0.2 MJ for gasoline). On the upside, this ensures ignition of lean mixtures and allows for prompt ignition. On the downside, it implies that there is the danger of hot gases or hot spots on the cylinder igniting the fuel, leading to issues with premature ignition and flashback (i.e., ignition after the vehicle is turned off).

Small Quenching Distance: Hydrogen has a small quenching distance (0.6mm for hydrogen versus 2.0mm for gasoline), which refers to the distance from the internal cylinder wall where the combustion flame extinguishes. This implies that it is more difficult to quench a hydrogen flame than the flame of most other fuels, which can increase backfire (i.e., ignition of the engine’s exhaust).

High Flame Speed: Hydrogen burns with a high flame speed, allowing for hydrogen engines to more closely approach the thermodynamically ideal engine cycle (most efficient fuel power ratio) when the stoichiometric fuel mix is used. However, when the engine is running lean to improve fuel economy, flame speed slows significantly.

High Diffusivity: Hydrogen disperses quickly into air, allowing for a more uniform fuel air mixture, and a decreased likelihood of major safety issues from hydrogen leaks.

Low Density: The most important implication of hydrogen's low density is that without significant compression or conversion of hydrogen to a liquid, a very large volume may be necessary to store enough hydrogen to provide an adequate driving range. Low density also implies that the fuel-air mixture has low energy density, which tends to reduce the power output of the engine. Thus when a hydrogen engine is run lean, issues with inadequate power may arise.

IV. Hydrogen Production

Hydrogen can be produced from a variety of feedstock. These include fossil resources, such as natural gas and coal, as well as renewable resources, such as biomass and water with input from renewable energy sources (e.g. sunlight, wind, wave or hydro-power). A variety of process technologies can be used, including chemical, biological, electrolytic, photolytic and thermo-chemical. Each technology is in a different stage of development, and each offers unique opportunities, benefits and challenges. Two of the methods of producing Hydrogen are explained below.

4.1 Methane Steam Reformer Plant

Steam reforming is a method for production of hydrogen, carbon monoxide or other useful products from hydrocarbon fuels such as natural gas. This is achieved in a processing device called as a reformer which reacts steam at high temperatures with fossil fuel. The steam methane reformer is widely used in industry to make hydrogen.

Steam reforming of natural gas - sometimes referred to as steam methane reforming (SMR) – is the most common method of producing commercial bulk hydrogen. Hydrogen is used in the industrial synthesis of ammonia and other chemicals. At high temperatures (700 – 1100 °C) and in presence of a metal-based catalyst (nickel), steam reacts with methane to yield carbon monoxide and hydrogen.

Synthetic gas is a fuel gas mixture consisting primarily of hydrogen, carbon monoxide, and very often some carbon dioxide:

(1) $CH_4 + H_20 \longleftrightarrow CO_2 + 3H_2 \qquad \Delta H_{295} = -206$ kJ/mol

(2) $CO + H_2O \longleftrightarrow CO_2 + H_2 \qquad \Delta H_{298} = -41$kJ/mol

(3) $CH_4 + H_2O \longleftrightarrow CO_2 + 4H_2 \qquad \Delta H_{298} = 165$ kJ/mol

The first equation being highly endothermic, consumes tremendous amount of energy. Also carbon monoxide is the raw material for the second reaction, this has become a cause of concern around the globe as it is a greenhouse gas and the cost of reformer plant does not suffice for the amount of hydrogen produced.

Researchers at NREL are developing advanced processes to produce hydrogen economically from sustainable resources. Researchers are now focusing on the following methods of extracting hydrogen:

1. Biological water splitting
2. Fermentation
3. Conversion of biomass and wastes
4. Photo electrochemical water splitting
5. Solar Thermal water splitting
6. Renewable electrolysis
7. Hydrogen dispenser hose reliability
8. Hydrogen production and delivery pathway analysis.

4.2 Production from coal

Hydrogen can be produced from coal through a variety of gasification processes (e.g. fixed bed, fluidized bed or entrained flow) [2]. In practice, high-temperature entrained flow processes are favored to maximize carbon conversion to gas, thus avoiding the formation of significant amounts of char, tars and phenols. A typical reaction for the process I s given in the equation below, in which carbon is converted to carbon monoxide and hydrogen:

(1) $C(s) + H_2O + heat \rightarrow CO + H_2$

Since this reaction is endothermic, additional heat is required, as with methane reforming. The CO is further converted to CO2 and H2 through the water-gas shift reaction. Hydrogen production from coal is commercially mature, but it is more complex than the production of hydrogen from natural gas. The cost of the resulting hydrogen is also higher. But since coal is plentiful in many parts of the world and will probably be used as an energy source regardless, it is worthwhile to explore the development of clean technologies for its use.

V. Hydrogen Storage

When it comes to using hydrogen as a source of power to be used in vehicles, it is the storage of hydrogen that poses one of the bigger challenges. As discussed before, hydrogen, having a lower weight-by-volume ratio, requires a space considerably more than that required to store the same amount of gasoline under similar conditions. Using a larger tank for the hydrogen is neither practical nor efficient as far as the design of the car is concerned, which has led to the development of better alternatives for the storage of hydrogen.

5.1 Liquid hydrogen

Liquefied hydrogen does away with the problem of low density prevalent in gaseous hydrogen. Liquid hydrogen vehicular storage systems have some of the highest mass fractions and lowest system volumes. This makes it a strong contender to be used in vehicles. As the hydrogen is in liquid state, it becomes increasingly easy to store it and to fill the vehicle tanks.

Though the liquefaction process of hydrogen is a considerably costly one, since, it is said to take up high energies for liquefaction to the order of almost 30% of the hydrogen heating value. Also when it comes to hydrogen, the factor of dormancy is one of the frequently faced problems. Liquid hydrogen too has this very drawback. When liquid hydrogen is stored unused for a certain period of time, high level of boil-off losses occur thus the overall efficiency of the storage system is highly reduced.

But all this said, it can be argued that liquid hydrogen is still the best alternative for vehicular applications since the various advantages of liquid hydrogen like its safety characteristics, higher density and its current success record overshadows its few disadvantages like dormancy and production costs.

5.2 Metal hydrides

Metal hydrides are arguably the best way to store hydrogen for portable use. These work on the principle of dissociation of gaseous hydrogen at a certain temperature. Accordingly the metal hydrides are widely divided into two types: low dissociation temperature hydrides and high dissociation temperature hydrides.

Both of these systems have good safety characteristics. But this presents a dilemma when choosing the type of hydride to be used. The safety characteristics of metal hydrides increase with the increase in the dissociation temperatures. This is so because the higher the dissociative temperatures are, lesser are the probability of the hydrogen getting discharged spontaneously in the incident of a crash. Also the low dissociation temperature metal hydrides have a hydrogen fraction which is too low for vehicular uses and similarly the high dissociation temperature metal hydrides need a temperature of the order of 300°C which is too high to be used in cars. Also, there is lot of precedent of metal hydrides being too heavy for vehicular use.

Considering all the aspects, metal hydrides can be used in vehicles only if a right compromise is found between low and high dissociation temperature hydrides. Though using the exhaust heat of the vehicle for the discharge of hydrogen from the metal hydrides is a field which has a lot of prospective.

5.3 Carbon adsorption

This method of hydrogen storage draws its advantages and functioning from the adsorbent properties of carbon. The adhesion present between carbon and hydrogen gas can be used to adsorb hydrogen and thus increase the volumetric density. Carbon nano fibres possess great potential in these aspects due to its adsorbent properties and the ease of design associated with carbon fibres.

Although the development of nano fibres for this purpose is at a speculative, it opens wide new possibilities in optimally designed hydrogen storage systems.

5.4 Compressed Hydrogen Gas

As the name suggests, hydrogen gas can be stored in specially designed tanks more effectively by pressurising it to a certain pre-determined level. The normally used pressure for this purpose is about 5000 psi. This remarkably improves the density characteristics of hydrogen for vehicular uses. The commonly used tanks for this purpose are metal or plastic lined, carbon fibre wound pressure vessels.

The advantage of this method is that the designer does not face the challenge of facilitating a tank of a large size into the design as the tank volume gets considerably reduced. But the greatest advantage is that of absence of dormancy issues usually found in liquid hydrogen.

However transportation of compressed hydrogen gas is less effective than that of liquid hydrogen. Compressed hydrogen gas is supportable by small scale as well as large H2 production facilities. Thus the

production of compressed hydrogen can be effectively incorporated in a larger liquid hydrogen production facility.
The recurring disadvantages of this method are high cost of production and speculative safety characteristics.

VI. Hydrogen Fuel Cell

6.1 Hydrogen Fuel Cell Working

Like a fuel cell, battery also is an electrochemical device. A battery has all of its chemicals stored inside, and it converts those chemicals into electricity. This means that a battery eventually "goes dead" and you either throw it away or recharge it.

For a fuel cell chemicals constantly flow into the cell so it never goes dead. As long as there is a flow of chemicals into the cell, the electricity flows out of the cell. Most fuel cells in use today use hydrogen and oxygen as the chemicals.

Fuel Cells generate electricity through an electrochemical process in which the energy stored in a fuel is converted directly into DC electricity. As electrical energy is generated without combusting fuel, fuel cells are extremely attractive from an environmental stand point. It consists of three components - a cathode, an anode, and an electrolyte sandwiched between the two. Oxygen from the air flows through the cathode. A fuel gas containing hydrogen, such as methane, flows past the anode.

Solid Oxide Fuel Cell

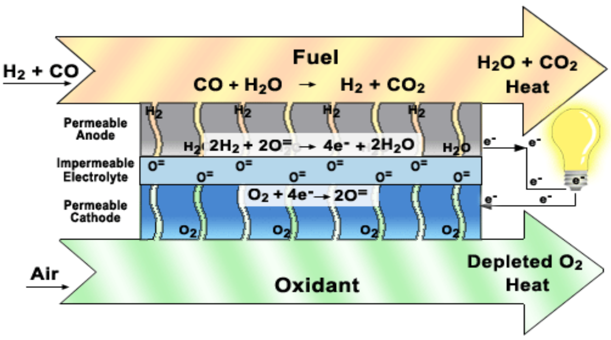

Fig. 1

6.2 Principle

An input fuel is catalytically reacted (electrons removed from the fuel elements) in the fuel cell to create an electric current. Fuel cells consist of an electrolyte material which is sandwiched in between two thin electrodes (porous anode and cathode). The input fuel passes over the anode (and oxygen over the cathode) where it catalytically splits into ions and electrons. The electrons go through an external circuit to serve an electric load while the ions move through the electrolyte toward the oppositely charged electrode. At the electrode, ions combine to create by-products, primarily water and heat. Depending on the input fuel and electrolyte, different chemical reactions will occur.

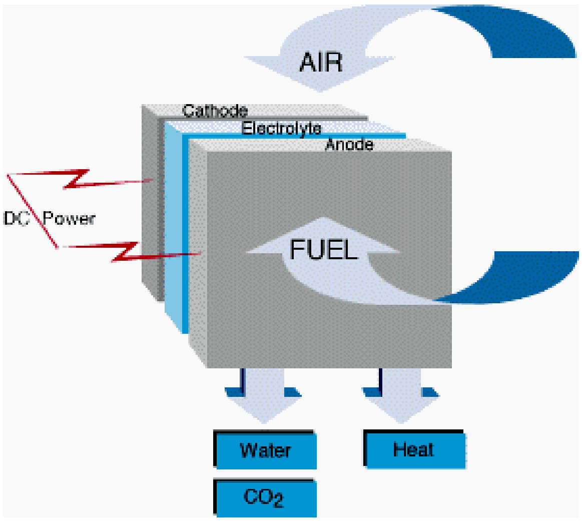

Fig. 2

6.3 Hydrogen Fuel Cells
Like every other thing in nature, hydrogen fuel cells too have their pros and cons. To decide whether hydrogen fuel cells can be a dream come true is however ambiguous.

6.3.1 Advantages
1. Hydrogen is readily available as there is no element in the entire universe as abundant as it.
2. Hydrogen is also a great source of energy as the energy content of hydrogen is the highest per unit of weight of any fuel, and thus, hydrogen fuel cells are considered as a favorable replacement for fossil fuels.
3. The most important feature of hydrogen fuel cells however is the fact that once the hydrogen gas is burnt it gives out water as a byproduct.
4. Hydrogen fuel cells have a higher efficiency than diesel or gas engines.

Besides being fuel efficient, hydrogen energy is powerful enough to propel spaceships. The gas is also non-toxic, which makes it a rarity amongst fuel sources. Nuclear energy, coal, and gasoline are all either toxic or found in hazardous environments. This makes hydrogen ideal for use in a number of ways other fuel sources can't compete against. The usage of hydrogen energy will greatly reduce the dependency on foreign oil.

6.3.2 Disadvantages:
As mentioned before, hydrogen is the most abundant element in the universe. However, it is still currently expensive as it is difficult to generate and store.
1. Hydrogen gas requires a lot of work to free it from other elements.
2. It's expensive and time-consuming to produce.
3. Though hydrogen energy is renewable and its environmental impacts are minimal, we still need other non-renewable sources like coal, oil and natural gas to separate it from oxygen.
4. Major obstacle to widespread use of fuel cells is in the storage and distribution of the hydrogen fuel.
5. Hydrogen gas is difficult to contain, and most methods add considerable weight to a vehicle.
6. Because of its volatility, the safety of hydrogen will always be a concern.
7. Hydrogen is highly flammable and thus has the potential risks associated with it.
8. The technology and infrastructure required to support the distribution of hydrogen fuel cells is not fully developed yet and thus hydrogen fuel cells are considered to be at least decades away from its commercial use.

VII. Hydrogen Internal Combustion Engines
As the drawbacks of FCV'S are a cause of concern, an alternative technology or method is of paramount importance to bridge the gap between FCV'S and conventional SI/CI Engines. With over a century of R&D since its inception the IC engines are most reliable and affordable but still environmentally challenging propulsive systems. This obstacle can however overcome by usage of an alternative source of fuel-like Hydrogen which on combustion with oxygen gives water. This is possible because we have the existing technology of SI/CI engines and need to make further relevant changes in order to put it actual use.

An overview of design considerations for a hydrogen fuelled IC Engine are as follows [4];

1. Abnormal combustion: The suppression of abnormal combustion and the backfire has been a particularly strenuous obstacle to development of hydrogen engines. Also the design of piston should be sufficiently flat so as to allow proper mixing of air-hydrogen mixture.

2. Air fuel mixture: Wide range of air-fuel mixtures have been tested for backfire free operations. External mixture formation by means of a port fuel injection method shows increased efficiency, extended lean operation and reduce NOx emissions over direct injection method, well the possibility of backfire is almost negligible in DI compared to PFI.

3. Load control: As we are well aware of hydrogen flammability and its flame speed limits, it permits lean operation of engines thus the engine efficiency and NOx emissions are responsible load control methods.

4. Hydrogen SI engines: The design and development of hydrogen engines depend on the design of spark plugs, ignition system, piston and crevice volumes, injectors, compression ratio, hotspots, lubrication and in cylinder turbulence to name a few.

7.1 Advantages
1. High flammability range
2. High speed burning of flame or turbulence in the cylinder and high octane rating of hydrogen all contributes the increase in engine efficiency.
3. No greenhouse gases are emitted due to absence of carbon content and NOx emissions are being reduced.

7.2 Disadvantages

1. Cost of Hydrogen SI engine is more compared to its gasoline counterpart.
2. The power output at low loads and the reduction of NOx emission in subsequent years.

VIII. Comparison of HFC's Vs HICE Vs SI/CI Engines

Taking the test results and various parameters into consideration, the graph (1) shows that the highest efficiency to load ratio is obtained in HFC'S followed by hydrogen ICE, conventional Diesel and Petrol engines respectively.

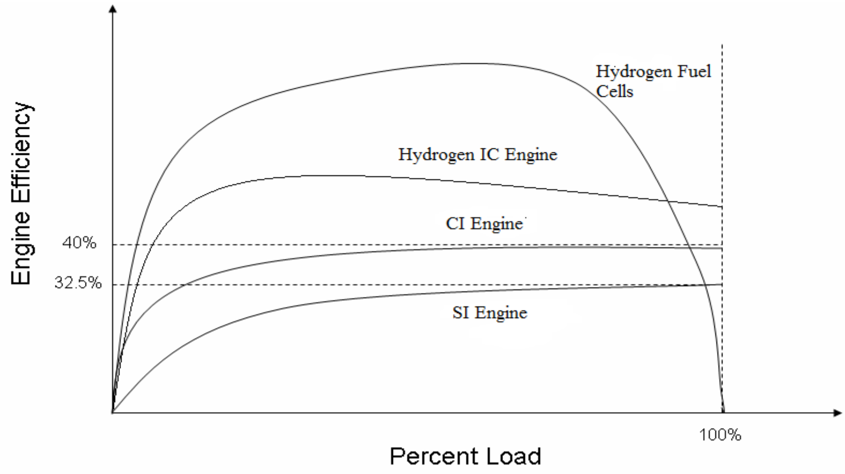

Fig. 3

Thus the final comparison is been drafted in the TABLE (1), which clearly shows that hydrogen powered vehicles are more fuel efficient than conventional engines.

Table 1:

	GASOLINE INTERNAL COMBUSTION ENGINE	GASOLINE HYBRID	HYDROGEN INTERNAL COMBUSTION ENGINE	HYDROGEN FUEL CELL
ENGINE TYPE	SPARK-IGNITION	SPARK-IGNITION & ELECTRIC MOTOR	COMPRESSED IGNITION (WITH ELECTRIC MOTOR)	FUEL CELL & ELECTRIC MOTOR
AVERAGE ENGINE EFFICIENCY	~30%	~30%	~40%	~55%
MAX ENGINE EFFICIENCY	32.5%	32.5%	~40%	~65%
TRANSMISSION TYPE	STANDARD	CONTINUOUSLY VARIABLE TRANSMISSION/ HYBRID	CONTINUOUSLY VARIABLE TRANSMISSION/ LIKELY HYBRID	CONTINUOUSLY VARIABLE TRANSMISSION / LIKELY HYBRID
TRANSMISSION EFFICIENCY	~40%	~60%	~60%	~60%
FUEL ECONOMY (MILES PER GALLON EQUIVALENT.)	21	31	41	51

IX. Conclusion

Thus we can see that hydrogen powered vehicles can be significant alternative for the future power needs and it still has a great scope for research in many areas. Though HFC'S wont venture into mass production so soon, the scope of Hydrogen ICE looks promising in the immediate future bridging the technological gap between HFC'S and conventional Petrol/Diesel engines.

This paper instills the future scope and the rising demand of an alternative fuel for conventional engines and with hydrogen as the fuel; it might just be the one.

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