A review on hydrogen as a fuel for IC engines

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Abstract

This review paper covers the use of hydrogen as an alternative fuel in IC engines. Large amounts of smoke, particulate matter and nitrogen oxide are emitted by diesel engines. Rapidly depleting fossil fuels and harmful emissions from existing engines also present a cause for concern. Hence, there is a need to embrace alternative fuels as the future. To adhere to various stringent norms, hydrogen is considered to be one of the most important fuels in the near future. Therefore, hydrogen can be added to enhance the performance and improve the emissions of diesel engines. Engine specific properties of hydrogen and the various induction methods used in order to make use of hydrogen as a fuel have been discussed in this paper.

Keywords: Hydrogen, Alternative fuel, Internal combustion engine, Emissions

Introduction

There has been a tremendous increase in the demand of fossil fuels owing to a huge growth of population over the last few decades. Diesel engines have been criticized due to the high level of air pollutants that they produce.

Intentional cheating by an automobile manufacturer in a recent emission scandal has increased awareness about diesel engines and their emissions, among people. Several reports and articles have been written about the dark future of diesel engines.

A method that can be used for environmental benefit is to improve operation of IC engines by reducing their emissions. By accounting for the various engine related properties of hydrogen, it is found that hydrogen can be used as a clean, viable alternative fuel.

Fuel cell was considered to be the best method to use hydrogen as a fuel for a greener environment. Fuel cells produce carbon-free emissions and hence, do not contribute to global warming. The main problem is, these fuel cells emit nitrogen dioxide in their exhausts which is a toxic gas and can be fatal, when inhaled. Hence an inexpensive technology to produce hydrogen is necessary to be found out. Using hydrogen as a fuel can only be profitable and feasible when it is produced by renewable sources of energy such as solar power and wind energy. Currently, the main process by which hydrogen is produced is by natural gas reforming which uses a fossil fuel (methane). Hence, efforts are being made to produce hydrogen by means of renewable sources of energy.

In hydrogen fueled engine, the main exhaust products are water vapour and NOx. Other emissions such as SOx, hydrocarbons and smoke are either not observed or are much lower than those of diesel engines. Unburned hydrogen may also come out of the engine. This does not pose a problem since hydrogen is non-toxic and is not involved in any smog producing reaction. Oxides of nitrogen are the most concerning emissions from a hydrogen engine. These emissions can be reduced by using a process known as exhaust gas recirculation which recirculates a part of the engine's exhaust back into the combustion chamber.

Benefits of choosing hydrogen

Table 1 – Major properties of hydrogen and gasoline.

Property	Hydrogen	Gasoline
Flammability limit %	4–75	1–7.6
Stoichiometric composition by vol	29.53	1.76
Minimum ignition energy, mJ	0.02	0.24
Auto-ignition temperature, K	858	501–744
Quenching gap in NTP, cm	0.064	0.2

Fig.1 Major properties of hydrogen and gasoline

The most abundant element present on earth is hydrogen. Its calorific value is high as compared to that of hydrocarbons and liberates a large amount of energy during combustion. It does not pollute groundwater and has clean burning characteristics. The main aim is that efficient engines need to be developed which will in turn, improve transportation. Hydrogen does not produce carbon on combustion and is not a pollutant.

Properties of hydrogen

Fuel	LHV (MJ/kg)	HHV (MJ/kg)	Stoichiometric Air/FuelRatio (kg)	Combustible Range (%)	Flame Temp(°C)	Min. Ignition Energy (MJ)	Auto Ignitin Temp. (°C)
Methne	50.0	55.5	17.2	5-15	1914	0.30	540-630
Propane	45.6	50.3	15.6	2.1-9.5	1925	0.30	450
Octane	47.9	15.1	0.31	0.95-6	1980	0.26	415
Methanol	18.0	22.7	6.5	6.7-36	1870	0.14	460
Hydrogen	119.9	141.6	34.3	4-75	2207	0.017	585
Gasoline	44.5	47.3	14.6	1.3-7.1	2307	0.29	260-460
Diesel	42.5	44.8	14.5	0.6-5.5	2327	-	180-320

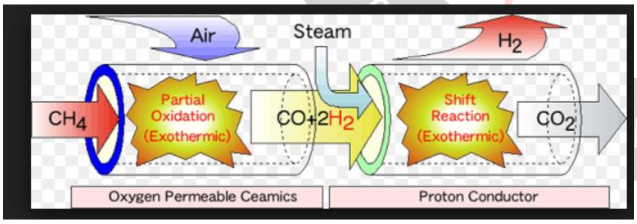
One of the main advantages of hydrogen fuel is its large energy density.A certain amount of hydrogen can produce almost 3 times the energy produced by the same amount of gasoline. Hydrogen and oxygen react to form water and release energy. This reaction can either occur as a chemical reaction in the process of electrolysis, or it can occur by combustion of the fuel at a high temperature and pressure

However, the major drawback regarding hydrogen fuel is its significantly low density. This raises issues regarding the amount of storage area required to power a vehicle over an adequate driving range, since the volume occupied by it is rather high.

The flammability range of hydrogen is wide in comparison with all other fuels used in IC engines. This makes it easier to use hydrogen over a large range of mixtures. For example, hydrogen can be used with lean mixtures which will improve fuel economy. Another advantage of hydrogen is that it can disperse rapidly in case of a leak due to its high diffusivity.

Methods of producing hydrogen

Natural gas reforming



This method accounts for most of the hydrogen produced today and is the most widely used process to produce hydrogen. In this process, hydrogen is produced by high temperature steam, with the help of a source of methane like natural gas. This process is also called steam methane reforming. This reaction is given by

Steam methane reforming reaction $CH_4 + H_2O$ (+ heat) $\rightarrow CO + 3H_2$

Fuel gas consisting mainly of carbon monoxide and hydrogen is called water gas. Subsequently, in a reaction known as "water gas shift reaction," steam and carbon monoxide react in the presence of a catalyst to produce carbon dioxide and more hydrogen.

Water gas shift reaction is given as follows: $CO + H_2O \rightarrow CO_2 + H_2$ (+ small amount of heat)

This is followed by a process called "pressure swing adsorption" in which impurities such as carbon dioxide are removed, basically leaving behind pure hydrogen in the gas stream.

Gasification

Gasification is a process by which biomass and a large amount of coal are burned at high temperatures to produce gaseous products which can then, in turn be used to produce electricity, chemicals, fertilizers and other useful components. The produced gas is processed using an array of chemical reactions to form hydrogen and carbon monoxide. Production of hydrogen using biomass gasification is a clean process because it is almost free from greenhouse emissions.

Electrolysis

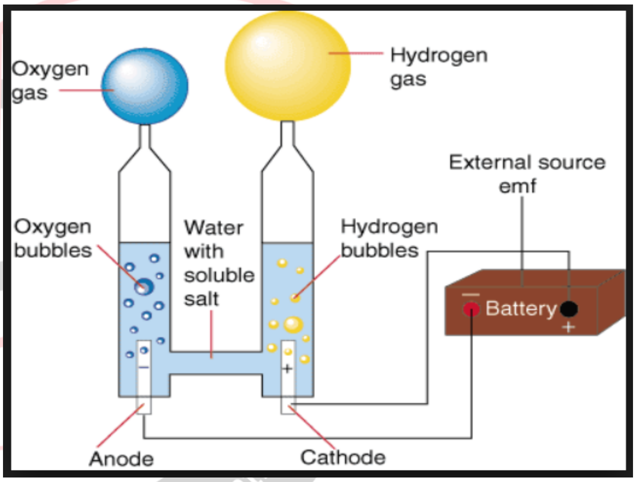


Fig: Electrolysis of water

Electrolysis is a process by which water is split into its constituent components, hydrogen and oxygen, by the passage of electric current. There are some drawbacks to this process. Firstly, this process uses a high amount of energy which can be expensive in the long run. Secondly,

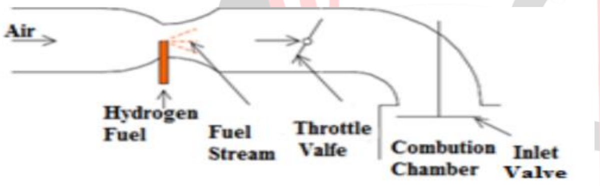
it is a viable and clean process only when the energy used to produce electric current is obtained from renewable energy sources such as solar power or wind energy. It is possible extremely pure hydrogen gas by means of electrolysis. Around 5% of the total hydrogen produced around the world is through electrolysis

Hydrogen in diesel engines

Hydrogen can be used in conjunction with diesel fuel in IC engines. Small amounts of hydrogen fuel injected into the combustion chamber of a diesel engine could make the diesel-fuel mixture less heterogeneous due to very high diffusivity of hydrogen. In a CI engine, hydrogen cannot be used as the sole fuel because of its high self-ignition temperature and the temperature during compression stroke is not high enough to warrant combustion of hydrogen. Therefore, hydrogen needs to be used in a diesel engine in dual fuel mode. In this mode, hydrogen is injected or carbureted into the intake air while diesel fuel acts as the main fuel that acts as an ignition source. In a hydrogen operated dual-fuel engine, oxides of nitrogen are the main problem. This can be solved with the help of exhaust gas recirculation (EGR) or by introducing water into the combustion chamber. Water helps in preventing knocking and pre-ignition, and cools the charge to reduce the rate of combustion. The drawback of using water is that, volumetric efficiency of engine is reduced.

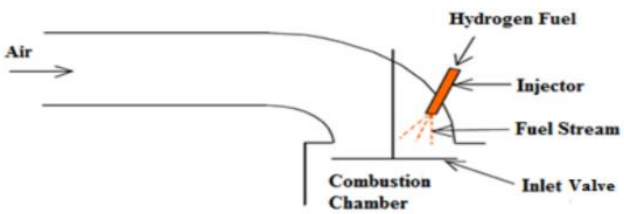
Types of fuel induction methods

Fuel carburetion method



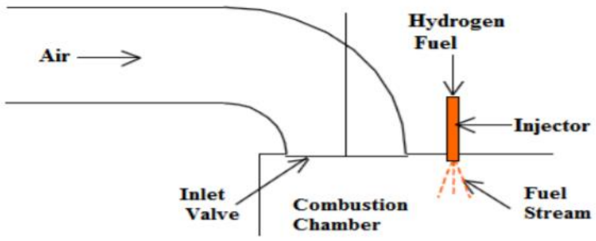
Carburetion system or central injection is the simplest method used for hydrogen induction. It does not require high hydrogen supply pressures. Carburetors are already being used in gasoline engines so, it will be easy to convert a gasoline engine to a hydrogen or hydrogen/gasoline engine. However, carburetion is not suitable for a hydrogen engine because it leads to uncontrolled combustion at different parts in the engine cycle. In a carbureted hydrogen engine, a considerable amount of inlet manifold contains a combustible air-fuel mixture. If ignition of this mixture occurs, there can be serious damage to the engine components due to backfire.

Inlet manifold and inlet port injection



In this system, fuel is injected directly into the intake manifold at each intake port. This is done with the help of a mechanically or electronically operated injector. At the beginning of intake stroke, air is injected separately to dilute residual gases. Hydrogen supply pressure is higher in inlet port injection systems as compared to carbureted systems, but less than that used in a direct injection system. The volume of air taken in during each cycle is kept constant but the amount of fuel injected in the air stream is varied to control the power output. Thus, this system can also be used with lean mixtures with less amount of fuel to increase fuel efficiency.

Direct injection systems



In direct injection systems, at the end of compression stroke, hydrogen is directly injected into the combustion chamber with the requisite pressure. Usually, a sparkplug is used as a source of ignition. This method is the most efficient one compared to other methods of injecting hydrogen. The power output of a direct injected hydrogen engine is considerably more than a gasoline powered engine since, the stoichiometric heat of combustion per kg of air is higher for hydrogen as compared to gasoline (approx. 3.37 MJ for hydrogen and 2.83 MJ for gasoline). The time taken for mixing of air-fuel mixture in a direct injection system is reduced due to high diffusivity of hydrogen. Therefore, this may lead to a non-homogeneous air-fuel mixture.

Conclusion

As time progresses, with sufficient amount of research, the methodology used to manufacture hydrogen will shift to one having no net greenhouse gas emissions. With the maturity and optimization of newer technologies and infrastructure, customers will have to shell out less for fuel. The main aim of researchers should be to develop automobiles using hydrogen as the sole fuel. This will reduce our dependence on fossil fuels and help in preserving the environment with cleaner emissions.

Over the recent years, our goal in reducing harmful emissions was not accomplished satisfactorily. Hence, alternative fuels need to be implemented as soon as possible for cleaner emissions. Hydrogen in CI engines provides a considerable reduction in smoke levels, carbon monoxide, carbon dioxide and hydrocarbon emissions since it does not contain carbon in its structure.

The physiochemical properties of fuels need to be studied in order to make advancements in combustion technology. Intricate kinetics of transportation fuels can help in shaping fuel or fuel additive designs. There are several hurdles that obstruct the growth of alternative fuels. Mainly, in a developing country like India, the required infrastructure is not in place to support the use of alternative fuels. Instead of using an alternative fuel as a standalone fuel in IC engines, we can use it in conjunction with conventional fuels to become aware regarding the advantages of specific fuels. The whole automotive industry should take this challenge as a whole to ensure a greener, cleaner environment in the decades to come.

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