# USING ALTERNATIVE ENERGIES IN INTERNAL COMBUSTION ENGINES

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## Abstract

This article presents the state-of-the-art research on the hydrogen fueled internal combustion engine. First, the fundamentals of the hydrogen engine are described by studying the engine-specific properties of hydrogen, and then the existing literature is reviewed.

**Keywords**: Internal combustion engine, hydrogen, emissions, alternative fuel 1.

## Introduction

Diesel engines are the main prime movers for transport, agricultural applications and stationary power generation. But diesel engines are emitting higher NOx and smoke emissions compared with gasoline operated vehicle. Hence it is necessary to find a suitable alternate fuel, which is capable of partial of complete replacement [1]. By accounting the various aspects of hydrogen fuel, considered as one of the suitable alternative source to replace the fossil fuel [2 ]. Its clean burning characteristics of hydrogen provide a strong incentive to study its utilization as a possible alternate fuel. Fuel cell was considered to be the cleanest and most efficient means of using hydrogen [3, 4]. Currently fuel cell technology is expensive and bulky. Hence a low cost technology to produce hydrogen is necessary [5, 6]. Hydrogen can be used in spark ignition a (SI) as well as compression ignition (CI) engines. In S.I engine hydrogen can be used as a sole fuel. The higher self-ignition temperature of hydrogen (858 K) needs external source to initiate the combustion such as spark plug or glow plug. Hydrogen fuel can be used in C.I engine such as Hydrogen enrichment in air Hydrogen injection in the intake system In cylinder injection In hydrogen fueled engine, the principal exhaust products are water vapor and NOx.

Emissions such as HC, CO, CO2, SOx and smoke are either not observed or are very much lower than those of diesel engine [7]. Small amount of hydrogen peroxide may be found in the exhaust of the hydrogen-operated engine [8]. Unburned hydrogen may also come out of the engine, but this is not a problem since hydrogen is non-toxic and does not involve in any smog producing reaction. NOx are the most significant emission of concern from a hydrogen engine [9].

## 1.1 HYDROGEN IN INDIA

Hydrogen reduces the smoke, particulate and soot emissions to the considerable amount by the maximum replacement of 20% in C.I engine without sacrificing the engine power output. The problems like pre- ignition and backfire could be eliminated compared to S.I engine that make the usage of hydrogen to be safer in CI mode. The Ministry of Non- conventional Energy Sources with an annual operating budget of US $ 100 million has been extensively supporting hydrogen and fuel cell research in many of the top universities and public research laboratories in India. Researchers have been successful in the biological production of hydrogen from organic effluents and a large-scale bioreactor of 12.5 m3 capacity is being developed in India [10]. The US Department of Energy and US based ECD Ovonics, Inc has launched a hydrogen powered three wheeler with a grant of US $ 5, 00,000 from the US agency for international development. The Ministry of Non-Conventional Energy is started to work towards the development of national hydrogen energy road map with the help of National Hydrogen Energy Board (NHEB). NHEB has also proposed to launch 1000 hydrogen vehicles by 2009 including 500 small three wheelers, 300 heavy vehicles and 200 buses [11].

## 1.2 REASONS FOR CHOOSING HYDROGEN

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

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. 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.

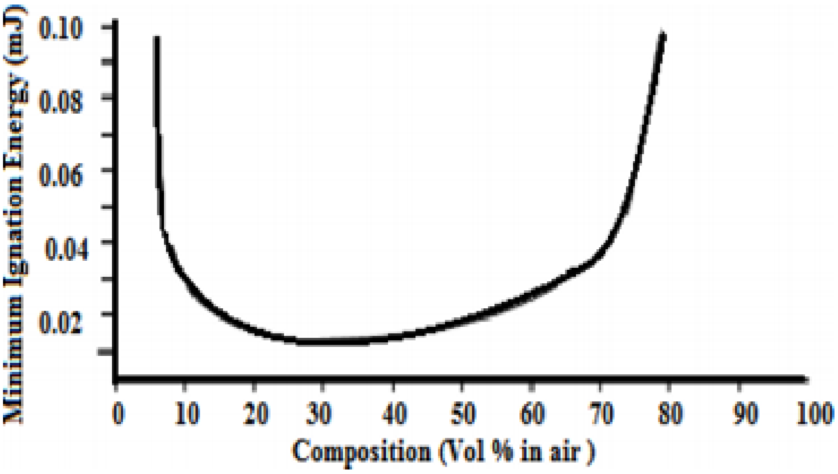


Figure 1. Minimum ignition energy of hydrogen in air [18]

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. 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. 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. 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.

## 3. ACCESSORIES THAT COMPLETE THE DESIGN

Crankcase ventilation [12] is even more important for hydrogen engines than for gasoline engines. As with gasoline engines, unburnt fuel can seep by the piston rings and enter the crankcase. Since hydrogen has a lower energy ignition limit than gasoline, any unburnt hydrogen entering the crankcase has a greater chance of igniting. Hydrogen should be prevented from accumulating through ventilation. Ignition within the crankcase can be just a startling noise or result in engine fire. When hydrogen ignites within the crankcase, a sudden pressure rise occurs. To relieve this pressure, a pressure relief valve must be installed on the valve cover. Hydrogen has a very low volumetric energy density at ambient conditions. Even when the fuel is stored as a liquid in a cryogenic tank or in a compressed hydrogen storage tank, the volumetric energy is small relative to that of gasoline. Hydrogen has a three times higher calorific value compared to gasoline (143 MJ/kg versus 46.9 MJ/kg). Some research has been done into using special crystalline materials to store hydrogen at greater densities and at lower pressures. [13] 3.1 Type of Fuel Delivery System [14] Port Injection System The port injection fuel delivery system injects fuel directly into the intake manifold at each intake port, rather than drawing fuel in at a central point. Typically, the hydrogen is injected into the manifold after the beginning of the intake stroke. At this point conditions are much less severe and the probability for premature ignition is reduced. The two types of port injection system are constant volume injector and electronic fuel injector. i) Direct Injection System In direct injection, the intake valve is closed when the fuel is injected, completely avoiding premature ignition during the intake stroke. Consequently the engine cannot backfire into the intake manifold. The power output of a direct injected hydrogen engine is 20% more than for a gasoline engine and 42% more than a hydrogen engine using a carburetor. iii). Central Injection System The simplest method of delivering fuel to a hydrogen engine is by way of a carburetor or central injection system. 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 carburetors are used on gasoline engines, making it easy to convert a standard gasoline engine to hydrogen or a gasoline/hydrogen engine. Ignition System

Due to hydrogen's low ignition energy limit, igniting hydrogen is easy and gasoline ignition systems can be used. At very lean air/fuel ratios (130:1 to 180:1) the flame velocity is reduced considerably and the use of a dual spark plug system is preferred. Ignition systems that use a waste spark system should not be used for hydrogen engines. These systems energize the spark each time the piston is at top dead center whether or not the piston is on the compression stroke or on its exhaust stroke.

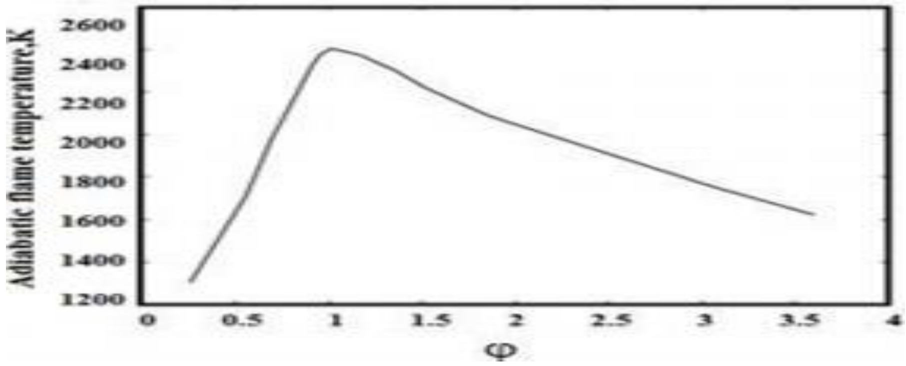
For gasoline engines, waste spark systems work well and are less expensive than other systems. For hydrogen engines, the waste sparks are a source of pre-ignition. Spark plugs for a hydrogen engine should have a cold rating and have non-platinum tips. A cold-rated plug is one that transfers heat from the plug tip to the cylinder head quicker than a hot-rated spark plug. This means the chances of the spark plug tip igniting the air/fuel charge is reduced. Hot- rated spark plugs are designed to maintain a certain amount of heat so that carbon deposits do not accumulate. Since hydrogen does not contain carbon, hot-rated spark plugs do not serve a useful function.

## 4. EFFICIENCY

The high octane and low lean-flammability limit of hydrogen provides the necessary elements to attain high thermal efficiencies in an engine. Direct comparison between the various studies have found compression ratio of approximately 14.5:1 to be optimal due to heat transfer losses at higher CR. [14, 16]. Besides the increase in BTE, by increasing compression ratio, engines have higher efficiencies than gasoline engines at similar CR. This is observed by comparing the gasoline and hydrogen data sets of experimental hydrogen fuelled automotive engine design data base project. Compared to gasoline operation the BTE with hydrogen operation is higher across the entire operating range, with the relative increase maximum at medium loads. The drop-off in the relative difference in BTE between gasoline and hydrogen at low loads is due to the need for some throttling. 4.1 Thermal Efficiency The theoretical thermodynamic efficiency of an Otto cycle engine is based on the compression ratio of the engine and the specific-heat ratio of the fuel as shown in the equation: V1/V2 = the compression ratio $\gamma$ = ratio of specific heats $\eta th$ = theoretical thermodynamic efficiency The higher the compression ratio and/or the specific-heat ratio, the higher the indicated thermodynamic efficiency of the engine. The compression ratio limit of an engine is based on the fuel's resistance to knock. A lean hydrogen mixture is less susceptible to knock than conventional gasoline and therefore can tolerate higher compression ratios. The specific- heat ratio is related to the fuel's molecular structure. The less complex the molecular structure, the higher the specific-heat ratio. Hydrogen ($\gamma = 1.4$) has a much simpler molecular structure than gasoline and therefore its specific-heat ratio is higher than that of conventional gaso-line ($\gamma = 1.1$). 4.2 Air Fuel Ratio The theoretical or stoichiometric combustion of hydrogen and oxygen is given as: $2H_2 + O_2 = 2H_2O$

Moles of $H_2$ for complete combustion = 2 moles Moles of $O_2$ for complete combustion = 1 mole Because air is used as the oxidizer instead oxygen, the nitro-gen in the air needs to be included in the calculation: Moles of N2 in air = Moles of $O_2$ x (79% $N_2$ in air / 21% $O_2$ in air) = 1 mole of $O_2$ x (79% N2 in air / 21% $O_2$ in air)
= 3.762 moles N2 Number of moles of air = Moles of O2 + moles of N2 = 1 + 3.762

= 4.762 moles of air Weight of O2 = 1 mole of O2 x 32 g/mole = 32 g Weight of N2 = 3.762 moles of N2 x 28 g/mole = 105.33 g Weight of air = weight of O2 + weight of N (1) = 32g + 105.33 g
= 137.33 g Weight of H2 = 2 moles of H2 x 2 g/mole = 4 g Stoichiometric air/fuel (A/F) ratio for hydrogen and air is: A/F based on mass: = mass of air/mass of fuel = 137.33 g / 4 g
= 34.33:1
A/F based on volume: = volume (moles) of air/volume (moles) of fuel = 4.762 / 2
= 2.4:1
The percent of the combustion chamber occupied by hydro-gen for a stoichiometric mixture: % $H_2$
= volume (moles) of $H_2$/total volume (2) = volume H2/(volume air + volume of H2) = 2 / (4.762 + 2)
= 29.6%
As these calculations show, the stoichiometric or chemically correct A/F ratio for the complete combustion of hydrogen in air is about 34:1 by mass. This means that for complete combustion, 34 pounds of air are required for every pound of hydrogen. This is much higher than the 14.7:1 A/F ratio re-quired for gasoline. Since hydrogen is a gaseous fuel at ambient conditions it displaces more of the combustion chamber than a liquid fuel.
Consequently, less of the combustion chamber can be occupied by air. At stoichiometric conditions, hydrogen dis-places about 30% of the combustion chamber, compared to about 1 to 2% for gasoline.



ls [19,20] Figure 2. Adiabatic flame temperature for hydrogen-air mixtures [17].

Table 1. Comparison of hydrogen with other fuel

| 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 |
| | | | | | | | |

## 1. HYDROGEN USE IN INTERNATIONAL COMBUSTION ENGINE

1.1 Hydrogen use in diesel engines There are several reasons for applying hydrogen as an additional fuel to accompany diesel fuel in the internal combustion (IC) compression ignition (CI) engine. Firstly, it increases the H/C ratio of the entire fuel. Secondly, injecting small amounts of hydrogen to a diesel engine could decrease heterogeneity of a diesel fuel spray due to the high diffusivity of hydrogen which makes the combustible mixture better premixed with air and more uniform [21]. Hence the formation of hydrocarbon, carbon monoxide, and carbon dioxide during the combustion can be completely avoided; however a trace amount of these compounds may be formed due to the partial burning of lubricating oil in the combustion chamber [22]. However hydrogen cannot be used as a sole fuel in a compression ignition (CI) engine, since the compression temperature is not enough to initiate the combustion due to its higher self-ignition temperature [23]. Hence hydrogen cannot CI engine without the assistance of a spark plug or glow plug. This makes hydrogen unsuitable for a diesel engine as a sole fuel. Because of this reason of the reported literature, activities on hydrogen

fuelling of a diesel engine were based on dual-fuel mode. In a dual fuel engine the main fuel is inducted/carbureted or injected into the intake air while combustion is initiated by diesel fuel that acts as an ignition source. The pilot fuel quantity may be in the range of 10–30% while the rest of the energy is supplied by the main fuel. Hydrogen operated dual fuel engine has the characteristics to operate at leaner equivalence ratios at part loads, which results in NOx reduction, and increase in thermal efficiency thereby reducing the fuel consumption.

Oxides of nitrogen (NOx) are the major problem in hydrogen operated dual fuel engine. One method that has been used to successfully reduce NOx emissions is exhaust gas recirculation (EGR). EGR is very effective in reducing NOx emissions due to the dilution effect of, where the oxygen concentration of the intake charge is reduced. In addition, volumetric efficiency reductions with increasing EGR rates are significant (reductions of about 15% compared with hydrogen dual-fuel operation without EGR are recorded). At the same time, EGR addition to hydrogen dual-fuel operation can increase particulate emissions compared with hydrogen dual-fuel operation without EGR. As a result, hydrogen dual-fuel operation with EGR produces smoke levels similar to normal CI engine operation. In addition to reducing NOx, increases in unburned HC, CO and $CO_2$ emissions with EGR addition are also recorded.

Another method of is introducing liquid water into the combustion chamber. Water injection can also prevent knocking and pre-ignition during hydrogen combustion. Here water acts in a similar manner to diluents such as EGR, cooling the charge and reducing the combustion rate. However, water injected into the intake manifold reduces volumetric efficiency [24].

Conventional diesel engines can be converted to operate on hydrogen–diesel dual mode with up to about 38% of full-load energy substitution without any sacrifice on the performance parameters such as power and efficiency [25]. 4.3 Hydrogen use in spark ignition (SI) engines Hydrogen can be used as a fuel directly in an internal combustion engine, almost similar to a spark-ignited (SI) gasoline engine.. Most of the past research on $H_2$ as a fuel focused on its application in SI engines. Hydrogen is an excellent candidate for use in SI engines as a fuel having some unique and highly desirable properties, such as low ignition energy, and very fast flame propagation speed, wide operational range. The hydrogen fuel when mixed with air produces a combustible mixture which can be burned in a conventional spark ignition engine at an equivalence ratio below the lean flammability limit of a gasoline/air mixture.

The resulting ultra-lean combustion produces low flame temperatures and leads directly to lower heat transfer to the walls, higher engine efficiency and lower exhaust of NOx emission.

Therefore, the extensive research pure $H_2$ as fuel has led to the development and successful marketing of hydrogen engine. For example, Ford developed P2000 hydrogen engine, which was used to power Ford's E-450 Shuttle Bus. BMW developed a 6 liter, V-12 engine using liquid $H_2$ as fuel. With an external mixture formation system, this engine has a power out about 170 kW and an engine torque of 340 Nm [26].

Natural gas-hydrogen mixtures engines Natural gas is considered to be one of the favorable fuels for engines and the natural gas fueled engine has been realized in both the spark- ignited engine and the compression-ignited engine. However, due to the slow burning velocity of natural gas and the poor lean-burn capability, the natural gas spark ignited engine has the disadvantage of large cycle-by-cycle variations and poor lean-burn capability, and these will decrease the engine power output and increase fuel consumption. [27]. Due to these restrictions, natural gas with hydrogen for use in an internal combustion engine is an effective method to improve the burn velocity, with a laminar burning velocity of 2.9 m/s for hydrogen versus a laminar burning velocity of 0.38 m/s for methane. This can improve the cycle-by-cycle variations caused by relatively poor lean-burn capabilities of the natural gas engine. Thus, natural gas engines can reduce the exhaust emissions of the fuel, especially the methane and carbon monoxide emissions. Also, the fuel economy and thermal efficiency can also be increased by the addition of hydrogen. The thermal efficiency of hydrogen enriched natural gas is covered. There are some challenges when it comes to using the hydrogen-natural gas mixture as a fuel. One of the biggest challenges using HCNG as a fuel for engines is determining the most suitable hydrogen/natural gas ratio. When the hydrogen fraction increases above certain extent, abnormal combustion such as pre-ignition, knock and backfire, will occur unless the spark timing and air-fuel ratio are adequately adjusted.

This is due to the low quench distance and higher burning velocity of hydrogen which causes the combustion chamber walls to become hotter, which causes more heat loss to the cooling water. With the increase of hydrogen addition, the lean operation limit extends and the maximum brake torque (MBT) decreases, which means that there are interactions among hydrogen fraction, ignition timing and excess air ratio [28].

**5.** 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. · Fuel Carburetion Method (CMI) · Inlet Manifold and Inlet Port Injection · Direct Cylinder Injection (DI) 5.1 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 carburetors 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%. 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 shown in Figure 3.

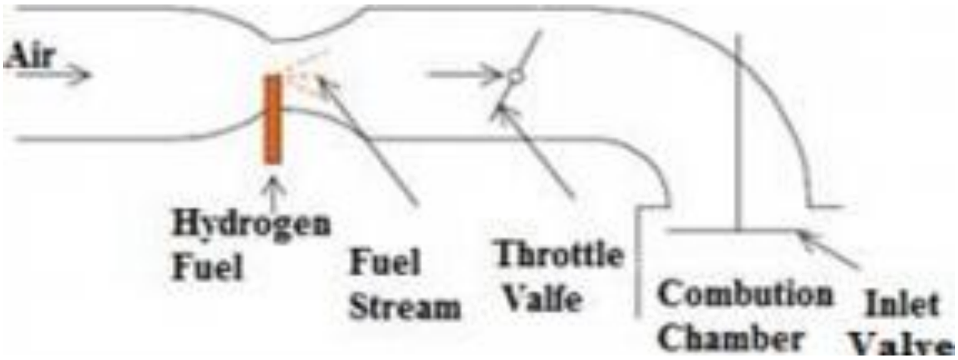


**Figure 3. Fuel carburetion method**

5.2 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 shown in Figure 4.

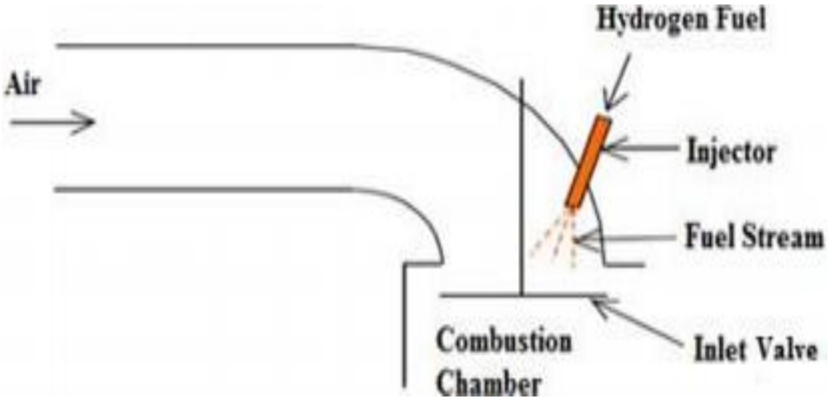


**Figure 4. Inlet manifold and inlet port injection**

Inlet manifold and inlet port injection 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. 5.3 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 shown in Figure 5.

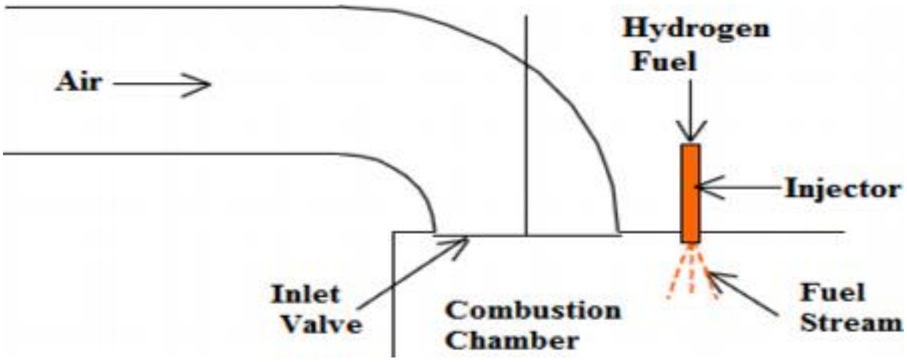


**Figure 5. Direct injection system**

## 6. Conclusions

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 theoretical maximum power of a hydrogen engine depends on the air/fuel ratio and fuel injection method. Stoichiometric air/fuel ratio for hydrogen is 34:1. At this air/fuel ratio, hydrogen will displace 29% of the combustion chamber leaving only 71% for the air. As a result, the energy content of this mixture will be less than it would be if the fuel were gasoline (since gasoline is a liquid, it only occupies a very small volume of the combustion chamber, and thus allows more air to enter). Since both the carbureted and port injection methods mix the fuel and air prior to it entering the combustion chamber, these systems limit the maximum theoretical power obtain-able to approximately 85% of that of gasoline engines. For direct injection systems, which mix the fuel with the air after the intake valve has closed (and thus the combustion chamber has 100% air), the maximum output of the engine can be approximately 15% higher than that for gasoline engines. Therefore, depending on how the fuel is metered, the maximum output for a hydrogen engine can be either 15% higher or 15% less than that of

gasoline if a stoichiometric air/fuel ratio is used. However, at a stoichiometric air/fuel ratio, the combustion temperature is very high and as a result it will form a large amount of nitrogen oxides (NOx), which is a dangerous pollutant. Since one of the reasons for using hydrogen is low exhaust emissions, hydrogen engines are not normally designed to run at a stoichiometric air/fuel ratio. Hydrogen can be used in both the spark ignition as well as compression ignition engines without any major modifications in the existing systems. An appropriately designed timed manifold injection system can get rid of any undesirable combustion phenomena such as backfire and rapid rate of pressure rise. · Internal combustion engine powered vehicles can possibly operate with both petroleum products and dual-fuels with hydrogen. · Because of hydrogen has a wide range of ignition, hydrogen engine can be used without a throttle valve. By this way engine pumping losses can be reduced. · Direct injection solves the problem of pre-ignition in the intake manifold; it does not necessarily prevent pre-ignition within the combustion chamber. · An appropriate DI system design specifically on the basis of hydrogen's combustion characteristics for a particular engine configuration ensures smooth engine operational characteristics without any undesirable combustion phenomena. · Backfiring is limited to external mixture formation operation and can be successfully avoided with DI operation. Proper engine design can largely reduce the occurrence of surface ignition. · Optimizing the injection timings can also control the onset of knock during high hydrogen flow. Hydrogen engine may achieve lean-combustion in its actual cycles.

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