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Use of Hydrogen in IC Engines Study on Performance, Emission and Fuel Injection System

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Abstract: ***Due to future crisis of energy and environmental degradation due to a carbon-containing fuel, hydrogen utilization as a fuel may be better for the near future. Hydrogen's vitality content per unit volume and larger heating esteem is around 3 times when compared with present fossil fuel [1], and it has a wide range of combustibility limits, and just requires a modest quantity of energy to initiate ignition, also for H_2 fuel ignition product is water vapour which doesn't affect the environment. This paper presents H_2 usage as a fuel in IC engines, and it also contains a study on its performance as compared to other fuel and mainly concentrates on various existing methods and various researches of H_2 production systems [3] which used to generate H_2 and inject it as a replacement for fuel in carburetor air intake. All data of different combustion characteristics was collected from a research paper of various authors [1], [8] given in the reference. The results obtained shows that the greatest estimation of Brake mean effective pressure is acquired at an engine speed of 3000 rpm, this is because of the appropriate burning in engine and increasing H_2 content, the CO_2 content decreases. It is found that when H_2 blends are used as fuel in IC engine, the brake thermal efficiency and most of the emissions were improved.***

Keywords: Hydrogen, emission, energy, ignition, injection

1. Introduction

Today world's most of the energy demand met by Non-sustainable power sources, are in a time of depletion. Moreover, their ignition items are causing overall issues, for instance, the nursery sway, ozone layer weariness, destructive storms and defilement, which are introducing many hazardous effects on earth. Then rigid outflow guidelines on car incited a considerable lot of the scientists to look for the possible elective fuel for the internal combustion engines. Numerous designers and researchers concur that the answer for these worldwide issues is supplant the current petroleum derivative framework with the perfect hydrogen energy framework. Among the accessible elective fuel choices; hydrogen finds unmistakable spot to supplant the current petroleum derivatives in IC engines. H_2 is accessible richly in our surroundings and produces closely zero emissions when utilized in internal combustion engines. It tends to be utilized in power modules or straightforwardly in IC engines.

The previously revealed fruitful business utilization of hydrogen-fueled vehicles goes back to the 1930s, with in excess of 1000 vehicles changed over into hydrogen and adaptable hydrogen/gas activity; be that as it may, specialized subtleties were allegedly obliterated in view of war and can presently don't be found.

The endeavor of building up a hydrogen motor was accounted for Cecil.R.W in front of timetable of the 19th century. During the midst of the only remaining century Otto utilized engineered maker gas which presumably contained H_2 substance nearly to half. H_2 is being extensively utilized in space programs because it has the best energy to weight proportion when compared with any other fuel and less in weight than any other fuel [3].

2. Literature Review

S. Naveen, C. P. Kiran, M. Prabhu Das, P. Naga Dilip, Dr. V.V. Prathibha Bharathi et al. in their work they demonstrated and concluded that as the distance between electrodes decreases the efficiency of electrolysis increases. Results of their tests have shown that there will be low power generation at low speeds whereas high speed characteristics could compete with gasoline performance. [23]

Phool Chand, Mukesh Kumar et al. in their work, they had suggested few modification in design that are necessary for utilizing H_2 as a fuel in existing 4-stroke gasoline engine. The change in values of torque, power, BTE, BMEP, exhaust gas temperature, and emissions of NO_X, CO, CO_2, HC, and O_2 versus engine speed are compared for a carbureted SI engine operating on gasoline and hydrogen. [24]

Shivaprasad K.V, Dr. Kumar G.N, Dr. Guruprasad K.R et al. studied the emission and performance characteristics of hydrogen fuelled SI engine. [25]

Mr. Deorukhkarsairaj R., Prof. Bhosale M.R., Mr. Salunkhe M.R., Prof.Gulavane T.S. et al. conducted an experimental analysis for H_2 as a supplementary fuel in 4 stroke IC engine. [26]

Vvn Bhaskar Dr. R. Hari Prakash Dr. B. Durga Prasad et al. they have analyzed the reasons of abnormal combustion effects of H_2 powered SI engine. [27]

Kirtan, Aryal et al.they presented their work in a paper which reviews the production of H_2, Performance and emission of hydrogen fuelled IC engines which gives idea about various researches has been made in hydrogen as a fuel in IC Engine. [28]

B.Rajendra Prasath, E.Leelakrishnan, N. Lokesh, H. Suriyan, E. Guru Prakash, K. Omur Mustaq Ahmed et al. their research was mainly focused on the various aspects and usage of hydrogen fuel in SI engine and CI engine. [29] **Ahmed Taha, Tarek Abdel-Salam, Madhu Vellakal** et al. performed a comparative study on hydrogen, biodiesel and ethanol for IC Engine. [30]

S. K. Sharma, P. Goyal And R. K. Tyagi et al. work specifically challenges the commercialization of hydrogen driven engines in automobile sectors. They had given possible suggestions to make this technology commercially viable. [31]

Niculae Negurescu, Constantin Pana, Marcel Ginu Popa, And Alexandru Cernat et al. work is specifically on making comparison with gasoline and hydrogen fuel engines. [33]

P.R.Chitragara, Shivaprasad K.Vb, Vighnesh Nayaka, P.Bedara, Kumar G.Na et al.performed an comparative analysis of gasoline, hydrogen and LPG fuelled IC Engine. [34]

The aim of this paper is to conduct a detailed study and analyze all papers available in this domain and to make a review on it and put forward our opinion on the basis of the outcomes of results.

Reasons for Choosing Hydrogen

Due to the ability of Hydrogen to eliminate carbon-based emissions like CO, CO_2 and soot and achieve higher efficiency, it has been considered as a future fuel. Adding to these, creation of hydrogen from environmentally friendly power sources is conceivable. H_2 ignition doesn't create any of the risky poisons, for example, hydrocarbon (HC), carbon monoxide (CO), oxides of sulfur (SO_x), smoke and so on The pollutant which should be checked intently is oxide of nitrogen (NO_x). Consequently, hydrogen may be the extraordinary flexible fuel which has ability of giving perpetual answers for our reliance on fuel, consumption of fuel and natural issues around the world.

Properties of Hydrogen

Hydrogen is an odourless gas which is very light in weight. At room temperature it remains in gaseous state. It has the density of 0.08375 kg/m^3 at standard temperature and pressure. The main properties of H_2 as contrasted with other fuels used to power IC engines and are listed in Table-1[2].

Property	Hydrogen	Gasoline	Methane	Diesel
Chemical formula	H_2	C_8H_{18}	CH_4	$C_{12}H_{23}$
Minimal ignition energy (mJ)	0.02	0.25	0.28	--
Limits of flammability (%by volume)	4-75	1.2-6.0	5.3-15.0	0.6-5.5
Auto ignition temperature (K)	858	500–750	813	453-593
Adiabatic flame temp (K)	2318	2470	2190	2600
Laminar flame speed at NTP (m/s)	1.90	0.37-0.43	0.38	0.22–0.25
Stoichiometric composition in air (% by volume)	29.53	1.65	9.48	
Density at 1 atm and 300 K (kg/m³)	0.082	730	0.651	830
Quenching distance at NTP (mm)	0.64	2.0	2.03	--
Stoichiometric fuel/air mass ratio	0.029	0.0664	0.058	0.069
Low heating value (MJ/kg)	119.7	44.79	46.72	42.5
High heating value (MJ/kg)	141.7	48.29	52.68	44.8
Combustion energy per kg of stoich. mixt. (MJ)	3.37	2.79	2.56	
Diffusion coefficient into air at NTP (cm² /s)	0.61	0.05	0.189	4.63
Kinematic viscosity at 300 K (mm² /s)	110	1.18	17.2	
Research octane number	>120	91-99	140	30

It can be observed that the H_2 auto-ignition temperature is more as compared to both C_8H_{18} and $C_{12}H_{23}$. Hence it is easier for H_2 to be used as an independent fuel in SI engine as compared to CI engine. Need for pilot fuel exists in case of Compression Ignition engines. The energy content of H_2 is very high which makes it a suitable option for use as an alternative fuel. It is this energy content that has pulled in a great deal of analysts to create sheltered and productive techniques for utilizing hydrogen as an essential fuel in IC engines. The wide flammability range of H_2 which makes it useful in a huge range of fuel to air ratios. The concern with hydrogen is the low ignition energy required which leads to the condition of knocking. The other concern is the effective and efficient storage of hydrogen.

There are various characteristics of hydrogen which are very useful for effective and clean emission from engine as well as engine performance.

a) Huge Flammability Range

The large combustibility range of H_2 is 4-75% when compared with all other fuels. This leads to obvious concerns regarding the H_2 handling. But, hydrogen has large range of F-A mixtures, along with a lean mixture of F/A. Lean mixture facilitates the engine with clean and complete combustion of fuel. There will be lower combustion temperature, which further lowers the emissions like nitrous oxides (NO_x).

b) Lower Ignition Energy

The energy required to ignite H_2 fuel is comparatively less than C_8H_{18} (Gasoline). (0.02 MJ for H_2 and 0.2 MJ for C_8H_{18}). It creates proper ignition of H_2. There may be chances of pre ignition phenomenon or flash back due to low ignition energy.

c) Small Quenching Distance

This is a boundary which quantifies how H2 flares head out nearer to the chamber divider before they stifle. Hydrogen has a tiny extinguishing separation of 0.6mm for hydrogen. In this manner it is a more troublesome assignment to extinguish a hydrogen fire than the fire of different fuels. Subsequently, this expands the inclination for backfire.

d) High Flame Speed

H_2 has a burning flame speed, which permits hydrogen engines come closer to ideal engine cycles. It has the foremost fuel power ratio when the stoichio-metric fuel blend is utilized. Be that as it may, when the engine runs on lean mixture to make strides fuel economy, flame speed moderates significantly.

H_2 has quick speed of flame at stoichio-metric proportions which is almost 2.65m/s which is a significant degree higher (quicker) than traditional fuels. This suggests that H_2 engines can more eagerly come closer to the thermodynamically ideal cycle of engine.

e) Auto Ignition Temperature

Hydrogen when contrasted with different fuels has a large auto start temperature of 858 K. This large temperature permits the hydrogen engine to utilize a higher compression ratio than the hydrocarbon motor. Fuel having high value of compression ratio, also provide high thermal efficiency to the engine, yet it is hard to light H_2 in a CI engine; this is on the grounds that the temperature needed for start is moderately high.

f) High Diffusivity

Hydrogen has an extremely high diffusion coefficient of $0.61cm^2$[2]. This shows the capacity to scatter in the air much more than the gasoline which is favorable for two primary reasons. The first advantage is that it helps promote the development of a uniform fuel-air mixture. Second advantage is, if there is a development of hydrogen leak, there will be rapid dispersion of hydrogen. Thusly, risky conditions can be evaded or limited and hydrogen spills are not a contamination to the climate.

g) Low Density

H_2 has an exceptionally lower density of $0.082kg/m^3$.The low density of hydrogen is a major concern for hydrogen storage. This create two issues, first, a huge volume is required for storing enough H_2 to give sufficient range of driving. Second, it lessens the power output. Low density means that the air-fuel mixture which will be produced will have a low energy density, Due to which it reduces the power output of the engine. When H_2 engines run on a lean mixture, there are issues of inadequate power.

Air Fuel Ratio

For complete ignition of hydrogen noticeable all around, the stoichiometric or chemically suitable gas-fuel ratio by mass is around 34:1 [2]. This is a lot higher than the air-fuel proportion needed for gasoline (14.7:1). Since H_2 is aerated fuel in surrounding conditions, it gives high space to the combustion chamber than fuel in liquid state. Due to this, small amount of the combustion chamber can be filled by air. In stoichio-metric conditions, around 30% of H_2 is displaced in the combustion chamber, while for gasoline is about 1 to 2%. Nonetheless, because of hydrogen's high adiabatic flame temperature, NO_x discharges from H_2 engines are commonly higher than those of gasoline engines, which to some degree restrict the commercialization of unadulterated hydrogen-fuel engines. Besides, the creation and capacity of H_2 is as yet costly, which is a block to the commercialization of unadulterated hydrogen engines soon. All in all, the energy density of H_2 is greater than that of gas.

Features of Hydrogen for Engine Applications

Notwithstanding prior one of a kind highlights only connected with hydrogen, numerous different engines can be referred to on the side of hydrogen applications. To show a portion of the fundamental highlights: Hydrogen has less cyclic variances than different fuels, even an extremely lean blend. This prompts decrease in discharges, improved productivity and calmer and smoother activity.

Hydrogen's high compelling octane rating might be mostly because of its high consume rates and moderate pre-ignition response. It has been demonstrated that hydrogen at generally low concentrations is a magnificent additive to some regular fuels, for example, methane. Its vaporous state empowers astounding cold starting and operation of engine. Hydrogen stays in vaporous state until it arrives at 20 K at its condensation point. H_2 engines are more qualified for operating high-speed engines predominantly due to the related rapid combustion rates. Ordinarily, less flash development is necessary, which improves efficiencies and force yield, as the majority of the heat delivered by ignition can be shut down following TDC. Operating H2 engine outcomes in less heat loss than different fuels. Dilute H_2 mixtures in air can be operated at sensibly high compression ratios, which allows for higher efficiencies and higher force yield. H_2 engines are appropriate for CHP applications on the grounds that the energy transfer because of the condensation of water vapor can prompt heat load and corresponding energy productivity. As opposed to most other business fuels, hydrogen is an unadulterated fuel with known properties and properties that permit ceaseless and better improvement of engine execution. The H_2 response rate is touchy to the presence of different catalysts. This component improves burning and exhaust gas dealing with. The thermodynamic and heat transfer properties of H_2 will in general bring about high compression temperatures that help improve engine productivity and lean burn. The high pace of hydrogen ignition makes the performance of a hydrogen-powered engine less delicate to changes looking like the burning chamber, turbulence level, and the vertical impact of the induction charge [6].

Internal combustion engines can burn more hydrogen in the air mixture than fuel gasoline. Makes hydrogen more efficient in stopping and starting with wide flare limits and fast flame speeds. Hydrogen tolerates the presence of pigments better. It will be better to use the fuel mixture with a lower temperature value. Hydrogen can be used very effectively with oxygenated air, as a result of electrolysis of water. Gas is highly variable and proportional, allowing for faster dispersal of fuel emissions and reduced risk of explosion associated with operating hydrogen engines.

Methods of producing Hydrogen

Hydrogen can be produced easily by electrolysis of water, using Hofmann Voltmeter. These simple experiments suggest that the water (H_2O) has two constituents, hydrogen and one part of oxygen. The main resource that has been applied for production of hydrogen is fossil fuel. There are number of processes for the generation of H_2 from fossil fuels. Currently the steam reforming process from the hydrocarbons is widely used. Other methods of hydrogen production from fossil fuels include partial oxidation, plasma reforming, petroleum coke and coal. Generation of hydrogen can be done from water using electrolysis, radiolysis, photo catalytic water splitting, and electrolysis. As a reactive nature, hydrogen seldom appears naturally as a pure gas. To consider hydrogen as an energy carrier, the technology must be developed to produce pure hydrogen economically.

Hosseini et al. has described the various methods of production of hydrogen. They had prepared a flowchart comprising the hydrogen development, production and storage. The main methods of production of Hydrogen are listed in table below [2].

Methods	Process
Gasification process (from coal)	At high pressure and temperature: Coal + $H_2O(g)$ + O_2 (g) → syngas Syngas = H_2 + CO + CO_2 + CH_4 This is the present method of mass production of H_2
Electrolysis of H_2O	Electric current is used to decompose water as, $2H_2O(l) \rightarrow 2H_2(g) + O_2(g)$ This method is not widely used due to electricity cost.
Solar Hydrogen production	Solar power electrolyser is used to decomposition of H_2O a: $2H_2O(l) \rightarrow 2H_2(g) + O_2(g)$ This method is generally not widely used due to cost of renewable source of energy.
Steam Reforming of Methane gas	At higher temperature (700° – 1100 °C), using Nickel as a catalyst, $CH_4(g)+H(g) \rightarrow CO(g)+3H_2(g)$ Following reaction occurs at lower temperature: $CO(g) + H_2O(g) \rightarrow CO_2(g) + H_2(g)$ At present, this is a major source of H_2

a) Water Electrolysis

The splitting of water into hydrogen and oxygen using electricity is known as electrolysis. It contains of 2 electrodes inserted in an aqueous conducting solution called electrolyte. A DC current is passed through the electrodes, which splits the water in the electrolyte into water and hydrogen. Theoretically, this is the simplest form of hydrogen generation. This innovation encounters an obstacle as a power conversion system as its impurities need to be provided as an excellent energy structure: electricity and in the current process of liquid electrolysis, electrodes are plated and therefore the process is less expensive.

b) Natural Gas Reforming

This method is the most common and widely used way for the production of hydrogen. Ninety five percent of the total H_2 produced in the US comes from this technique. Natural Gas contains CH_4 which can be utilized to create H_2 using the thermal processes like partial oxidation and steam methane reformation (Source: energy.gov). Steam-CH_4 reforming technique creates an environment in which steam at 3-25 bar is reacted with methane (CH_4) , where nickel present as a intermediate catalyst, products of reaction are (H_2), CO_2 and CO.

$CH_4 + H_2O$ (+ heat) $\rightarrow CO + 3H_2$

In partial oxidation method, CH_4 and other hydrocarbons react with less quantity of O_2 than needed for a stoichiometric reaction. This results in hydrogen and carbon monoxide as main products with fewer amounts of carbon dioxide and other compounds.

$CH4 + ½O_2 \rightarrow CO + 2H_2$ (+ heat)

c) Gasification

It is a process where coal is burned at about 1200°-1500°C to convert into gaseous components. The product of this reaction is processed to form hydrogen and carbon monoxide.

Hydrogen Storage Methods

H_2 is conveniently stored in high pressure cylinders under a pressure of 35-70 MPa. This method of storage is large as huge amounts of steels are required to store small quantities of H_2. In case of an accident, hydrogen is released instantaneously that causes an explosion. Car manufacturers such as Honda and Nissan use this type of storage. A more practical approach of storing hydrogen is the cryogenic technique in which hydrogen is stored at 21.2 K in cryogenic tanks. There are different drawbacks in this technique. Flammability danger comes into picture because liquefied gases of atmosphere would come in the vicinity of hydrogen storage tanks. Another problem lies in the energy required to convert hydrogen into liquid form. 25-30% of the heating value of H_2 is needed to condense H_2. Various alloys and metals form strong mixes called metal hydrides, by direct reaction with H_2 gas. At the point when the hydride is heated, H_2 is delivered and the original metal is recovered for further usage. Metal hydride is one of the solutions for storage problems regarding hydrogen. The most encouraging hydrides are those of lanthanum nickel $(LaNi_5)H_6$, iron titanium $(FeTi)H_2$, and magnesium nickel (Mg_2NiH_4). The most common drawback of metal hydrides is the high cost and the ineffectiveness of metal or the alloy after some cycles [5].

Hydrogen usage in SI Engines

H_2 is an incredible possibility for utilization in Spark Ignition engines as a fuel having a few one of a kind and profoundly alluring properties, such as less ignition energy, wide operational range and quick flame propagation speed. The H_2-air blend delivers a flammable mix that can be scorched in a traditional SI engine at an equality proportion beneath the lean combustibility cut-off of a air/gasoline combination. Similar to spark-ignited (SI) gasoline engines, H_2 can be utilized as a fuel straightforwardly in an IC engine. Hence, the broad examination of unadultered H_2 as fuel has prompted the turn of events and fruitful promoting of hydrogen engine. For instance, Ford built up the P2000 H_2 engine, which is used to run Ford's E-450 Shuttle Bus. BMW has developed a six litre,V-12 engine uses H_2 fluid as fuel. This motor has a force out around 340 Nm and a motor force out of 170 kW with an outer combination development framework [22]. Fig.1 portrays the utilization of fluid and vaporous H_2 in Spark Ignition engines.

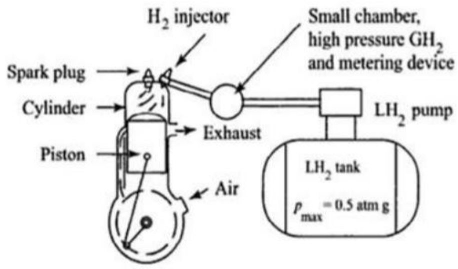

Figure 1: H_2 in SI engine [3]

Anomalies in combustion

The H_2 properties it as a alluring fuel moreover bear obligation for unusual ignition events related with it. In

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specific, lower ignition energy, the large combustibility limits and higher flame speeds may bring out about in un-desired burning phenomena which are by and large summed up as ignition irregularities. These irregularities consolidate pre start (surface ignition), backfiring, and auto ignition, rapid pressure rise [3]. The challenge in hydrogen engine is to suppress the abnormal combustion that generally happens in it, important implications in design of engine, formation of mixture, and load control are necessary.

a) Pre-Ignition

H_2 has property of large combustibility limits and also has lower ignition energy which causes pre-ignition. At high engine speed and at high load, if H_2-air mixture reaches at stoichiometric value there are more chances of occurrence of pre-start because of higher gas temperature and chamber temperatures. As untimely start makes the blend consume generally in the midst of the the compression stroke, which causes the rise in temperature within the combustion chamber, and it results in a hot spot, due to which pre-ignition tends to increase the temperature, it causes the new pre-ignition in upcoming cycle. If the pre-ignition happen in midst of suction stroke, its progression may stop because of backfire [3].

b) Backfire

Backfire could be a rough result of the phenomena of pre-ignition. When pre-ignition happens during the suction stroke at a guide close to the inlet valve, the inflamed charge may go into the inlet manifold through the open valve, this causes backfire. In pre mixed fuel inducted engine, ignitable fuel is present in the manifolds which can create a dangerous problem because of backfire. The event of backfiring is commonly restricted to formation concepts of external mixture. To reduce the risk of backfiring we have to take every measure to avoid pre-ignition [3].

c) Knock and Auto-Ignition

Knocking combustion is a typical issue found in H_2 powered engines. At the point when fuel and oxidizer inside the chamber arrives at cut-off points of temperature at that point end gas lights precipitously without the guide of sparkle which is named as auto-start, at that point follows a fast arrival of the excess energy producing pressure waves having large amplitude, alluded as engine knock. The pressure waves with large amplitude can cause harm to engine because of expanded mechanical and thermal stress. The engine design and fuel air mixture properties are the parameters to decide whether knocking will happen or not [3].

Hurdles and Solutions to Pre-Ignition

The essential issue which was experienced during the progression of operational H_2 engines is untimely start. Due to low ignition energy of H_2 , wider combustibility range, and shorter quenching distance, Untimely start could be a significantly more imperative issue in H_2 fuelled engines when compared with any other IC engines. If Fuel mixture present in combustion chamber ignites before the spark plug ignite this is called as premature ignition and it results in rough running engine with low efficiency. If this premature ignition takes place near the fuel intake valve backfire conditions may occurs because flames can travel back to inlet manifold system. Many ponders have been pointed at deciding the reason for pre-start in H_2 engines. A couple of the outcomes suggest that pre-start are brought about by problem areas(Hot spots) inside the ignition chamber, for example, on deposits of carbon, on a spark plug or at exhaust valve. Some of the researches also results to that if exhaust and intake valves have some overlap that will cause backfire. Sometime preignition also takes place due to the pyrolysis of the oils present at crevice volume and suspended in cylinder. This pyrolised oil comes in combustion chamber through blow-by from crankcase [3].

Fuel Delivery Systems

There is only effective way to reduce or eliminate the pre-ignition is to redesign the fuel delivery system. The three main types of the H_2 fuel delivery system are
(1) Central injection (carburetor),
(2) Port injection,
(3) Direct injection.

First two delivery system work for forming the mixture of fuel and air during the suction stroke. For carburetor or can be say as central injection, injection will takes place at the air intake manifold. And for port injection it is happen at intake port. The third one, direct cylinder injection involves direct forming of mixture in the combustion chamber, it is happen when the intake valves are not open.

a) Central Injection or Carburetted Systems

Central injection or Carburetted system is simplest techniques to inject fuel to a H_2 engine. This system has many advantages. Right off the bat, central injection doesn't require the H_2 supply pressure to be much high with respect to different techniques. Besides, central infusion or carburettors are utilized on gasoline engines, making it simple to change a standard gasoline engine over to hydrogen or a gasoline/hydrogen engine. The burden of central infusion in worldwide ignition engine, the volume involved by the fuel is around 1.7% of the blend though a carburetted H_2 engine, utilizing vaporous H_2, brings about a loss of 15% in power output. Subsequently, carburetion isn't at all favourable for H_2 engines, since it offers ascend to uncontrolled ignition at unplanned spots in the engine cycle. Likewise the more noteworthy measure of hydrogen/air combination inside the intake manifold intensifies the impacts of pre-start. On the off chance that pre-start happens while the inlet valve is open in a premixed engine, the flame can engender past the valve and the fuel-air blend in the inlet manifold might get ignited or backfired. In a carburetted H_2 engine, a significant segment of the intake manifold contains a flammable air-fuel blend and outrageous consideration must be taken to guarantee that start of this blend doesn't happen. Genuine harm to the engine segments can result when backfire happens [3].

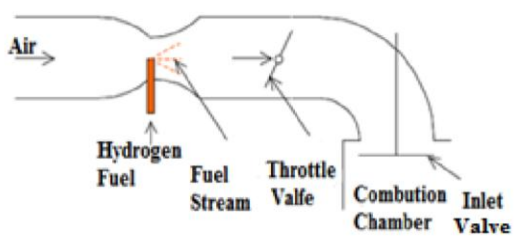

Figure 2: Fuel Carburetion Method [32]

a) Port Injection Systems

The port injection fuel delivery framework infuses fuel legitimately into the intake manifold at every intake port, as opposed to attracting fuel at a mid point. Commonly, the H_2 will be infused into the manifold after the start of the stroke of intake. Now situations are significantly less serious and the likelihood for pre-start is decreased. In port injection, the air is infused independently toward the initiation of the intake stroke to weaken the hot lingering gases and cool any problem areas. Since less gas (H_2 or air) is in the complex at any one time, any pre-start is less serious. The inlet supply pressure for port infusion will in general be greater than for carburetted or central injection systems, however not exactly for direct infusion frameworks [3].

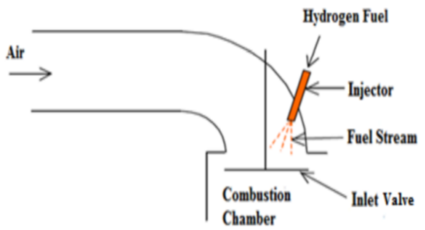

Figure 3: Inlet port injection and inlet manifold [32]

The constant volume injection (CVI) system utilizes a cam-worked gadget to inject the H_2 to every chamber at right time.

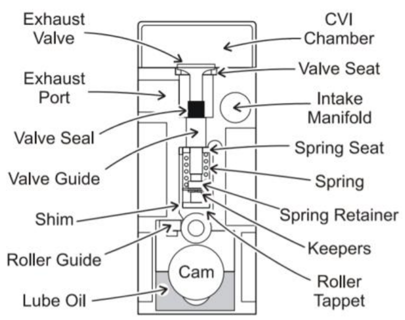

Figure 4

The electronic fuel injection (EFI) framework meters H_2 to every chamber. This framework utilizes individual electronic fuel injectors (solenoid valves) for every chamber and are fixed to a typical fuel rail situated below the midst of the intake manifold. Though the CVI framework utilizes constant injection timing and variable fuel rail pressure, the EFI framework utilizes variable injection timing and consistent fuel rail pressure.

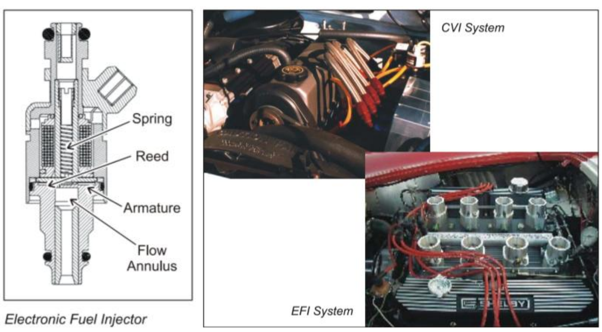

Figure 5: EFI and CVI Systems

b) Direct Injection Systems

During the pressure stroke advanced H2 engines utilize direct infusion into the combustion chamber. In direct injection system, the intake valve is closed when the fuel is infused, totally keeping away from untimely start during the intake stroke. Thusly the engine can't reverse discharge into the intake manifold. The force yield of a direct infused H_2 engine is twenty percent greater than when compared with a gasoline engine and forty two percent in excess of a H_2 engine utilizing a carburetor. The direct infusion takes care of the issue of pre-start in the intake manifold; it doesn't really forestall pre start inside the burning chamber. Furthermore, because of the diminished blending season of the air and fuel in an immediate infusion motor, the fuel/air combination is non-homogenous. Research has proposed this can prompt higher NO_x discharges than the non-direct infusion frameworks. Direct injection frameworks need a higher fuel rail pressure than different techniques [3].

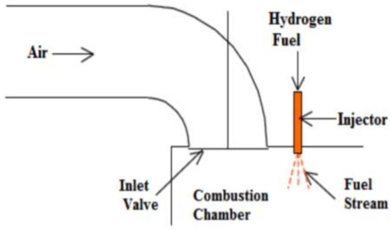

Figure 6: Direct injection system [32]

c) Thermal Dilution

The thermal dilution techniques like exhaust gasoline recirculation (EGR) or water injection can be used to decrease pre-ignition conditions. The name itself indicates an EGR system recirculation is a part from the exhaust gas back in the intake manifold. The launch of exhaust gas helps you to decrease the particular temperature associated with warm spots, decreasing the particular opportunity associated with pre-ignition. Furthermore, recycling exhaust framework gases delayed up the top ignition temperature, which for the most part lessens NO_x debilitates. Typically the twenty five to thirty percent recirculation of exhaust system fuel is efficient within eliminating backfire. However, the output of energy of the engine using an EGR will be reduced. The existence of wear out gases decreases the amount of gas blend which can be infused into the burning chamber. An additional strategy for weakening the gas combination thermally may be the infusion of water. Infusing water in to the H_2 stream not long prior to joining with air offers delivered preferable outcomes over infusing it in to the hydrogen-air blend inside the intake manifold. A likely issue with such a sort of framework will be that water can get blended in with the oil, so care must be taken to verify that closes don't outflow.

Engine Design

Using hydrogen in SI engine requires some modification to the SI engine to prevent the pre ignition and knocking problems, storage problem is also a concern there, to compete with gasoline in terms of power production. Supercharging can be use they may help to cure this by packing the approaching blend before entering in cylinder, this increases energy per unit volume for fuel. For preventing backfire spray nozzles for water are essential. Modifications are required for cooling the cylinder, power

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gain and the back fire resisting property. It increases the weight but compensates for all drawbacks.

Ignition Systems

Due to the low hydrogen heat capacity, hydrogen heating is easy and can be used to fuel, fuel systems. At higher values of excess air ratio (130: 1 to 180: 1) generally use of dual spark plugs are preferred due to significant reduction in the flame [3]. Whenever piston passes from TDC spark is generated at spark plug. The price for spark plugs is low for gasoline engine. But for hydrogen engines sparks act as source of pre ignition. Cold-rating plugs are should be used in hydrogen engine and tips should be non-platinum. Standard spark plus are slower than the cold rating plugs in terms of transferring heat from the tip of plug to the cylinder tip to burning the charge. Because of this, chance of burning of air/fuel charge decrease. To reduce the accumulation of Carbon deposits maintaining the heat is essential for these hot rated plugs are designed. And hydrogen does not have any carbon content so they are not useful here. Non platinum tip is mentioned above because it plays a role of catalyst in oxidation reaction of hydrogen.

Emission Analysis

Emission products escaped from the internal combustion engines are consist of many toxic pollutants, mainly it is HC, CO, and NO_x and also CO2. Now in the following context analysis of the hydrogen-fuelled engine about variation in concentration of escaped pollutants at different hydrogen fractions in fuel, has been discussed.

a) Emission of HC

After so much research work it was found that HC emission generally has an inverse varying proportion with Hydrogen addition fraction present in the fuel mixture as it is shown in the following graph in the figure. The reason for the decrease in emission is that as we increase the H_2 fraction it accelerates the formation of OH- radicals so that more amount of fuel mixture can be burnt fully and reduces the HC emissions. This makes less HC emission in hydrogen fuel mixture than gasoline.H_2 also has a shorter quenching distance between flame extinguishment and wall of the cylinder, it also reduces the HC emission. One more property of Hydrogen is diffusivity due to which it makes a more homogeneous and uniform fuel mixture. HC emission increases abruptly after $\lambda = 1.36$, λ is excess air ratio, its values can be decreased by adding more amount of hydrogen, as the property of high flammability of H_2 helps in increasing combustion in the cylinder, that reduces HC emission.

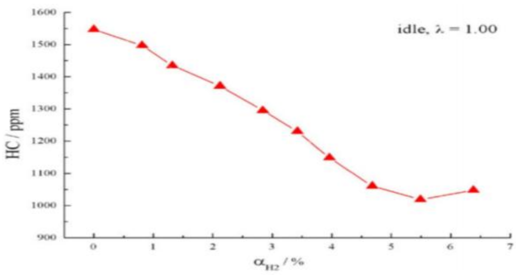

Figure 7: HC emission variation with hydrogen fraction for SI hydrogen-ethanol engine [1]

b) CO and CO_2 Emissions

From many research works, it was found that near the stoichiometric conditions of the excess air ratio, an increase in hydrogen percentage increases the CO emission. As the air-to-fuel ratio of H_2 is more than gasoline. Lean oxygen zone forms in the combustion chamber during the combustion of hydrogen because of the inhomogeneous nature of the mixture of fuel and air, reduction in the oxidation rate happens for CO. If we increase hydrogen addition fraction in an engine running under lean conditions CO emission gets improve as there is sufficient oxygen accessible for CO to be changed over into CO2, this exothermic reaction also helps to activate the oxidation. The expanded in-chamber temperature after hydrogen expansion additionally adds to animating the oxidation response of CO into CO2. When the value of excess air fuel ratio exceeds the value 1.36, emission of CO from gasoline spark ignition engine increases, since the expanded excess air fuel ratio animates the chance of a halfway failure to discharge, bringing about diminished in-chamber temperature, hindering the response energy of CO oxidation into CO_2.

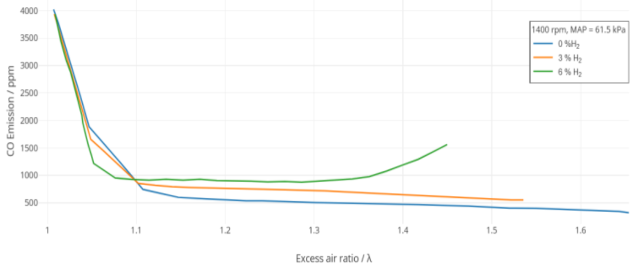

Figure 8: CO emission variation vs. excess air ratio.[1]

With respect to CO_2 emission is concerned, CO_2 emission diminishes with an increase in amount of hydrogen. Burning of H_2 does not produce CO_2.

c) NO_x Emissions

As we increase the hydrogen percentage in a mixture in spark-ignition engine NO_x emission also increases. The emission of NO_x also depends on the in-cylinder temperature conditions and concentration of oxygen. For a given excess air ratio and given concentration of oxygen, the maximum temperature inside the cylinder increases with an increase in hydrogen percentage; this is due to its property of a wide range of flammability. It is showed by Ji [20] that a significant excess air ratio for the greatest NO_x emission somewhat increases with an increase in H_2 addition fraction in the cylinder. A good explanation for this is as Hydrogen requires more amount of air for its complete combustion, and increases the temperature inside the chamber. Despite the fact that the engine with higher Hydrogen content, emits a higher amount of NO_x if the value of λ(excess air ratio) is near to its stoichiometric value; to drop the NO_x emissions for any hydrogen fraction to the acceptable value, the engine has to be run under very lean conditions i.e. $\lambda > 1.5$. This value again extends for a higher amount of hydrogen and with this NO_x emission also decreases. If there is an increase in H_2 addition fraction it results in the decrease of the overall fuel energy stream rate at a lean burn limit, and hence temperature inside the chamber gets decreased and consequently, the formation of NO_x gets constrained. The following graph illustrates the above work.

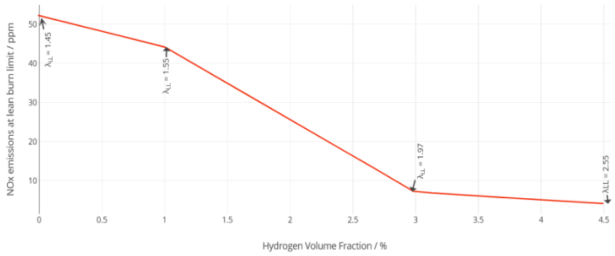

Figure 9: NO_x emission variations at lean burn limit vs. hydrogen volume fraction at 1400 rpm and 61.5 KPa [1]

Performance Characteristics

a) Engine Brake Mean Effective Pressure:-

The power output of any engine can be compared in terms of Bmep. The following figure shows the variation of brake thermal effective pressure with the varying speed of engine at different H_2 fractions. It can be shown from the following graph that Brake mean effective pressure ascends with an increase in hydrogen percentage as compared to the operation with gasoline. This happens because of the Hydrogen's property of wide flammable range which causes much quicker propagation speed to the flame and also much higher temperature than gasoline, this accelerates the combustion of complete mixture in the cylinder. But as the H_2 addition fraction increased to 25% value, Brake mean effective pressure drops because of inappropriate ignition as the air fraction in the intake is bit by bit diminished with the increment of hydrogen portion in the total inlet. The greatest estimation of Brake mean effective pressure acquired at an engine speed of 3000 rpm, this is because of the appropriate burning in engine.

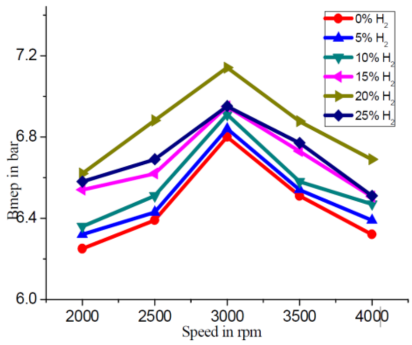

Figure 10: Bmep(bar) vs. engine Speed(rpm) [For various H2 vol. fractions] [8]

b) Engine Brake Thermal Efficiency

For evaluating the economy and overall performance of a particular engine, the thermal efficiency of the engines a crucial parameter. Generally, it depends on the fuel properties and state of the combustion system. The graph in the following figure shows the variation in thermal efficiency with a different engine speed for various percentages of hydrogen. It can be shown from the following graph that as the hydrogen percentage increasing in the gasoline engine, the thermal efficiency of the engine gets increases. Thermal efficiency for the gasoline engine operation having rich amount of hydrogen is higher when contrasted with an engine with pure gasoline.

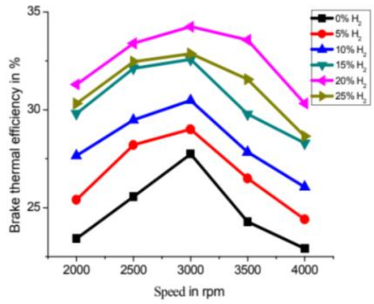

Figure 11: Brake thermal efficiency (%) vs. Engine speed (rpm) [For various H_2 vol. fractions] [8]

The burning velocity of the hydrogen blend is much higher than gasoline, also have more extended flame limit, the reason for these are hydrogen's high flame speed and wider flammability range, due to these hydrogen-gasoline blend's burning duration is short and have a complete burning of fuel. The performance of the engine is nearly ideal and at all operating speeds, it gives higher thermal efficiency than gasoline.

At 25% H_2 fraction thermal efficiency gets reduced, the reason for the same is that at such higher fraction, hydrogen accumulates cylinder volume because of this air quantity that required for the combustion reaction to be completed get reduces. This collective outcome reduces the thermal efficiency of engine.

c) Volumetric Efficiency (ηv):-

Volumetric efficiency can be defined as the ratio of the actual mass of fuel intake in the combustion chamber to the mass of the fuel that can be hold by swept volume if the fuel mixture is at ambient density [8]. Following graph is showing an increase in volumetric efficiency with an increase in engine operating speeds this is because of a reduction in pumping losses.

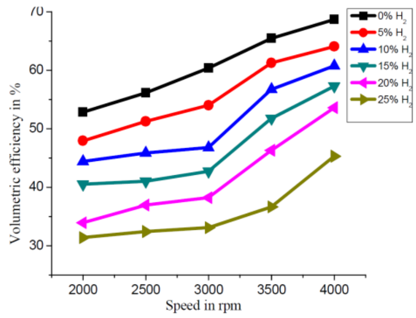

Figure 12: Volumetric efficiency (%) Vs. Speed (rpm) [For various H_2 vol. fractions] [8]

At 4000 rpm pure gasoline attains highest volumetric efficiency of 70%.With the increase in H_2 fraction there is a decrease of volumetric efficiency the reason for this is a difference in between their densities, being lighter one hydrogen displaces air. Burning of fuel in engine also affects the volumetric efficiency of engine. Hydrogen fuel vapor takes much space and leave very less space for air inside displacement volume, this causes the decrease in volumetric efficiency.

3. Results and Discussion

Due to depleting fossil fuel resources, the entire industry is now looking forward for an alternate fuel, where H_2 comes in the first place as an alternative. A detailed analysis on performance and emission characteristics has been carried and results have been put forward. On addition of hydrogen it is found that emission of HC is decreasing due to its ability to accelerate the formation of OH- radicals. It is found that with increasing the content of H_2 in fuel increases the emissions of CO whereas with respect to CO_2 emission, it diminishes with an increase in the amount of hydrogen present. As the content of H_2 increases we can find an increase in emissions of NO_x.

While coming to parameters related to performance, Brake mean effective pressure increases with increase in Hydrogen percentage when compared to gasoline. On increasing Hydrogen percentage, the thermal efficiency of the engine also increases. With an increase in hydrogen fraction there is a decline of volumetric efficiency.

On an overall when compared to existing fuels and the advantages of Hydrogen over its disadvantages, it can said that Hydrogen can play a crucial role in giving a hope to future fuels.

4. Conclusions and Future Scope

It is evident from the emerging trends that the diesel and gasoline powered engines will be history in the near future. In the scenario of electric powered cars the hydrogen powered engines can be also considered a potential option if used with utmost care. The electric powered cars are considered as the best replacement for conventional fuels but they come with their own problems of waste disposal. Here, hydrogen fuelled engines can come into the main frame and efficiently be used if proper precautions are taken care of. The emission control technologies for both engines have reached to their minimum level using various techniques and hydrogen can have a greater potential considering future emission norms. The better BTE as well as BSFC also further adds more weight to the claim of hydrogen substitution. Although hydrogen reduces emissions considerably, care must be taken to reduce NOx emissions to a significant level. There is a good scope of research work in this area. Safety aspects and storage are the main problem for using hydrogen as a fuel. If a good method of storage is found out then there will not be any other concern that will be able to stop hydrogen from replacing the conventional duo of gasoline and diesel.

The major outcomes of this study are discussed below:

- H_2 can be utilized in IC engines either as a fuel, or in terms of a fuel cell.
- With or without any changes or modifications in the existing systems, H_2 has ability to be used in SI engines.
- Pure H_2 or H_2 blended with gasoline can be utilized in IC engines.
- With a proper design of direct injection system, the problem of Backfiring can be eliminated. Backfiring in H_2 engines is limited to external mixture formation operation.
- In comparison to gasoline and diesel operated engines, the thermal efficiency of the H_2 operated engine is higher.
- Depending upon the fuel injection method selected, the power output of H_2 IC engines is 15-20% greater or lesser than the gasoline or diesel engine.
- Proper design of injection can help us in avoiding pre-ignition.
- H_2 internal combustion engines are a raising hope for cutting down the global warming and local pollutions problems in comparison with gasoline and diesel engines.
- When compared Hydrogen is found to be a safer fuel than conventional fuels.
- Lean combustion may be achieved in its actual cycles of Hydrogen engine, thereby reducing NO_x emissions.

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