International Journal of Engineering Research
Volume No.5, Issue No.10, pp :792-794
ISSN:2319-6890)(online),2347-5013(print)
1 October 2016

Feasibility of Hydrogen-Diesel Dual Fuel IC Engine -A Review

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Abstract : This paper presets a review of hydrogen technologies for the solution of long term internal combustion engine fuel problem with better reliability. A short overview about hydrogen is explained with some comparison among petrol and diesel. In this reviw it is found that still lot of research is going across the world at institutional and industry level. The production and storage of hydrogen are still costly at present, which are also the barriers for the pure hydrogen engines to be commercialized in the near future. The general purpose of the article is to understand how efficiently hydrogen technology can be used as a fuel in the engine such as compression ignition and solve the World`s increasing engine fuel problem . Due to the small quenching distance and high auto ignition temperature hydrogen is suggested in internal combustion engine as an alternate fuel instead of gasoline .Direct Injection (DI) system was reviewed as most apt injection system.
Keywords : Hydrogen fuel, IC Engine, NO_X and Direct injection .

I .Introduction

Hydrogen as a fuel in ICEs dates back as far as 1807, where François Isaac de Rivaz invented an internal combustion engine that used a mixture of oxygen and hydrogen for fuel [i]. Since then, institutions(mainly automotive companies) have been developing and improving the technology, mainly by automotive companies searching for a more sustainable and clean fuel source.

The greatest quantity of research came from the late 1990s through to the late 2000s, where large investments were coming from automotive companies, energy companies, governments, and universities, meaning development of the technology moved at a swift pace. Companies such as BMW,Ford, Mazda and MAN all saw great opportunities with hydrogen as a cleaner fuel source for their vehicles. However, research slowed after this period – perhaps because many automotive companies chose to turn to hydrogen fuel cell research over H2ICE, perhaps because although the technology was improving at a fast pace, the infrastructure required to support the collection, storage and supplyof hydrogen fuel on a large scale was not ready.

As a part of Indian research , In Delhi, 15 hydrogen-fuelled three wheelers were launched [129]. This was realised within a pilot project of the United Nations Industrial Development Organization (UNIDO), co-funded by its International Centre for Hydrogen Energy Technologies (UNIDO-ICHET) and the Indian Institute of Technology - Delhi, Air Products, Indian Trade Promotion Organization (ITPO) and Mahindra & Mahindra as project partners. 10 of the 15 vehicles are for passenger transport, 5 are for carrying load. The 0.4Litre single cylinder compressed natural gas ICE was converted to hydrogen operation, with 34 Litres of hydrogen stored in a tank at 200 bar. The brake thermal efficiency increased from 16.5%to 22% after the conversion, and power output decreased from 6.1kW to 4.62kW.

Hydrogen is considered as a potential carrier of energy and can be generated domestically from variety of methods including coal gasification, natural gas steam reforming, electrolysis using solar or wind generated electricity. When hydrogen is burnt in the combustion chamber the exhaust emitted contains water. The only pollutant of concern is NOx which can be drastically reduced at lean operation of engine. Thus the hydrogen operated engines are intrinsically capable of providing ultimate solutions to the problems. Also it is believed that use of hydrogen as a fuel would reverse or decelerate the greenhouse phenomena.

II. Hydrogen Fuel Characteristics

Hydrogen has significantly different combustion characteristics than other hydrocarbon fuels. The burning velocity of hydrogen-air mixture ranges from 153 to 232 cm/s for its stoichiometric mixture [ii]. This results in a more isochoric, thus thermodynamically more favorable combustion than conventional diesel engines which experience a pressure rise spread over several degrees of crank angle.

The minimum energy required for ignition of hydrogen-air mixture is 0.02 mJ only.This enables hydrogen engine to runwell on lean mixtures and ensures prompt ignition.The high auto ignition temperature of hydrogen allows for high compression ratios. When combined with the faster burn rate and the possibility of load control (changing the mixture richness at wide open throttle (WOT)), potentially high engine efficiencies can be achieved. However, heat losses from cylinder gases to the combustion chamber walls can be higher with hydrogen compared to conventional fuels ,negatively affecting efficiencies. As the hydrogen self ignition temperature is 858 K, compared to diesel of 453 K. Moreover, the high auto-ignition temperature of hydrogen encourages the use of higher compression ratios as prevalent in diesel engines.The hydrogen properties are shown in the Table .1

Table 1- Some comparative properties of Hydrogen, and Gasoline

Properties	H2	Gasoline
Limits of Flammability in air, vol %	4-75	1.0 -7.6
Minimum energy for ignition in air, mJ	0.02	0.24
Auto ignition Temp, K	858	501-744
Flame Temperature in air, K	2318	2470
Burning Velocity in NTP air, cm/s	325	37-43
Quenching gap in NTP air, cm	0.064	0.2
Normalized Flame Emissivity	1.0	1.7
Equivalence ratio flammability limit in	0.1-	0.7-3.8

III. Hydrogen Mixture formation for combustion in IC Engine

Injection timing and duration have been found to be factors just as important as differences in the fuel properties; research findings have shown that improvements in efficiency of up to 4% can be gained when using an optimized injection strategy .

The proper design of the mixture formation process is crucial for achieving high engine efficiencies while meeting more and more stringent emissions targets. The main classification of mixture formation strategies is based on the location of the formation of the hydrogen and conventional fuel mixture: External mixture formation refers to where hydrogen is introduced outside the combustion chamber (usually within the intake manifold), which contrasts with internal mixture formation, wherethe hydrogen is introduced directly into the combustion chamber(DI).

Generally, hydrogen injection systems for external mixture formation are operated at lower injection pressures (2–8 bar) compared to systems for hydrogen direct injection (5–250 bar). If an existing engine were to be fuelled by hydrogen, problems, such as backfire, pre-ignition, high rate of pressure rise and even knock can occur [xii].

IV. Hydrogen as a fuel in CI engine system

Madhujit Deb etal [ii] conducted experimentation on diesel-hydrogen dual fueled CI engine and concluded in their paper that , the hydrogen-diesel dual fuel concept method combines the advantages of the high part load efficiency, lower specific fuel consumption of a diesel engine and the clean combustion characteristics of hydrogen.

However, hydrogen with its cetane- number being very low, are not directly suited to compression ignition engines. Some source of ignition has to be created in the combustion chamber to ensure ignition [iii]- [vii].

Hoeffel James W, Mcclanahan Michael N, Norbeck Joseph M[iii] have studied that in comparison with other fuels, hydrogen engine operation contributes less undesirable exhaust emissions; for instance, there are no un-burnt CO and CO_2 gases.

Shioji et al [viii] observed that, fast engine operation, which leads to high power output, can be provided due to the hydrogen’s fast burning properties. Moreover, these types of engines can be started easily in cold weather conditions because of hydrogen’s low boiling temperature characteristics.

Karim [ix] reported that in SI engine, hydrogen as an engine fuel provides high-power output efficiencies by over wide temperature and pressure ranges (wide range flammability) .Hydrogen might have high octane number, due to the hydrogen’s slow pre-ignition reactivity and fast burning rates. Unlike most other fuels, hydrogen can be used as a pure fuel which permits sustainable and better optimization for engine performance.

Verhelst and Wallner,[x] have studied recently, some achieving developments about hydrogen fuelled ICE on compressive ignition. One of them is homogenous charge compression ignition .

There are several reasons for using hydrogen as an additional fuel with the diesel fuel in the ICE on CI. The most important reason is that it leads to increase the H/C ratio of the entire fuel. Secondly, heterogeneity of a diesel fuel spray can be reduced with addition small amounts of hydrogen due to the high diffusivity of hydrogen. This property leads to occur the combustive mixture better premixed. Moreover, due to the high flame speed, combustion duration can be reduced [iv]. Furthermore, faster combustion with constant volume provides more efficiency[vi].

Madhujit Deb etal [ii] conducted experiments with several hydrogen strategies and shown that ,the brake thermal efficiency of the engine with hydrogen enrichment reaches to a maximum of 32.24% at full load condition with hydrogen injection, whereas with diesel alone it was 26.79% .

It has been observed that there was a persistent trend of reduction of BSEC with increase in load for a given hydrogen enrichment strategy. This is an indicative of the enhanced combustion of conventional diesel combustion on account of high flame velocities and high calorific content of the participating hydrogen with air resulting in complete combustion of fuel and a little more engine power due to the increase in the amount of hydrogen fuel.

V. Some drawbacks of hydrogen engine applications

Most of the studies have been reported positive aspects of hydrogen engine applications. However, several limitations associated with hydrogen as an engine fuel. One of the most important negative features of hydrogen as a compressed gas is that it is obtained at 200atm and atmospheric temperature has only 5% of the energy of gasoline for the same volume. This is significant limitation especially for transport applications. Hydrogen engine requires almost 40-60% larger in size than a gasoline engine for the same power output. This causes to increase mechanical and motoring losses and decrease tolerance [ix].

Hydrogen’s wide range flammability and high auto ignition temperature provide a great deal of flexibility to be used hydrogen in SI engine. On the other hand, ignition of hydrogen is difficult for compression or diesel engines because these types of ignition require relatively high temperatures.

Hydrogen has lower heating value (LHV) compared to diesel fuel which is the further reason for high NOx emission, which results in an enhancement in the peak in-cylinder temperature.

The soot formation reduces surprisingly with hydrogen addition. It has been observed that in this TMI technique the maximum soot reduces by 38.62% when compared to diesel with the augmentation of hydrogen share with the main fuels at higher load. The increase in hydrogen induction enhances the overall H/C ratio during the dehydrogenation of the hydrocarbon fuel and thus reduces soot.s

With the addition of hydrogen, an increase in NOx emission was observed and which reaches to a maximum of 10.35kg/kW-hr at full load condition for hydrogen- operated engine at maximum injection durations of hydrogen (DH3) compared to diesel of 3.15kg/kW-hr. The reason for this higher concentration of NOx in case of hydrogen enrichment due to peak combustion temperature and high residence time of the high temperature gases in the cylinder [xi] –[xii] .

VI. NO_X reduction methods

In order to control NOx formation, the temperature in the combustion chamber should be less then N-N dissociation temperature. This can be achieved by using lean mixture of hydrogen . This has shown engine has been decreased significantly. Decrement i.n brake mean effective a significant decrement in the NOx emission. But due to lean mixture power output and efficiency of hydrogen pressure was also noticed due to low temperature which results in low brake thermal efficiency.

Also there are other methods for lowering down NOx emission like exhaust gas recirculation and water injection in the combustion chamber in order to bring its temperature below N-N bond dissociation temperature. But in these methods brake power and thermal efficiency become a matter of concern and were not equivalent to gasoline engine.

VII. Hydrogen retrofits for cars and their costs

Limited information is available regarding *the* cost of hydrogen ICE vehicles, or the cost of retrofitting a conventional gasoline ICE to run on hydrogen.The research is still at development stage so we are in a situation where there is a very limited user interface with these car companies small scale leasing programs. There's limited report on what those prices are going to be if and when these cars are available to the general public [i].

The following are the retrofit components for Hydrogen gas run cars :

High pressure Hydrogen tank, Hydrogen PRV (pressure reducing valve), Hydrogen Injection Nozzles ,Progressive Controller, Hydrogen Solenoid Valve and Hydrogen piping/tubing. High-pressure tanks are generally made with glass fiber, metal wrapped with filament winding and carbon fiber.

VIII. Conclusions

The use of hydrogen in internal combustion engines may be part of an integrated solution to the problem of depletion of fossil fuels and pollution of the environment. Today, the infrastructure and technological advances in matters of engines can be useful in the insertion of hydrogen as a fuel. Consequently, with the increasing of the new technology, the cost of the hydrogen production can be decreased which cause an increase in production. However, the works so far reported in the literature show encouraging results from the performance and emission points of view. The highest efficiencies are obtained for hydrogen, running lean and with wide open throttle. Many researches have been conducted for different injection system for suitable combustion phenomena. Direct Injection (DI) system was reviewed as most apt injection system.

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