CHAPTER 5

HYDROGEN FUELED ENGINE APPLICATION

The main utilize of hydrogen as an engine fuel is an effort on very limited foundation results in varying degrees of success from several researchers and investigators over a past decades and a large amount of information about their findings is available in the literatures.

From the large volume of information available and recent advance work connecting to hydrogen fueled compression ignition engines, dual fuel type homogeneous charge CI engines are generally identified as HCCI engines. In these engines the ignition is achieved either by surface ignition or catalytic ignition.

Due to this individuality, research is progress to use H$_2$ as an alternate fuel in internal combustion (IC) engines and also in the advance of fuel cell powered vehicles. H$_2$ can be used as the fuel in SI engine but in CI engine H$_2$ cannot be used directly due to its high self-ignition temperature (858 K) compared to neat diesel (553 K).

5.1 Hydrogen as an engine fuel

There are many features related with hydrogen that make it a well suited in principle to engine applications. Some of those predominant features are as follow:
Hydrogen over an extensive temperature and pressure range has very high propagation rates in the engine cylinder in comparison to other fuels. This rate remains effectively in stoichiometric combination section. The associated energy discharge is also faster with respect to the combustion duration. The combustion of lean hydrogen-air mixtures in combination with the faster combustion energy discharge rates around top dead center results in high output efficiency standards. However such lean mixture combustion lower the power output for any engine size.

One of the most significant features of hydrogen engine is less exhaust emissions than other fuels. There are no un-burnt hydrocarbons, carbon monoxide, carbon dioxide, and oxides of sulfur, smoke or particulates. The oxides of nitrogen and water vapor are the only byproducts of combustion. Also in lean combustion, NOx emission is much smaller than those encountered in combustion of other fuels.

The faster combustion characteristics of hydrogen allow it as high speed engine fuel. This permits an increase in output power with reduced penalty during lean mixture burning. Moreover the low boiling temperature of hydrogen results in fewer problems when operated in cold weather condition. Varying the ignite timing in hydrogen engine results in an unusually effective way for improving engine performance and suppression of knocking. Furthermore, the heat transfer characteristics of hydrogen combustion in
engines are very much dissimilar from those in engine that operates on other fuels. The sensitivity of the oxidation reactions of hydrogen to catalytic achievement with accurate control can be complete to provide positively towards engine performance.

**5.2 Hydrogen as a fuel in CI and SI Engine**

The theory of using hydrogen as an alternative to diesel fuel in diesel engines is not a new one. The hydrogen self ignition temperature is 858 K, hence it cannot be used in CI engine without the help of a spark plug or glow plug to ignite. This makes hydrogen is not a suitable for a diesel engine as a single fuel. One of the alternative methods is to accept hydrogen-enrichment or hydrogen-induction technique, which uses diesel as a pilot fuel for detonation purpose. Hydrogen is another alternate fuel tried for IC engines. Investigations were carried out extensively in many countries. The most attractive features of hydrogen as an IC engine fuel are that it can be produced from a potentially available raw material, water, and the main product of its combustion again is water.

Hydrogen has very low density both as gas and as liquid. Hence, in spite of its high calorific value on mass basis its energy density as a liquid is only one fourth that of gasoline. As a gas it has less than one tenth the density of air and its heating value per unit volume is less than one third that of methane. This is one of its chief disadvantages of hydrogen.
Hydrogen has to be stored as compressed gas, as liquid (in cryogenic containers) or in absorbed form (as metal hydrides), none of which is as convenient as gasoline storage.

Hydrogen has extremely wide ignition limits. This allows a spark ignition engine to operate on hydrogen with very little throttling, a decided advantage. Stoichiometric hydrogen air mixture burns seven times as fast as the corresponding gasoline air mixture. This too is a great advantage in IC engines, leading to higher engine speeds and greater thermal efficiency. Hydrogen has a high self-ignition temperature but requires very little energy to ignite it. Hence, it is highly prone to pre ignition and flashback in SI engines.

Adiabatic flame temperature for hydrogen is a little lower than for gasoline but the rapid combustion allows very little heat loss to the surroundings and hence, high, instantaneous, local temperatures are produced. This leads to high nitric oxide formation.

5.3 Various method of using hydrogen in SI and CI engines

5.3.1 Methods of using Hydrogen in SI engine

There are two methods by which hydrogen can be used in gasoline engines.

(i) By manifold induction
(ii) By direct introduction of hydrogen into the cylinder,
(iii) By supplementing gasoline.
In the manifold introduction of hydrogen, cold hydrogen is forced through a valve controlled passage in the manifold. This helps to reduce the risk of back flash. The power output of the engine is limited by two factors, pre-ignition and back flash. Also the energy content of air hydrogen mixture is lower than that of liquid hydrocarbon fuels.

In the direct injection of hydrogen into the cylinder, hydrogen is stored as liquid state in a cryogenic cylinder. A pump that pumps the liquid hydrogen through a heat exchanger, where it is transforms into cold hydrogen gas. The metering of the hydrogen is also carried out in this unit. The usage of cold hydrogen helps to prevent pre-ignition and also reduces NO\textsubscript{X} formation.

Hydrogen also finds usage as a supplementary fuel to gasoline in SI engines and this is done through induction of hydrogen along with gasoline, before the mixture is compressed and ignited by a spark plug.

5.3.2 Methods of using Hydrogen in CI Engine

There are two methods by which hydrogen can be used in diesel engines.

(i) By introducing hydrogen with air and using a spray of diesel oil to ignite the mixture that is by the dual fuel mode. The limiting conditions are when the diesel quantity is too small to produce effective ignition, that is failure of ignition and when the hydrogen air mixture is so rich that the combustion
becomes unacceptably violent. In between these limits, a wide range of diesel to hydrogen proportion can be tolerated. Investigations show that beyond a certain range (30 to 50% substitution of diesel fuel by hydrogen), leads to violent pressure rise.

ii) By introducing hydrogen directly into the cylinder at the end of compression. Since the self ignition temperature of hydrogen is very high, the gas spray is made to impinge on a hot glow plug in the combustion chamber i.e. by surface ignition. It is also possible to feed a very lean hydrogen air mixture during the intake into an engine and then inject the bulk of the hydrogen towards the end of the compression stroke.

Since, hydrogen is a highly reactive fuel it requires great care in handling. Flash black arresters have to be provided between the engine and the storage tank to prevent flash back from going to the tank.

Hydrogen has been used widely as cryogenic engine fuel in the space program due high specific impulse and for it excellent energy-to-weight proportion of any fuel. Liquid hydrogen is the fuel of choice for rocket engines and it has been utilized in the upper stages of launch vehicles to obtain the injection velocity on several space missions. In recent years, the concern for cleaner air along with stringent air pollution norms and the urge to decrease the fossil fuel usage has increased the interest in hydrogen as an engine fuel.
5.4 Preventive Maintenance

Flame arrestors are one of the important systems for suppressing explosions inside a hydrogen-containing system. In a hydrogen engine system flame traps have been working suitably while unwanted combustion phenomenon such as backfire occurs. Installation of a non-return valve (NRV) in the fuel line prevents the turnaround flow of gases to the engine cylinder.

5.5 Some other positive features of hydrogen for engine applications

In addition to the earlier unique features related with hydrogen, a number of others features can be mentioned to substantiate the hydrogen applications in engines. The following lists some of the most important of these features:

- Less cyclic deviation are noticed with hydrogen when compared with other fuels, even in lean mixture operation. This results in lower emissions, improved efficiency, quieter and smoother operation.
- Hydrogen has a high effective octane number because of its high combustion rates and its sluggish pre-ignition reactivity.
- Hydrogen behaves as an excellent additive in relatively small concentrations for few common fuels such as methane.
- Its gaseous state offers an excellent cold starting capability and smoother engine performance.
Hydrogen fuels are more suitable for high-speed engine operation mainly due to their fast burning rates.

Hydrogen engine operation can be related with less heat loss than the other fuels.

High compression ratio operation is possible with lean mixtures of hydrogen in air, which offers higher efficiencies and increased power output.

Hydrogen engines are most suitable for cogeneration applications since the energy transfer due to condensing water vapor can provide significantly thermal load output.

Unlike most other commercial fuels, hydrogen is a clean fuel of well-defined properties and characteristics, which permits continuous optimization of engine performance.

The hydrogen reaction rates are sensitive to the presence of a wide range of catalysts. This feature helps to improve the combustion and treatment of exhaust emissions.

The thermal characteristics of hydrogen tend to produce high compression temperatures which contribute to increase in engine efficiency and lean mixture operation.

High combustion rates make the hydrogen engine performance robust to variation of the combustion chamber shape, level of turbulence and the intake charge swirling erect.
5.6 Some limitations associated with hydrogen engine applications

A large quantity of the information and details in the open literature on the performance of engines on hydrogen as a energy emphasize the benefits of hydrogen while disregard the many of limitations connected with its purpose. There is a requirement to focus uniformly well on this and providing a means for overcoming some of their negative feature. The following is a list of some features related to hydrogen as an engine fuel that as requiring some improvement and remedial action:

Hydrogen as a gas at 200 bar and atmospheric temperature has nearly 5% of the energy of gasoline of the same volume. This is a major limitation particularly for transport applications.

Engines fueled with hydrogen suffer from reduced power output, due to the very low calorific value of hydrogen on volume basis and lean mixture operation.

The intake air mass is reduced because of the relatively high stoichiometric hydrogen to air ratio.

There are many impending operational problems related with the uncontrolled preignition and backfiring in the intake manifold of hydrogen fuel engines.

Hydrogen generates high pressures and temperatures during combustion in engines when in operating near stoichiometric mixtures. This lead to high exhaust emissions of oxides of nitrogen.
There are severe limitations for the application of cold exhaust gas recirculation for emissions control.

There is always high possibility of security problems with hydrogen operation.

Hydrogen combustion in engine results in increased noise and vibrations due primarily to the steep pressure increase rate resulting from faster burning.

Great care is essential to choose up materials that are compatibility with hydrogen applications in engines.

In applications such as in very frozen climates the exhaust emissions that are in steam form can be an undesirable feature like poor visibility and icing problems.

The sensitivity of hydrogen-air mixtures to catalytic action may contribute to low safety and poorer control of the combustion process.

Hydrogen requires a very little ignition energy which leads to uncontrolled preignition and knocking.

There is high potential for unwanted corrosion and lubricating oil pollution due to engine exhaust water vapor condensation.

There is high possibility for operational durability troubles with lubricants.

Heat transfer losses are high and under some circumstances they are quite low.
A hydrogen engine has to be 40 to 60% larger in size compared to gasoline engine for the same power output. This leads to few requirements like reduction in engine speed, improved mechanical and motoring losses, reduced tolerance to knocking and some engine design modifications to overcome it.

5.7 Advantages of Hydrogen as fuel for I.C engine

The advantages of hydrogen as an engine fuel are listed below:

- Hydrogen –air mixture burns early 10 times more rapidly compared to gasoline air mixture.
- Being burning rate significantly high it is more favored in high speed engine. As the flaming rate are very high, working approaches to direct combustion of an ideal Otto cycle performance.
- Hydrogen ignition limits are much wider. So it can flame easily and give significantly higher efficiency.
- Its clean exhaust is the most attractive feature of all. As it does not create carbon
- Less cyclic deviations are observed with hydrogen in comparison to other fuels even for very lean mixture operation. This results in lower emissions, improved efficiency, quiet and smoother action.
5.8 Disadvantages of Hydrogen as fuel for I.C engine

- The demerits of hydrogen as a fuel are given below.
- Hydrogen engines have been in the risk of back fire during combustion. Therefore flame arresters are essential in hydrogen fuelled engines.
- Hydrogen fuelled engine are having low pollution level but create toxic emission of NOx.
- The handling of hydrogen is more tricky and storage requires high capital and operation cost particularly for liquid H$_2$. 