

USING HYDROGEN AS A FUEL IN AUTOMOTIVE ENGINES - AN INVESTIGATION

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Abstract—In the fast moving world, hydrocarbon based fuels have become significant for a century's development. The fuels derived from crude oil are critical source of energy for fueling vehicles. However, crude oil based fuels are non renewable. The present investigation of using hydrogen was carried out in a direct injection diesel engine having a compression ratio of 17.5:1 and a capacity of 5.9 kW at a rated speed of 1800 rpm. In this investigation, the hydrogen was fed to the engine through the inlet manifold along with intake air during suction stroke of the engine. In order to maintain safety, the flame trap and flame arrestor were also used in the experimental setup. The results shows that there is an increase in brake thermal efficiency of the engine and reduction in carbon monoxide emission when, the hydrogen is used as a dual fuel, in the operation of the diesel engine.

Keywords-diesel engine, hydrogen, wide flammability limit, high burning rate, engine-out emissions

I. INTRODUCTION

At the current and projected rate of consumption of crude, it is estimated that these reserves will be badly depleted in due course and it may become impossible to meet the requirements [1]. It is therefore, important to develop alternative energy sources. Gaseous fuels are best suited for IC engines since physical delay is almost nil [2]. However, as fuel displaces equal amount of air the engines may have poor volumetric efficiency [2]. Hydrogen is one of the most promising fuels. Its clean burning characteristic and better performance derives more interest over the hydrogen fuel, compare with other alternative fuels. Properties of hydrogen are compared with other fuels in a table I. Many researchers tried to use hydrogen, as a fuel in SI engine [3-5]. When, using hydrogen in SI engine, the power output of the engine is reduced about 30%, and apart from that, problem like pre ignition, back firing and knocking occurs at high loads. When, using hydrogen as a sole fuel in the compression ignition engine, the compression temperature is not enough to initiate the combustion of the hydrogen due to higher self-ignition temperature of hydrogen [6]. So, when using hydrogen in CI engine, an ignition source is required [7]. In dual fuel operation mode, the diesel acts as an ignition source for the hydrogen fuel. Hydrogen has a wide flammability range in comparison with all other fuels. Wider flammability limits allow its utilization over extremely wide air/fuel ratio without misfire. The wider ignition limits of hydrogen make it possible to use lesser throttling compared to operation on gasoline. It has fast burning rates. The high burning velocity of hydrogen facilitates, to operate CI engines at higher speeds. The high auto-ignition temperature of hydrogen makes it very good knock resistant. Its low emissivity allows lesser heat losses to cylinder walls, thereby increasing the thermal efficiency of the engines. The ignition energy required for hydrogen is

very low. It's nearly 10 times less than that of gasoline. So it is very easy to ignite the hydrogen with a relatively weak spark.

TABLE I. COMPARISON OF PROPERTIES OF HYDROGEN WITH OTHER HYDROCARBON FUELS

Properties	Hydrogen H ₂	Diesel C ₁₀ H ₂₂	Gasoline C ₈ H ₁₈
Auto ignition temperature (K)	858	553	714
Minimum ignition energy (mJ)	0.02	20	0.24
Flammability limits (volume % in air)	4-75	0.6- 5.5	1.2-7.1
Molecular weight (g)	2.016	170	107
Density (kg/m ³)	0.0899	850	730
Stoichiometric A/F ratio (mass basis)	34.4	15.2	14.7
Flame velocity (cm/s)	270	22-25	30-50
Specific gravity	0.091	0.833	0.739
Adiabatic flame temp. (K)	2318	2200	2470
Quenching gap (cm)	0.064	0.21	0.2
Heat of combustion (MJ/kg)	120	42.46	43.4
Octane number	130	30	87
Cetane number	---	40-60	Below 15
Boiling point (K)	20.27	645	473

II. COMBUSTIVE PROPERTIES OF HYDROGEN

The properties contribute to use hydrogen as a combustible fuels are:

- Wide range of flammability limits (4 – 75%)
- Low ignition energy (0.02 mJ)
- Small quenching distance (0.064 cm)
- High auto ignition temperature (585⁰ C)
- High flame speed (2.91 m/s)
- High diffusivity (0.63 cm²/s)
- Low density (0.0899 kg/m³)

A. Wide Range of Flammability

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 [8-9]. A lean mixture is one, in which the amount of fuel is less than the theoretical, stoichiometric or chemically ideal amount for combustion with a given amount of air.

B. Low Ignition Energy

Hydrogen has very low ignition energy. The amount of energy needed to ignite hydrogen is about one third order of magnitude less than that of gasoline. This enables hydrogen engines to ignite lean mixtures and ensures prompt ignition. Low ignition energy means that hot gases and hot spots on the cylinder can serve as sources of ignition, creating problems of premature ignition and flashback. Preventing this is one of the challenges associated with running an engine on hydrogen.

C. Small Quenching Gap

Hydrogen has a small quenching distance, smaller than other hydrocarbon fuels, consequently, hydrogen flames travel closer to the cylinder wall than other fuels before they extinguish. The smaller quenching distance can also increase the tendency for the backfire since the flame from a hydrogen-air mixture passes more rapidly towards closed intake valve, than a hydrocarbon-air flame.

D. High Auto Ignition Temperature

Hydrogen has a relatively high auto ignition temperature. This has important implication, 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 compression is related to the compression ratio. The temperature may not exceed hydrogen's auto ignition temperature without causing premature ignition. The high auto ignition temperature of hydrogen allows larger compression ratios can be used in a hydrogen engine than in a hydrocarbon engine.

E. High Flame Speed

Hydrogen has high flame speed at stoichiometric ratio. The hydrogen flame speed is nearly an order of magnitude higher than that of other fuels. This means that combustion in hydrogen engines closely approaches the thermodynamically ideal engine cycle. At leaner mixture however, the flame velocity decreases significantly.

F. High Diffusivity

Hydrogen has very high diffusivity. This ability to disperse in a considerably greater than gasoline and is advantages for two main reasons. Firstly, it facilitates the formation of a uniform mixture of fuel and air. Second one, if a hydrogen leak develops, the hydrogen disperses quickly.

G. Low Density

Hydrogen has low density. This result in two problems; first one, a very large volume is necessary for storing system and the second one, the low energy density of a hydrogen-air mixture, and hence the power output of the hydrogen fueled engine gets reduced.

III. EXPERIMENTAL SETUP

An experimental setup was made with necessary instruments to evaluate the performance, emission and combustion parameter of the compression ignition engine at different operating conditions. The overall view of the engine setup is shown in Fig. 1. The engine used for the investigation was a four stroke, water cooled, single cylinder vertical diesel engine, developing a rated power 5.9 kW at a rated speed of 1800 rpm. The engine was coupled with an eddy current dynamometer for loading. Mineral diesel was used as a pilot fuel in the test engine and the hydrogen was inducted through the inlet manifold. Lone mineral diesel combustion was taken as a base line reading, to evaluate the engine characteristics, when it was dual fueled with hydrogen of various flow rates.

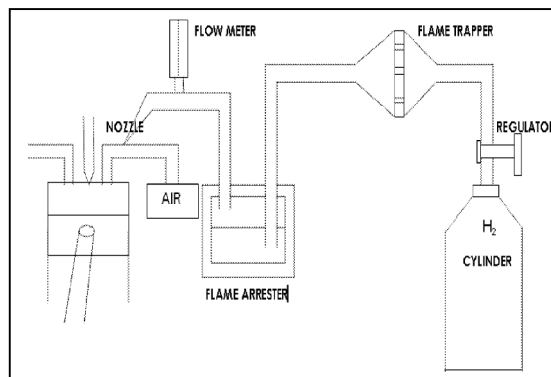


Figure 1. Experimental Setup.

IV. RESULTS AND DISCUSSION

Fig. 2 compares the specific fuel consumption for the various flow rate of hydrogen. It can be seen that the SFC is highest in the case of 2 lpm of hydrogen flow rate followed by base line engine and is least in the case of 8 lpm of flow rate of hydrogen. It was also evident that the SFC of the engine at the hydrogen flow rate of 4lpm and 6lpm are in between other two ranges. This decrease in SFC is due to fast burning velocity of hydrogen [10] and its high calorific value.

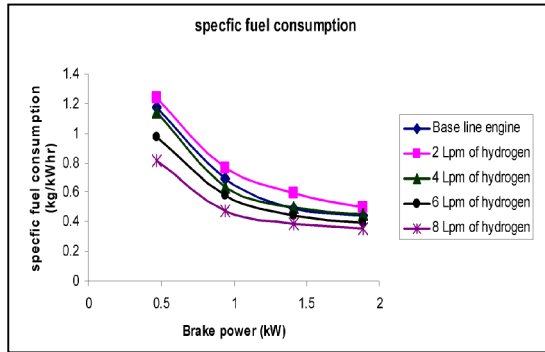


Figure 2. Brake Power Vs Specific Fuel Consumption.

Fig. 3 compares the brake thermal efficiency for the various flow rate of hydrogen. The efficiency of the hydrogen dual fuel operation was quite higher than the diesel fuel operation over the entire brake power range. In 8 lpm flow rate of hydrogen, brake thermal efficiency is the highest one, due to increase in calorific value of the overall fuel mixture. The high value of brake thermal efficiency can be attributed to the better mixing of hydrogen with air which results in better combustion [11-12]. The flame velocity of hydrogen is about 9 times as that of diesel; this may be a cause of higher brake thermal efficiency.

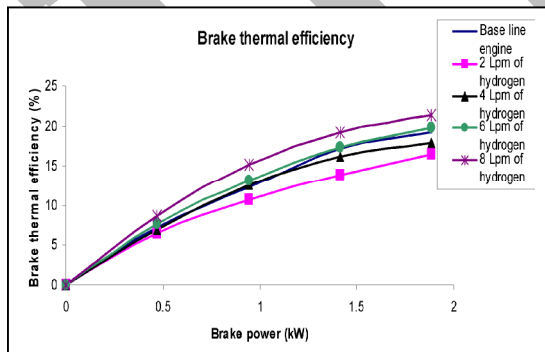


Figure 3. Brake Power Vs Brake Thermal Efficiency.

The variation of carbon monoxide emission with respect to brake power is shown in Fig. 4. Here, the carbon monoxide content is decreasing in the order of base line engine, 2lpm, 4lpm, 6lpm and 8lpm. The CO emission is lowest, when the flow rate of hydrogen is 8 lpm and is nearly 80% lower than the base line reading of the engine. This reduction in CO emission is due to high rate of combustion [12] associated with

high diffusion rate of hydrogen and its non carbonaceous nature of species in its molecular structure [13].

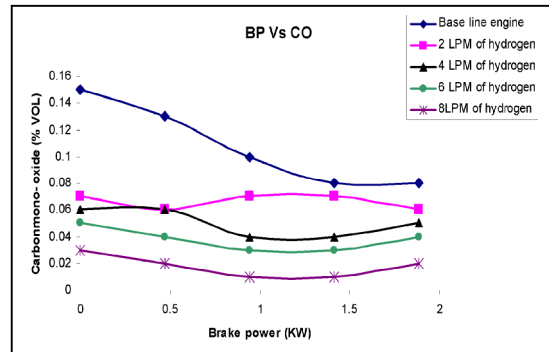


Figure 4. Brake Power Vs Carbon monoxide emission.

V. CONCLUSION

A single cylinder compression ignition engine was experimented successfully, using various flow rates of hydrogen, to study the performance and emissions characteristics of a test engine. The experimental results of this investigation are summarized as follows.

- The specific fuel consumption of hydrogen with diesel decreased at hydrogen flow rate of 8lpm, when compared with base line engine. The SFC increased at 2lpm compared with base line operation.
- The brake thermal efficiency of the hydrogen dual fuel operation was quite higher than the diesel fuel operation, over the entire brake power range.
- There was 80% decrease in CO emission, when hydrogen was used as dual fuel

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