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# Hydrogen Fuelled I.C. Engine

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***Abstract**: In this paper, initially in this paper some design modification is required for using hydrogen as a fuel in existing four stroke gasoline engine that has been discussed. Combustive properties of hydrogen fuel have been discussed. After that the performance and emission characteristics of a conventional fourcylinder spark ignition (SI) engine operated on hydrogen and gasoline has been reviewed. The variations of torque, power, brake thermal efficiency, brake mean effective pressure, exhaust gas temperature, and emissions of NOx, CO, CO2, HC, and O2 versus engine speed are compared for a carbureted SI engine operating on gasoline and hydrogen.*

## 1. Introduction

The incentives for a hydrogen economy are the emissions, the potentially CO2-free use, the sustainability and the energy security. In this paper the focus is on the use of hydrogen in internal combustion engines (ICE), or more precisely, hydrogen fuelled spark ignition (SI) engines. Internal combustion engines are classified as spark ignition (SI) and compression ignition (CI) engines, depending on the combustion process initiated in the cylinder. A spark plug initiates the combustion of the fuel-air mixture in SI engines. In CI engines, fuel-air mixture is self-ignited by compression. It must be mentioned that hydrogen's auto-ignition temperature is high (about 576), and it is impossible to bring hydrogen to its auto-ignition temperature by compression only. So, supportive ignition triggering devices should be used in the combustion chamber. Many researchers have been directed their studies towards the effect of using hydrogen in internal combustion engines. Evaluated the potential of using hydrogen for small horsepower SI engines and compared hydrogen fuelling with compressed natural gas (CNG). Another study dealt on certain drawbacks of hydrogen fuelled SI engines, such as high NOx emission and small power output determined the performance, emission and combustion characteristics of hydrogen fuelled SI and CI engines. Karim reviewed the design features and the current operational limitations associated with the hydrogen fuelled SI engine.

## 2. Combustive Properties of Hydrogen

### 2.1 Wide Range of Flammability

As can be seen the flammability limits (= possible mixture compositions for ignition and flame propagation) are very wide for hydrogen (between 4 and 75 percentage hydrogen in the mixture) compared to gasoline (between 1 and 7.6 percentage). This means that the load of the engine can be controlled by the air to fuel ratio, as for diesel engines. Nearly all the time the engine can be run with a wide open throttle, resulting in a higher efficiency.

### 2.2 Low Ignition Energy

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.

### 2.3 Small Quenching Distance

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.

### 2.4 High Auto-ignition Temperature

The temperature may not exceed hydrogen's auto ignition temperature without causing premature ignition. Thus, the absolute final temperature limits the compression ratio. The high auto ignition temperature of hydrogen allows larger compression ratios to be used in a hydrogen engine than in a hydrocarbon engine.

### 2.5 High Flame Speed

Hydrogen has high flame speed at stoichiometric ratios. Under these conditions, the hydrogen flame speed is nearly an order of magnitude higher (faster) than that of gasoline. This means that hydrogen engines can more closely approach the thermodynamically ideal engine cycle. At leaner mixtures, however, the flame velocity decreases significantly.

### 2.6 High Diffusivity

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.

### 2.7 Low Density

Hydrogen has very low density. This results in two problems when used in an internal combustion engine. Firstly, averylargevolumeisnecessarytostoreenoughhydrogentogivea vehicleanadequate driving range. Secondly, the energy density of a hydrogen-air mixture, and hence the power output, is reduced.

## 3. Design Modification

### 3.1 Spark plugs

Use cold rated spark plugs to avoid spark plug electrode temperatures exceeding the auto-ignition limit and causing backfire. Cold rated spark plugs can be used since there are hardly any spark plug deposits to burn off. Do not use spark plugs with platinum electrodes as this can be a catalyst to hydrogen oxidation.

### 3.2 Ignition system

Avoid uncontrolled ignition due to residual ignition energy by properly grounding the ignition system or changing the ignition cable's electrical resistance. Alternatively, the spark plug gap can be decreased to lower the ignition voltage; this is no problem for hydrogen engines as there will be almost no deposit formation. Spark plug gaps as small as 0.25mm has been used.

### 3.3 Injection system

Provide a timed injection, either using port injection and programming the injection timing such that an initial air cooling period is created in the initial phase of the intake stroke and the end of injection is such that all hydrogen is inducted, leaving no hydrogen in the manifold when the intake valve closes; or using direct injection during the compression stroke.

### 3.4 Hot spots

Avoid hot spots in the combustion chamber that could initiate pre-ignition or backfire.

### 3.5 Compression Ratio

The choice of the optimal compression ratio is similar to that for any fuel, it should be chosen as high as possible to increase engine efficiency, with the limit given by increased heat losses or appearance of abnormal combustion (in the case of hydrogen primarily pre-ignition

## 4. Experimental set up and procedure

The tests were performed at the Engines Laboratory of DokuzEylul University at Izmir. The laboratory consists of test benches involving an eddy current-type dynamometer, exhaust emission analyser, fuel metering device and auxiliary equipment. Fig. 1 shows the basic set up of the test bench. The engine was Fiat licensed one produced by the Tofas Company. Besides the engine itself, flywheel,starting motor, alternator, fuel pump, fuel tank, dashboard and exhaust assemblies were mounted to the proper places. Load applied to the engine was varied by using the knobs that change the current in the stator of eddy current dynamometer.

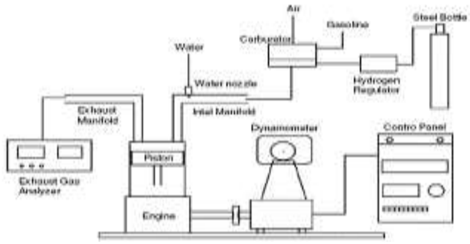


**Figure 1:** Experimental set up

## 5. Comparison of Performance Characteristics

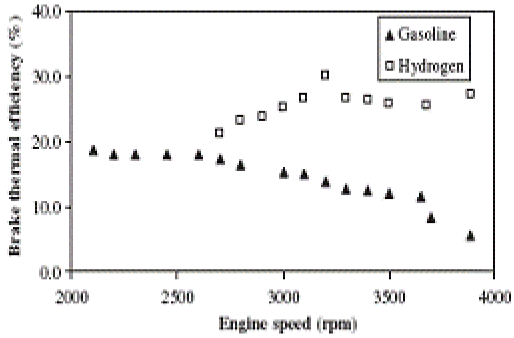


**Figure 2:** Brake thermal efficiency

Hydrogen fuel has higher brake thermal efficiency and even can operate at lower engine loads with better efficiency. It can be noticed that brake thermal efficiency is improved to about 31 percentageswith hydrogen fuelled engine compared to gasoline fuelled engine.Comparison of brake thermal efficiency of the fuels is shown in Fig. 2 Here brake thermal efficiency of hydrogen is much better than the brake thermal efficiency of gasoline engine even at a low speed.

## 6. Comparison of Emission Characteristics

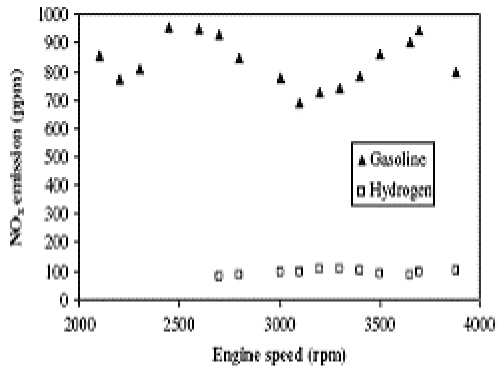


**Figure 3:** Emissions of NO

Fig. 3 illustrates NOx levels of both engines. Significant decrease in NOx emission is observed with hydrogen operation. Almost 10 times decrease in NOx can be noted, easily. The cooling effect of the water sprayed plays important role in this reduction. Also operating the engine with a lean mixture is kept NOx levels low.

Fig. 4 shows CO emission versus engine speed for both engines. Although excess air for complete combustion is present in the cylinder, the engine is not capable of burning the total fuel. Itwas expected that hydrogen fuelled engine must have zero CO emission.

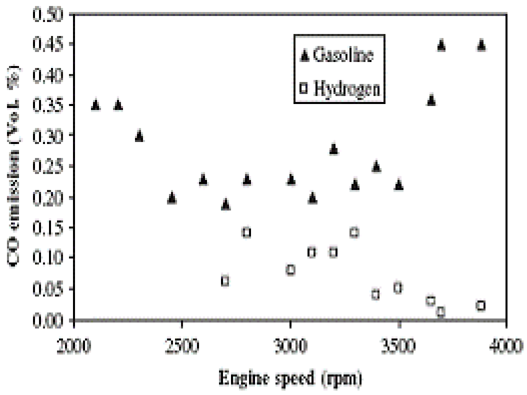


**Figure 4:** Emissions of CO

As it is seen in Fig. 4, some amount of CO is still present. This is due to the burning of lubricating oil film inside the engine cylinder. As engine speed increases, CO emission tends to decreases.

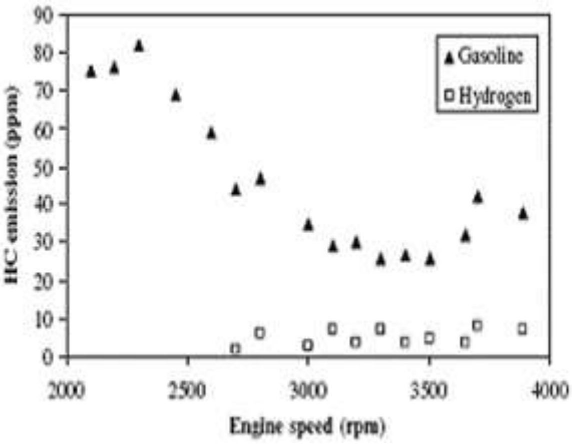


**Figure 5:** Emissions of HC

The temperature caused by combustion is very high inside the cylinder. As the piston expends the heat evaporates some amount of oil. In addition to this evaporated oil, incompletely burned oil also contributes to HC emission shown in Fig.5.

## 7. Conclusion

Specific features of the use of hydrogen as an engine fuel have been analyzed.

- Power and torque loss occurs at low speed hydrogen operation. At high speed hydrogen gives better performance as compare to gasoline operation.
- Similarly Thermal efficiency and Brake mean effective pressure of hydrogen is more at higher speed.
- NOx emission of hydrogen fuelled engine is about 9-10 times lower than gasoline fuelled engine.
- Emission of CO, HC and CO2 of hydrogen is very less so hydrogen is environment friendly.
- Emission of CO, HC and CO2 of hydrogen is very less so hydrogen is environment friendly.
- Short time of combustion produces lower exhaust gas temperature for hydrogen.
- Hydrogen is a very good candidate as an engine fuel. Appropriate changes in the combustion chamber together with better cooling mechanism would increase the possibility of using hydrogen across a wider operating range.

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