Port Fuel Injected Hydrogen in Dual Fuel Mode in Direct Injection Diesel Engine

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Hydrogen is expected to be one of the most important fuel in the near future for solving the problem caused by the greenhouse gases, for protecting environment and saving conventional fuels. In this study, a dual fuel engine of hydrogen and diesel was investigated. Hydrogen was conceded through the intake port, and simultaneously air and diesel was pervaded into the cylinder. Using Electronic Gas Injector and Electronic Control Unit (ECU), the injection timing and duration are varied. In this investigation, a single cylinder, KIRLOSKAR AV1, DI Diesel engine was used. Hydrogen injection timing was fixed at TDC and injection duration was timed for 30°, 60°, and 90° crank angles. The injection timing of diesel was fixed at 23° BTDC. When hydrogen is mixed with inlet air, emanation of HC, CO and CO₂ decreased without any emission (exhaustion) of smoke while increasing the brake thermal efficiency.

Keywords: Hydrogen, Injection Timing, Injection Duration, Performance, Emission, Emanation.

Introduction

In recent days, the significance of environment and energy is more accentuated because, among various energy sources, the fuels for automotive use are drawing attention as they are directly associated with our day to day life. The fossil fuels, which are widely used nowadays, have some grave problems such as restriction over preservation, unfeasible for recycling and it also produces various kinds of toxic waste emanation[1]. Therefore, various researches were carried on alternative fuels to substitute the fossil fuels. Among them, hydrogen has the outstanding advantages of wide flammable assortment and will also not produce unburned hydrocarbon and carbon monoxide[1-4], if there are no lubricants in the combustion chamber. In order to adopt, gaseous hydrogen as a fuel for an internal combustion engine, lots of research were carried out on hydrogen supply system[2,10,13,14] and combustion characteristics[5-6] and so on. And many areas of research are concerned with the adoption of in-cylinder type injection system for high pressure hydrogen. This type of injection system can eliminate the possibility of backflow of hydrogen into the intake pipe and can as well produce more power than an intake port injection system. But this system has a very complicated structure and greater durability problem. To overcome the disadvantages of high pressure in cylinder, injection system was tried with timed injection[11]. In this study, an intake port injection system was constructed and installed on a single cylinder engine, using a solenoid as the driving source of the injection valve. In order to minimize the possibility of flashback occurrence, injection timing of the hydrogen injection valve was set within the duration of intake valve opening[7]. Specifically, the hydrogen is supplied while the intake valve is open. So that the hydrogen injected into the intake port could be inducted into the combustion chamber as much as possible[8-9]. With this system, performance and emission characteristics of hydrogen combustion in the internal combustion engine were investigated.

Experimental setup

The engine used for the experimental investigation was a Kirloskar AV1, single cylinder, four strokes, water cooled, direct injection diesel engine, developing a rated power of 3.7 kW at a rated speed of 1500 rpm. The specifications of the test engine are given in Table 1. The engine is coupled to an electrical dynamometer with resistance loading. The engine is mounted on an engine test bed with suitable connections for lubrication and for the supply of cooling water. The electronic control unit (ECU) controls the operation of Hydrogen fuel injector. The one end of the positive power supply from the 12 V battery is connected to the injector, the other negative terminal of the injector is connected to the ECU,
which is having the control of injector opening timing and duration.

The electronic control unit is also having the input from the infrared detector. The IR Detector is used to give the signal to the ECU for the injector opening timing. The negative terminal of the injector is connected to the ECU. Based on the preset timing, the duration the injector will be opened for injection and closed after injection. The injection timing and injection duration will vary within the specified range by using the knob control. The power supply for the injector opening is 4A and for holding the injector to inject the fuel 1A will be the power supply required. Based on the presetting, the hydrogen will flow and the flow of hydrogen can be controlled either by using the pressure regulator or by using the digital mass flow controller. Rotameter is used to maintain the water flow, at the outlet of the engine. The range of the rotameter varies from 0 to 1000 lpm.

**Experimental procedure**

Hydrogen gas is stored on a high-pressure cylinder, which is at 150 bar, is reduced to a value of 3 – 4 bar by using a pressure regulator. Hydrogen is then passed through a fine control valve to adjust the flow rate of hydrogen. Then hydrogen is allowed to pass through mass flow controller, which meters the flow of hydrogen in terms of Standard Litres Per Minute (SLPM). Hydrogen is then passed through flame arrestor which is used to restrain possible fire hazards in the system. These flame arrestors operate on the basic principle on which the flame gets douse, if sufficient heat can be removed from the gas by the arrestors. It also acts as a non-return valve. Then hydrogen is allowed to pass through flame trap, which is used to suppress the flash back, if any, into the intake manifold. The flame trap used here is a wet type flame trap. In general, wet flashback arrestor work by turning out the gas into bubbles, in the non-flammable and ideally non-gas-absorbing liquid; and in this case, the liquid used is water. The hydrogen from the cylinder after passing through the flame trap is inducted into the gas injector, which is fitted in the inlet port. The engine was started with diesel as the fuel. Then hydrogen was introduced in the intake port by using hydrogen gas injector and it is brought to steady state conditions. The engine parameters were measured with different timing. At the end of the process, hydrogen flow rate was reduced to zero and the engine was made to run at steady state condition using diesel at no load condition. The start of injection hydrogen is fixed at TDC and three injection durations of 30° [3.3 ms], 60° [6.6 ms] and 90° [9.9 ms] crank angles were selected, since the fuel injector can be open for a maximum duration of 10 ms.

**Results and Discussion**

In the present work, adopting timed port injection technique in Compression Ignition (C.I.) engine with diesel being the ignition source uses hydrogen gas-air mixture. The performance and emission characteristics are compared with baseline diesel operation. In the test, the start of injection was fixed at TDC position at variance in the hydrogen duration of 30°(3 ms), 60° (6 ms), and 90°(9 ms) crank angle respectively. The hydrogen flow rate was fixed at 6 slpm.

**Brake Thermal Efficiency**

Fig. 1 clearly shows that for all the duration of hydrogen injection gives better brake thermal efficiency than that of baseline diesel. Maximum efficiency occurs at 60° hydrogen duration at full load was 43.23 %. The high value of brake thermal efficiency can be attributed to the better mixing of hydrogen with air, which results in better combustion and the operation of engine at leaner equivalence.

**Specific Energy Consumption (SEC)**

The variation of SEC with load is shown in Fig. 2. The specific energy consumption is reduced to 37 % when compared to baseline diesel at 100 % load of 60° duration. The lower specific energy consumption of timed port injection technique is due to the uniform mixing of hydrogen with air ensuing better combustion than neat diesel fuel operation.

![Fig. 1—Variation of Brake Thermal Efficiency with Brake Power](image-url)
Specific Fuel Consumption (SFC)

The specific fuel consumption is reduced to 26 % when compared to baseline diesel at 100 % load of 60˚ duration.

Oxides of Nitrogen

It can be observed from Fig. 3, that NO\textsubscript{x} emission in timed port injection technique is higher than that of baseline diesel. The higher concentration of NO\textsubscript{x} of hydrogen is due to the peak combustion temperature and high residence time of the high temperature gases in the cylinder. At 75 % load of 60˚duration attained to its maximum NO\textsubscript{x} emission.

Hydro Carbon

The HC emissions are lower compared with the base line diesel with the maximum being 18 ppm at full load in the case of 60 deg crank angle duration of hydrogen. The main reason for the reduction of HC is non-hydrocarbon fuel, and also sighted some traces due to the partial combustion with lubricating oil.

Carbon monoxide

The CO emissions are lower compared with the base line diesel, the maximum being 0.1 % by volume at a full load in the case of 60˚ crank angle duration of hydrogen. The CO emission are lower because of the reason that the hydrogen content does not contain any carbon in its structure and moreover, some traces of CO is sighted in the engine exhaust due to the burning of lubricating oil.

Smoke

The smoke level is reduced at full load compared to baseline diesel. Hydrogen on combustion produces mainly water and does not form any particulate matter, hence exhibits lower smoke level. The smoke level increases with the increase in the diesel flow due to the formation of a particulate matter by diesel fuel. In general the smoke levels are lesser with increased hydrogen intakes.

Carbon dioxide

The CO\textsubscript{2} emissions is lower compared with the base line diesel at 60 deg crank angle duration. The CO\textsubscript{2} emission of hydrogen is lowered because the combustion is expected to be complete comprising hydrogen flame at a higher velocity.

Exhaust Gas Temperature

The exhaust gas temperature was ahead of diesel in all the durations of hydrogen. This may be due to the better combustion of hydrogen fuel in port injection technique.

Pressure-Crank angle Diagram

Cylinder pressure versus crank angle data over the compression and expansion strokes of the engine operating cycle can be used to obtain quantitative information on the progress of combustion. There is a delay of few crank angle degrees between the start of injection and start of combustion, as identified by the change in slope of pressure crank angle curve. The dual fuel mode cylinder pressure occurs in a steep rise, because the hydrogen burns faster than diesel fuel.

Heat Release Rate

Fig. 4 shows the variation of heat release for hydrogen- diesel combustion at TDC, 60° injection duration at full load condition. From the graph it is evident that, heat release for hydrogen is steeper than diesel. From the rate of heat release it is also observed that, hydrogen-diesel fuel mixture is having the highest heat release rate at 79 J/degree CA compared
to neat diesel of 75 J/degree CA. This is due to the property of instantaneous combustion (constant volume) that takes place with hydrogen fuel.

**Conclusion**

Experiments were conducted to study the performance and emanation characteristics of a DI diesel engine using hydrogen gas by means of timed port injection technique with diesel as the mode of ignition. The emissions such as CO, CO$_2$, and HC are reduced drastically to negligible concentrations. The NOx emission decreases from 1500 ppm to 250 ppm at full load in the 60° CA duration. The reductions in emissions are due to efficient combustion as resultant of the hydrogen combustion. The smoke emission reduces from 6.8 BSN to 1.8 BSN along with simultaneous reduction of NOx when using the hydrogen in dual fuel mode. Brake thermal efficiency increases from around 20% to 25%. In 60° CA duration SEC decreases by 15% compared to base line diesel in timed port injection technique at full load. The hydrocarbon emission is 80% lower, when compared with diesel fuel. This is due to hydrogen being a non-hydrocarbon fuel. And some traces are sighted due to the combustion of lubricating oil and from diesel. The pressure variation shows that in hydrogen fuelled operation, the peak pressure increases rapidly. Thus the present experimental investigation on a single cylinder diesel engine indicates that by using hydrogen as a fuel adopting timed port injection technique, gives better competence and condensed emission compared to the neat diesel fuel operation.

**Table 1—Specifications of Test Engine**

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Make and Model</td>
<td>Kirloskar, AV1</td>
</tr>
<tr>
<td>General</td>
<td>4-Stroke / Vertical</td>
</tr>
<tr>
<td>Type</td>
<td>Compression Ignition</td>
</tr>
<tr>
<td>Number of Cylinder</td>
<td>One</td>
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<tr>
<td>Bore</td>
<td>80 mm</td>
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<tr>
<td>Stroke</td>
<td>110 mm</td>
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<tr>
<td>Swept Volume</td>
<td>553 cc</td>
</tr>
<tr>
<td>Clearance Volume</td>
<td>36.87 cc</td>
</tr>
<tr>
<td>Compression Ratio</td>
<td>16.5:1</td>
</tr>
<tr>
<td>Rated Output</td>
<td>3.7 kW @ 1500 rpm</td>
</tr>
<tr>
<td>Rated Speed</td>
<td>1500 rpm</td>
</tr>
<tr>
<td>Combustion Chamber</td>
<td>Hemispherical Open</td>
</tr>
<tr>
<td>Type of Cooling</td>
<td>Water Cooled</td>
</tr>
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![Image](image_url)
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References