



Hydrogen Gas as a Fuel in Direct Injection Diesel Engine

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Abstract Hydrogen is expected to be one of the most important fuels 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, the injection timing and duration 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 [2–5], if there are no lubricants in the combustion chamber. In order to adopt, gaseous hydrogen as a fuel for an internal engine, lots of research were carried out on hydrogen supply system [3, 6–8], combustion characteristics [9, 10] 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 [12]. 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 [13, 14]. With this system, performance and emission characteristics of hydrogen combustion in the internal combustion engine were investigated.

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Experimental Setup

The engine used for the experimental investigation was a Kirloskar AV1, single cylinder, four stroke, cooled water, 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 cool water. The electronic control unit (ECU) controls the operation of H₂ 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 4 A and for holding the injector to inject the fuel 1 A 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 rota meter varies from 0 to 1000 lpm. Figure 1 shows the photographic view of the experimental setup.

Experimental Procedure

Hydrogen gas is stored on a high-pressure cylinder, which is at 150 bars, 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. 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 functions 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

Table 1 Engine specifications

Make and model	Kirloskar, AV1 make
General	4-stroke/vertical
Type	Compression ignition
Number of cylinder	One
Bore	80 mm
Stroke	110 mm
Swept volume	553 cc
Clearance volume	36.87 cc
Compression ratio	16.5: 1
Rated output	3.7 kW @ 1500 rpm
Rated speed	1500 rpm
Combustion chamber	Hemispherical open
Type of cooling	Water cooled



Fig. 1 Photographic view of the experimental setup

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 injectors 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. Figure 2 shows a clear view for injection timing and injection duration for hydrogen fuel. Subsequently, Table 2 shows the list of instrumentation applied for the study.

Results and Discussion

In the present work, adopting timed port injection technique in compression ignition 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°, 60°, and 90° crank angle respectively. The hydrogen flow rate was fixed at 20 lpm.

Brake Thermal Efficiency

Figure 3 clearly shows that overall duration of hydrogen results in better brake thermal efficiency than that of baseline diesel. The study shows that maximum efficiency occurring at 90° duration is 27.23 % with hydrogen at 75 % load. 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 specific energy consumption (SEC) with load is shown in Fig. 4. The specific energy consumption is reduced to 15 % when compared to baseline diesel at 75 %

load of 90° 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.

Oxides of Nitrogen

It can be observed from Fig. 5, that NO_x emission in timed port injection technique is higher than that of baseline diesel. The higher concentration of NO_x of hydrogen is due to the

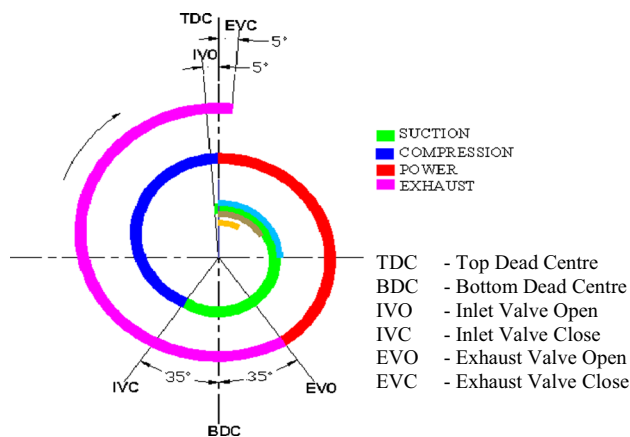


Fig. 2 Valve timing diagram of single cylinder (Kirloskar AV1 Model) C.I. engine

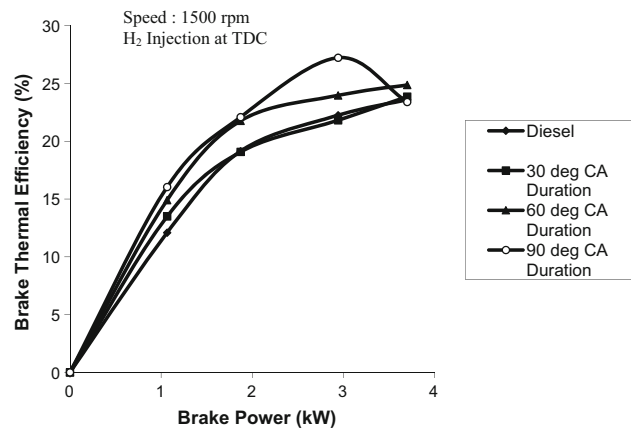


Fig. 3 Variation of brake thermal efficiency with load

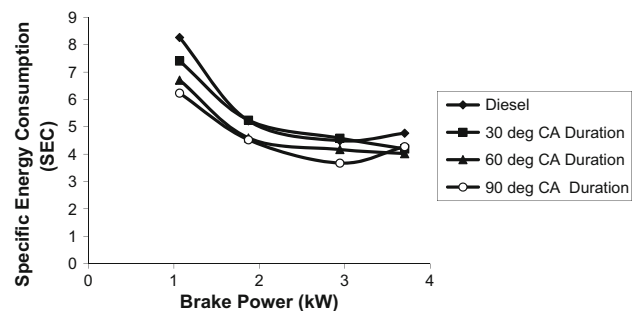


Fig. 4 Variation of specific energy consumption with load

Table 2 Instrumentation list

Instrument	Purpose	Make/model
Electrical dynamometer	Measurement of power output	Laurence Scott and electromotor Ltd., Norwich and Manchester, UK, Capacity-10 kW, Current rating-43 amps
Exhaust gas analyser	Measurement of HC, CO, CO ₂ and NO _x	QRO 401, Qrotech Corporation Limited, Korea
Smoke meter	Measurement of smoke	TI diesel tune, 114 smoke density tester TI Tran service
Pressure transducer and charge amplifier	Measurement of cylinder pressure	Type 5015A, Kistler instruments, Switzerland
Digital mass flow controller	Measuring the H ₂ flow	DFC 46 mass flow controller AALBORG, USA
Hydrogen leak detector	To identify the H ₂ leakage	Finch Mono II, portable single gas monitor, INIFITRON INC, Korea

peak combustion temperature and high residence time of the high temperature gases in the cylinder. At 75 % load of 30°, duration attained to its maximum NO_x emission at 2564 ppm.

Hydro Carbon

The variation of hydrocarbon emissions with load is shown in Fig. 6. The HC emissions are lower compared with the base line diesel with the maximum being 18 ppm at full load in the case of 30 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 variation of carbon monoxide emissions with load is shown in Fig. 7. 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 90° 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 variation of smoke level with load is shown in Fig. 8. The smoke level is reduced at full load compared to

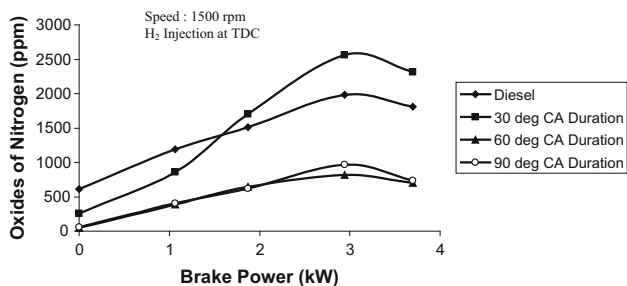


Fig. 5 Variation of oxides of nitrogen with load

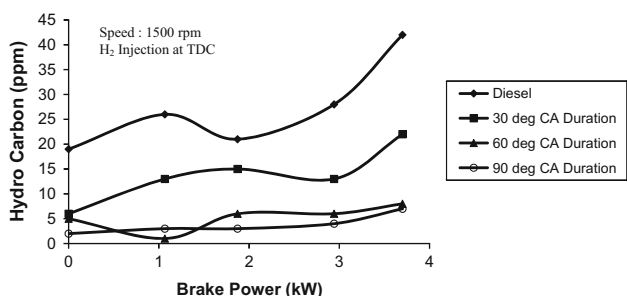


Fig. 6 Variation of hydro carbon with load

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 CO₂ emissions is lower compared with the base line diesel at 60° and 90° crank angle duration as shown in Fig. 9. The CO₂ emission of hydrogen is lowered because the combustion is expected to be complete comprising hydrogen flame at a higher velocity.

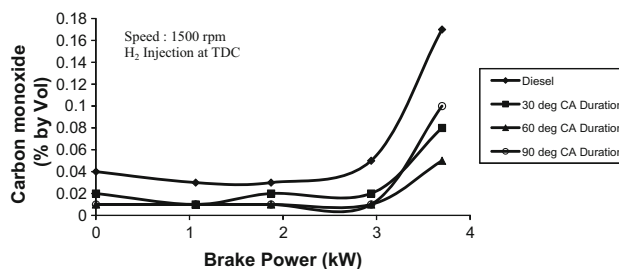


Fig. 7 Variation of carbon monoxide with load

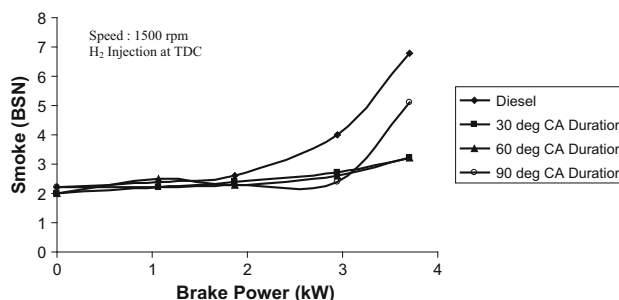


Fig. 8 Variation of smoke with load

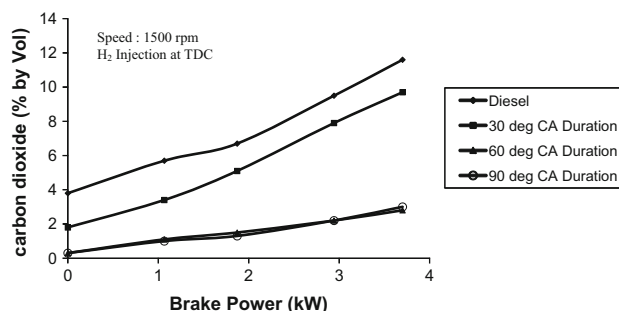


Fig. 9 Variation of carbon dioxide with load

Exhaust Gas Temperature

The variation of exhaust gas temperature with brake power is shown in Fig. 10. 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. The pressure crank angle diagram for diesel and hydrogen with diesel dual fuel mode graph is shown in Fig. 11. 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 as shown in the figure.

Heat Release Rate

Figure 12 shows the variation of heat release for hydrogen-diesel combustion at TDC, 90° 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

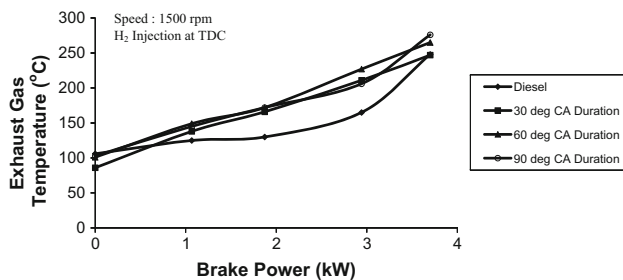


Fig. 10 Variation of exhaust gas temperature with load

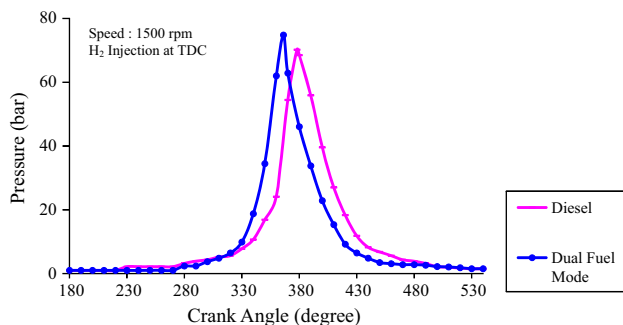


Fig. 11 Variation of pressure with crank angle at full load

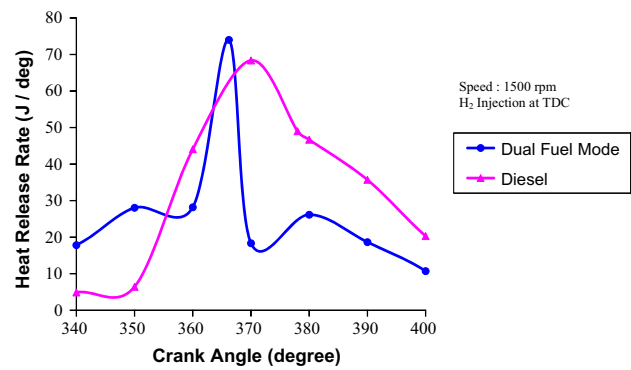


Fig. 12 Variation of heat release rate with crank angle at full load

mixture is having the highest heat release rate at 75 J CA compared to neat diesel of 68 J 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, CO₂, and HC are reduced drastically to negligible concentrations. The NO_x emission decreases from 1500 to 250 ppm at full load in the 60° and 90° CA durations. The reductions in emissions are due to efficient combustion as resultant of the hydrogen combustion. The smoke emission reduces from 6.8 to 1.8 BSN along with simultaneous reduction of NO_x when using the hydrogen in dual fuel mode. Brake thermal efficiency increases from around 20 to 25 %. In 90° 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.

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