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Experimental Investigation of Hydrogen Fuel Injection in DI Dual Fuel Diesel Engine

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ABSTRACT

Hydrogen is expected to be one of the most important fuel in the near future to solve greenhouse problem and to save conventional fuels. In this study, a Direct Injection (DI) diesel engine was tested for its performance and emissions in dual-fuel (Hydrogen–Diesel) mode operation. Hydrogen was injected into the intake port along with air, while diesel was injected directly inside the cylinder. Hydrogen injection timing and injection duration were varied for a wider range with constant injection timing of 23° Before Injection Top Dead Centre (BITDC) for diesel fuel. When hydrogen is used as a fuel along with diesel, emissions of Hydro Carbon (HC), Carbon monoxide (CO) and Oxides of Nitrogen (NO_{X}) decrease without exhausting more amount of smoke. The maximum brake thermal efficiency obtained is about 30 % at full load for the optimized injection timing of 5° After Gas Exchange Top Dead Centre (AGTDC) and for an injection duration of 90° crank angle. The NO_X emission tends to reduce to a lower value of 888 parts per million (ppm) at full load condition for the optimized injection timing of 5° AGTDC and with an injection duration of 90° compared to neat diesel fuel operation.

Keywords: Hydrogen, injection timing, injection duration, performance, emission.

INTRODUCTION

Regulations on exhaust emissions such as HC, CO and NOx from engines are being tightened; hence it is very important to improve thermal efficiency at the same time to reduce exhaust emissions simultaneously. Higher thermal efficiency and excess air usage in diesel engines certainly have advantages for conserving energy and solving the greenhouse problem. However, in diesel engine a trade-off is made between smoke and NO_X, since it is difficult to reduce both simultaneously. Hydrogen is considered as a clean fuel since it has no carbon in it [1]. Hydrogen has some peculiar features compared to hydrocarbon fuels. For example, the burning velocity is high hence very rapid combustion can be achieved. The limits of flammability of hydrogen varies from an equivalence ratio (Ø) of 0.1 to 7.1, hence the engine can be operated with a wide range of air-fuel ratio [2].

Some researchers tested diesel engines using hydrogen as a sole fuel. However it is very difficult to operate a diesel engine with hydrogen just by increasing the compression ratio, due to its higher self-ignition temperature. Therefore a glow plug is often used and Wong et.al tried to use a ceramic glow plug to retain heat as ignition source [3]. Ikegami et.al investigated the hydrogen combustion with a special injector that is equipped with a leak structure and a glow plug and they obtained moderate engine performance [4].

Numerous research works were carried out on dual fuel engines using Hydrogen-Diesel with diesel as a pilot source of ignition [5]. In the present research work hydrogen was used as a source of energy and diesel as a source of ignition. The hydrogen flow rate was maintained constant at 10 lpm to obtain the optimized injection timing and injection duration for hydrogen fuel [6].

Hydrogen was injected into the intake port of the engine and ignited with diesel. The heat release rate was obtained from the in-cylinder pressure data. Exhaust emissions including smoke, CO, NOx, HC and CO_2 were measured.

EXPERIMENTAL SETUP

The test engine used was a water-cooled single cylinder DI diesel engine, which was modified to work on diesel and hydrogen in the dual fuel mode. The specifications of the test engine are shown in Table 1.

Table 1 Engine specifications

Type	Compression ignition
No of Cylinders	One
Bore	80 mm
Stroke	110 mm
Speed	1500 rpm
Rated Power	3.7 kW @ 1500 rpm
Compression Ratio	16.5: 1
Type of Cooling	Water Cooled

ENGINE MODIFICATION

The cylinder head of the engine was modified to fit the solenoid operated hydrogen gas injector. The cross section of the hydrogen injector is shown in Fig. 1.

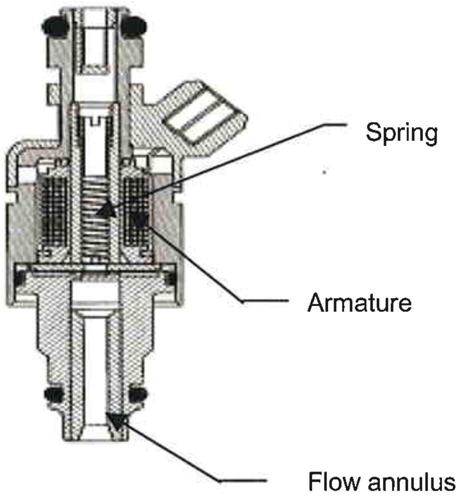

Fig.1 Hydrogen gas injector

The injector was placed just above the intake valve at a distance of 15 mm from the intake valve seating position. The injector was controlled by using an electronic control unit (ECU). The specifications of the injector are shown in Table 2. An Infrared sensor was used to sense the crank angle position. The start of injection and the duration of the injector opening were controlled by using the ECU [7]. Fig. 2 shows the photographic view of the experimental test setup and Fig. 3 shows the schematic diagram of the experimental setup.

Table 2 Hydrogen fuel injector specifications

Make	Quantum technologies
Supply Voltage	8 – 16 Volts
Peak Current	4 Amps
Holding Current	1 Amp
Flow Capacity	0.8 g /s @ 483-552 kPa
Working Pressure	103 – 552 kPa

Fig. 2 Photographic view of the experimental setup

TEST PROCEDURE

Hydrogen was stored in a high-pressure storage tank at a pressure of 150 bar. A double stage pressure regulator was used to regulate the hydrogen pressure. The pressure was reduced to the range of 1 to 4 bar based on the flow requirements. The hydrogen from the pressure regulator was passed through a shut off valve, which can be closed if any backfire results in the fuel line [8]. The hydrogen after passing through the shut off valve was allowed to pass through the digital mass flow controller (DFC). The DFC precisely measures the flow rate of hydrogen in standard liters per minute. Since the hydrogen flow to the injector should be free from any impurities the hydrogen was allowed to pass through a filtering device [9]. The hydrogen from the filter was passed to a flame arrestor that acts as a non-return valve in addition to a visible indicator for hydrogen flow [10]. The flame arrestor consists of a bursting diaphragm, which punctures when the pressure inside the system exceeds 10 bar during backfire conditions [11].

To determine the best optimum injection timing and duration, the duration and start of injection were varied. 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 open only for a maximum duration of 10 ms. The injector opening timings used were -5° Before Gas exchange Top Dead Centre (BGTDC), at Gas exchange Top Dead Centre (GTDC), 5° After Gas exchange Top Dead Centre (AGTDC), 10° AGTDC and 15° AGTDC. Since the intake valve opening was 4.5° BGTDC it was taken as the initial reading and injector opening timing was varied in steps of 5° till the optimum condition was reached. The hydrogen flow rate was set to 10 liters per minute (lpm) for the entire range of operation. The injection timing and duration were optimised based on the performance and emissions [12]. From the results it was observed that the optimized injection timing was 5° AGTDC and with an injection duration of 90°.

INSTRUMENTATION

The power output of the test engine was measured by an electrical dynamometer. The power capacity of the dynamometer is 10 kW with a current rating of 43.5 amps.

The exhaust emissions HC, CO, CO_2, and NO_X were measured by an NDIR type exhaust gas analyzer and smoke with BOSCH type Smoke meter.

The cylinder pressure was measured using a piezoelectric pressure transducer and a charge amplifier and the pressure data were given as input to the oscilloscope for further analysis.

RESULTS AND DISCUSSION

The performance and emission characteristics were studied with different injection timings and duration for hydrogen as shown in Table 3.

Table 3 Values for start of injection and duration

Index number	Start of injection	Injection Duration
1(Diesel)	23°BITDC	30°
2(Hydrogen)	5°BGTDC	30°
3(Hydrogen)	GTDC	30°
4(Hydrogen)	5°AGTDC	30°
5(Hydrogen)	10°AGTDC	30°
6(Hydrogen)	15°AGTDC	30°
7(Hydrogen)	5°BGTDC	60°
8(Hydrogen)	GTDC	60°
9(Hydrogen)	5°AGTDC	60°
10(Hydrogen)	10°AGTDC	60°
11(Hydrogen)	15°AGTDC	60°
12(Hydrogen)	5°BGTDC	90°
13(Hydrogen)	GTDC	90°
14(Hydrogen)	5°AGTDC	90°
15(Hydrogen)	10°AGTDC	90°
16(Hydrogen)	15°AGTDC	90°

CYLINDER PEAK PRESSURE

Fig. 4 shows the variation in peak pressure at different power output conditions along with start of injection and injection duration. It can be observed that, there is a significant variation in peak pressure in hydrogen diesel dual fuel operation, which can lead to the phenomena of knocking in engines. Hence the peak pressure has to be limited in hydrogen-operated engines. The peak pressure for this type of engine should be between 70 to 75 bar at full load condition.

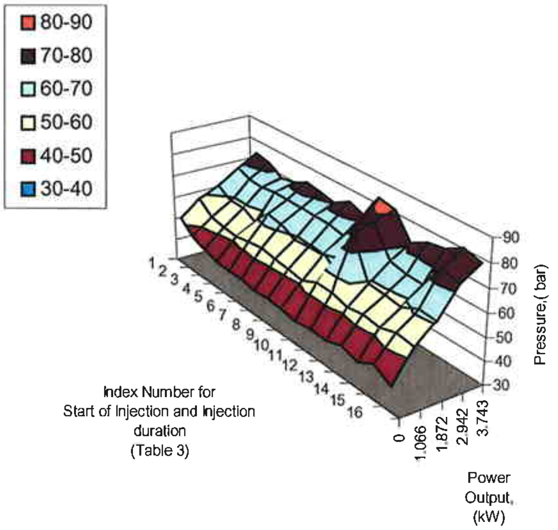

Fig. 4 Variation of cylinder peak pressure with power output

PRESSURE–CRANK ANGLE CURVES

The variation of cylinder pressure with crank angle is shown in Fig. 5. From the Pressure-Crank angle curve, it is observed that, in the hydrogen fuelled dual fuel operation, the peak pressure occurred late by about 5° crank angle compared to that of diesel. This may be due to the late combustion that takes after the diesel fuel injection. Proper selection of injection timing and injection duration will reduce the peak pressure developed during hydrogen operation, which in turn reduce knocking. With diesel the peak pressure is 73 bar at full load and is about 76 bar for optimized hydrogen fuel condition in dual fuel mode.

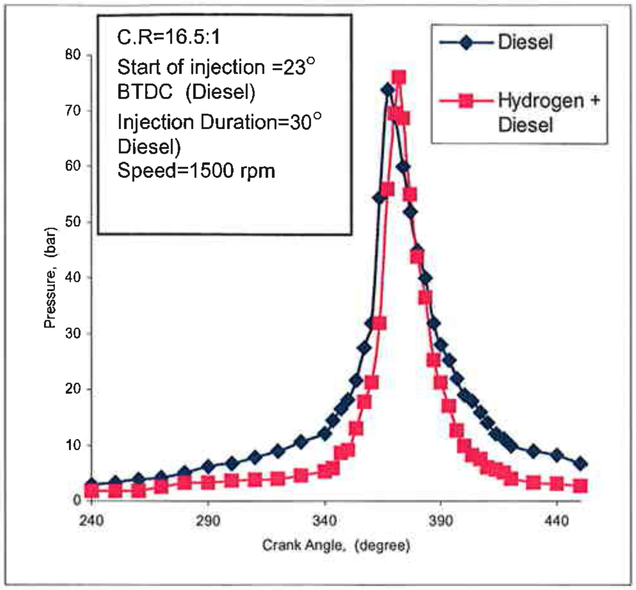

Fig. 5 Variation of cylinder pressure with Crank angle at optimized maximum power output condition

HEAT RELEASE RATE

Fig. 6 depicts the variation of heat release for hydrogen-diesel combustion at 5°AGTDC, 90° injection duration at full load condition. From the figure it is evident that, heat release for hydrogen is rapid than diesel. The ignition of hydrogen in dual fuel mode operation will take place only after the injection of diesel at 23° BITDC. Hence there is a gap of 4°CA between neat diesel fuel and hydrogen-diesel (Dual fuel mixture). From the rate of heat release it is also observed that the highest heat release rate is 95 J / degree CA for hydrogen-diesel fuel mixture compared to neat diesel of 82 J / degree CA. This is due to the instantaneous combustion (constant volume) that takes place with hydrogen fuel.

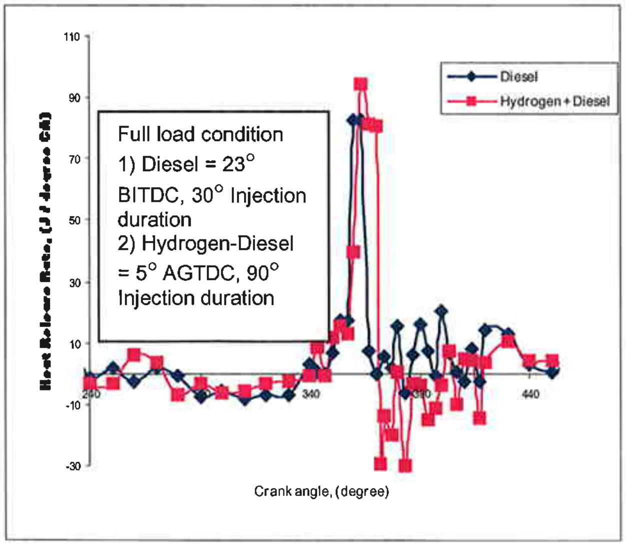

Fig. 6 Variation of heat release with crank angle at optimized maximum power output condition

SPECIFIC ENERGY CONSUMPTION

The variation of specific energy consumption with power output along with the start of injection and injection duration is shown in Fig. 7. It can be observed that, the start of injection at 5° AGTDC and the duration of 90° CA is the most efficient one at all load conditions with a decrease in brake specific energy consumption from 4.7 for diesel to 3.4 for dual fuel mode at full load condition. It can also be noticed that the specific energy consumption is still lower at injection timing of 15° AGTDC and injection duration of 60° but under this condition a high smoke was observed. Table 4 shows the energy contribution for hydrogen and diesel under optimized conditions.

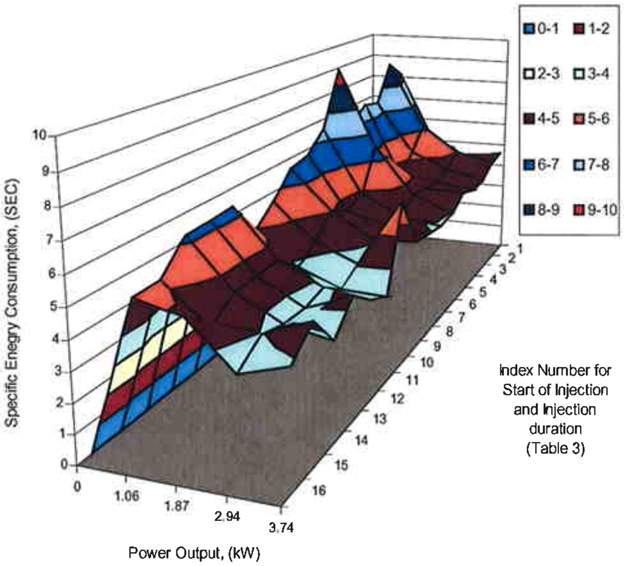

Fig. 7 Variation of specific energy consumption with power output

Table 4 Energy contributions by hydrogen and diesel under optimized conditions

Power output, kW	Hydrogen energy, %	Diesel energy, %
0	39.73	60.27
1.06	25.20	74.80
1.87	19.92	80.08
2.97	15.42	84.58
3.74	13.14	86.86

BRAKE THERMAL EFFICIENCY

Fig. 8 shows the variation of brake thermal efficiency with power output for different operating conditions. The efficiency increases from 23.6 % to 29.4 % for the injection timing of 5° AGTDC and for injection duration of 90° crank angle. The reason for increase in brake thermal efficiency is due to hydrogen combustion. The maximum brake thermal efficiency of about 31.67 % was obtained at 15° AGTDC with 60° injection duration but knocking was observed in this condition.

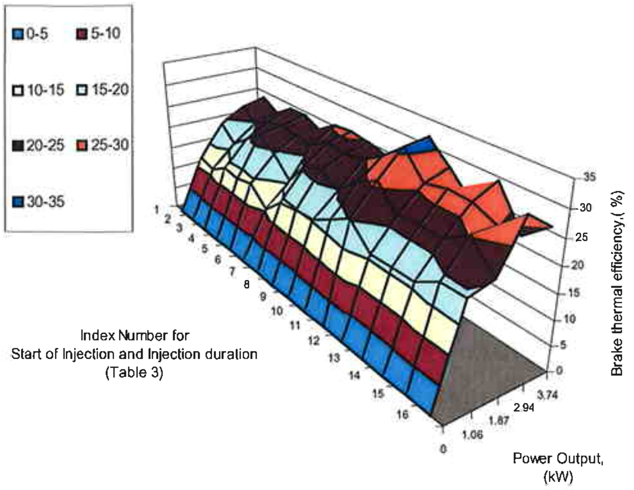

Fig. 8 Variation of brake thermal efficiency with power output

NO$_X$ EMISSIONS

The variation of NO$_X$ emission under different power output conditions along with the start of injection and injection duration is shown in Fig. 9. The NO$_X$ value for the neat diesel fuel at full load is 6.74 g/kW-h, whereas it is 3.14 g/kW-h in dual fuel mode with an injection duration of 90° crank angle with 5° AGTDC injection timing. The lowest NOx level obtained was 2.54 g/kW-h at full load with the start of injection at GTDC and duration of 60° crank angle. This reduction in NO$_X$ is attributed to the operation of engine with leaner mixture.

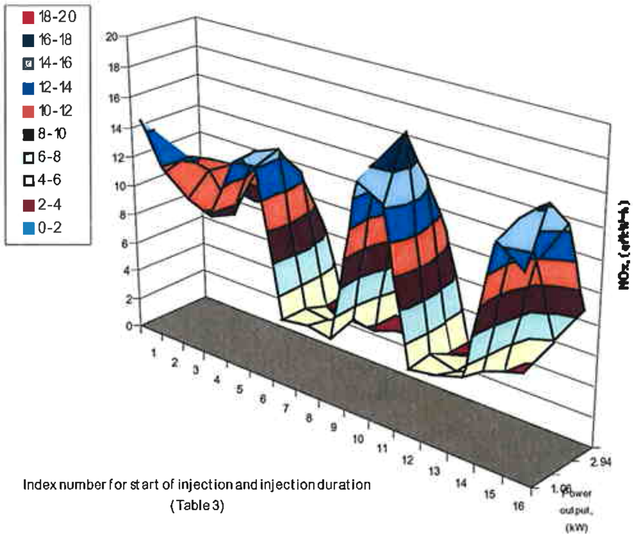

Fig. 9 Variation of NOx with power output

HYDROCARBON

The variation of hydrocarbon emissions is depicted in Fig. 10 under different power output conditions along with the start of injection and injection duration. The HC emission varies from 0.07 g/kW-h at full load for diesel operation to 0.01 g/kW-h for dual fuel operation with injection duration of 90° and an injection timing of 5° AGTDC. In the dual fuel mode, the reduction in HC is attributed to the absence of carbon in hydrogen fuel and also better mixing and reaction of hydrogen with air.

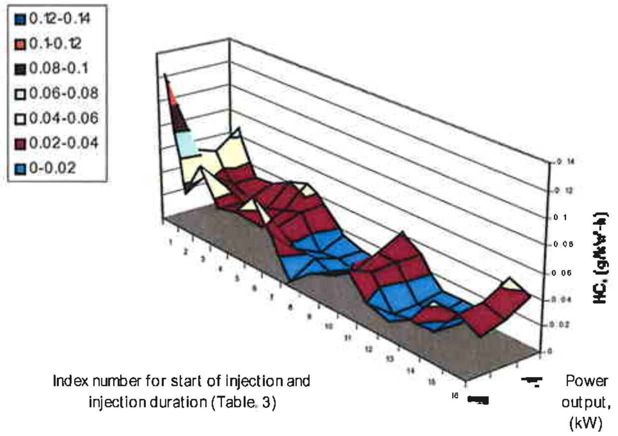

Fig. 10 Variation of Hydrocarbon with power output

SMOKE

Fig. 11 shows the variation of smoke emission with engine power output along with start of injection and injection duration. For neat diesel operation, the smoke value is 4.8 BSN which decreases to 0.3 Bosch Smoke Number (BSN) for an injection duration of 90° with an injection timing of 5° AGTDC in dual fuel mode. This is the lowest smoke emission compared to other sets of values at full load condition. The reduction in smoke is attributed to the use of carbon free hydrogen fuel.

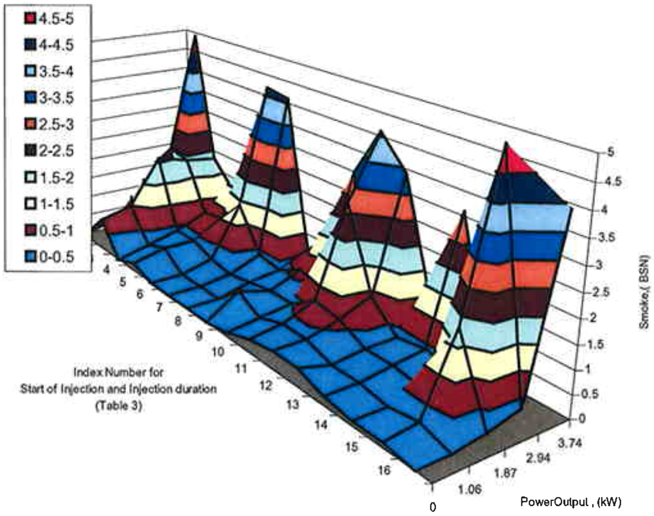

Fig. 11 Variation of Smoke with power output

CARBON MONOXIDE

The CO emission with power output along with start of injection and injection duration is shown in Fig. 12. At full load the CO emission reduces from 2.83 g/kW-h with diesel combustion to 0.03 g/kW-h in dual fuel mode with injection duration of 90° crank angle and injection timing of 5° AGTDC. This is the lowest value compared to other values obtained at other injection timing and injection duration. The reduction in CO is due to the operation of hydrogen-fuelled engine with leaner equivalence ratio and better mixing of hydrogen with air, which enhances the combustion.

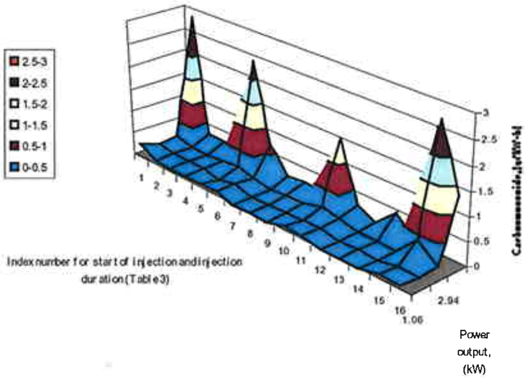

Fig. 12 Variation of CO with power output

CARBON DI OXIDE

The variation of CO_2 emission with power output along with start of injection and injection timing is shown in Fig. 13. The CO_2 for diesel operation is 11.6 % volume at full load whereas it is 2.4 % by volume in dual fuel mode for injection duration of 90° crank angle with an injection timing of 5° AGTDC. The reduction in CO_2 emission is attributed to carbon free hydrogen fuel.

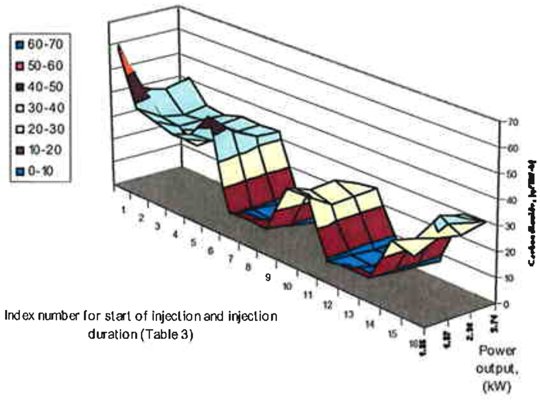

Fig. 13 Variation of CO_2 with power output

CONCLUSIONS

1) From the experiments conducted it is concluded that an injection duration of 90° crank angle and the start of injection at 5° ATDC gives the best results from the performance and emission point of view.

2) The pressure variation shows that in hydrogen fuelled operation, the peak pressure increases rapidly. This rapid rise in pressure could be controlled and optimized with proper injection timing and injection duration. The peak pressure can be maintained with in the limit and knock free combustion can be achieved.

3) The smoke emission reduces from 4.8 BSN to 0.3 BSN with simultaneous reduction of NOx when using the hydrogen in dual fuel mode. Brake thermal efficiency increases from around 23.59 % to 29 % with optimized injection starting and duration.

4) The emissions such as CO, CO_2, and HC are reduces drastically. The NOx emission decreases from 6.14 g/kW-h to 3.14 g/kW-h at full load. The reduction in emissions is due to efficient combustion resulting from the hydrogen combustion.

5) In general the use of hydrogen in the dual fuel mode, leads to better performance with significant reduction in emissions. Further by optimizing the injection timing and injection duration the hydrogen fuelled engine can be operated quietly in the dual fuel mode.

6) It is finally concluded that, the hydrogen fuel in dual fuel mode can give better performance, cleaner exhaust and best fuel economy.

REFERENCES

[1] Eiji Tomita, Nobuyuki Kawahara, Zhenyu Piao and Shogo Fujita, "Hydrogen Combustion and Exhaust Emissions Ignited with Diesel Oil in a Dual Fuel Engine", SAE Paper 2001-01-3503, (2001).

[2] H.S.Yi, K.Min and E.S. Kim, "Optimized Mixture Formation for Hydrogen Fuelled Engines", International Journal of Hydrogen Energy, Vol.25, p.685-690, (2000).

[3] Wong, J.K.S., "Compression Ignition of Hydrogen in a Direct Injection Diesel Engine Modified to Operate as a Low Heat Rejection Energy", International Journal of Hydrogen Energy, Vol 15, p.507, (1990).

[4] Ikegami, M., Miwa, M and Shioji, M., "A Study on Hydrogen Fuelled Compression Ignition Engines", International Journal of Hydrogen Energy, Vol.7, p.341, (1982).

[5] DasL.M,"Fuel Induction Techniques for a Hydrogen Operated Engine" Hydrogen fuel for surface transportation, Published by Society of Automotive Engineers, Inc U.S.A, pp 27-36, (1996).

[6] Ravi.M, M.C.Ramaswamy, T.R.Jagadeesan, A.N.Rao "Experimental investigation on Dual Fuel Operation of Hydrogen in a C.I. Engine", Proceedings of the National Conference on I.C.Engines and Combustion, Indian Institute of Petroleum, Dehradun, sep 15-18, pp 86-91, (1992).

[7] James W.Heffel, Michael N. Mcclanahan, Joseph M. Norbeck, "Electronic fuel injection for Hydrogen Fueled Internal Combustion Engines", University of California, Riverside, CE-CER SAE 981924, (1998).

[8] Michael F.J. Brunt and Harjit Rai, "The Calculation of Heat Release Energy from Engine Cylinder Pressure Data", SAE 981052, (1998).

[9] S.J.Lee, H.S. Yi, and E.S.Kim, "Combustion Characteristics of Intake Port Injection Type Hydrogen Fueled Engine", International Journal of Hydrogen Energy, Vol. 20, No. 4, pp. 317-322, (1995).

[10] B.Haragopala Rao, K.N.Shrivastava and H.N.Bhakta, "Hydrogen for Dual Fuel Engine Operation", International Journal of Hydrogen Energy, Vol.8, No.5, p. 381-384, (1983).

[11] L.M. Das, "Near-term Introduction of Hydrogen Engines for Automotive and Agriculture Application", International Journal of Hydrogen energy Vol. 27, pp 479-487, (2002).

[12] J.D. Naber and D.L.Siebers, "Hydrogen Combustion Under Diesel Engine Conditions", International Journal of Hydrogen Energy, Vol. 23, No. 5, pp no. 363-371, (1998).

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ABBREVIATIONS

GTDC - Gas Exchange Top Dead Centre
AGTDC- After Gas Exchange Top Dead Centre
BGTDC- Before Gas Exchange Top Dead Centre
BITDC - Before Ignition Top Dead Centre
TDC - Top Dead Centre
bSEC - Brake Specific Energy Consumption
CA - Crank Angle
ECU - Electronic Control Unit
BSN - Bosch Smoke Number
DFC - Digital mass Flow Controller
P-θ - Pressure Vs Crank angle
ppm - Parts Per Million
lpm - Liters Per Minute
NO_X - Oxides of Nitrogen
CO - Carbon mono oxide
CO_2 - Carbon di oxide
HC - Hydro Carbon
IR - Infra Red Sensor
NRV - Non Return Valve
Ø - Equivalence Ratio
C.R - Compression Ratio

DATA FOR THE FIGURES

Table 5 Specific Energy Consumption and Brake Thermal Efficiency under different operating conditions

Power output, (kW)	0	1.06	1.87	2.94	3.7	0	1.06	1.87	2.94	3.7
Various Start of Injection & Duration	SEC					Brake Thermal Efficiency, (%)				
1	0	8.26	5.233	4.494	4.767	0	12.09	19.14	22.25	23.59
2	0	8.894	6.154	5.03	4.673	0	11.24	16.25	19.88	21.39
3	0	7.407	5.241	4.584	4.191	0	13.5	19.08	21.82	23.86
4	0	7.595	4.571	4.344	4.165	0	13.17	21.88	23.02	24.01
5	0	7.085	5.138	4.453	4.439	0	14.11	19.46	22.45	22.52
6	0	9.598	6.475	4.579	3.956	0	10.42	15.46	21.08	25.27
7	0	7.405	4.898	4.104	3.91	0	14.2	20.42	24.37	25.58
8	0	6.706	4.594	4.171	4.02	0	14.91	21.77	23.97	24.87
9	0	6.516	5.05	4.078	4.15	0	15.34	19.81	24.53	24.06
10	0	5.666	4.26	3.642	6.098	0	17.65	23.47	27.45	16.39
11	0	4.938	3.829	3.22	3.158	0	20.25	26.11	31.05	31.67
12	0	6.308	4.612	3.834	3.606	0	15.85	21.64	26.08	27.74
13	0	6.232	4.526	3.673	4.275	0	16.04	22.09	27.23	23.4
14	0	6.218	4.514	3.68	3.4	0	16.08	22.15	27.18	29.42
15	0	5.26	3.945	3.955	4.61	0	19	25.34	25.28	21.69
16	0	5.235	4.893	3.381	3.857	0	19.1	20.4	29.58	25.9

Table 6 NO_X and HC under different operating conditions

Power output, (kW)	1.06	1.87	2.94	3.7	1.06	1.87	2.94	3.7
Various start of injection & duration	Oxides of Nitrogen, (g/kW-h)				Hydro carbon, (g/kW-h)			
1	14.68	10.63	9.10	6.74	0.13	0.06	0.05	0.07
2	11.67	12.14	11.42	8.76	0.03	0.04	0.03	0.03
3	10.38	11.79	11.62	8.39	0.06	0.04	0.02	0.03
4	9.81	9.27	11.38	8.66	0.03	0.03	0.02	0.04
5	13.83	14.02	11.73	7.41	0.04	0.02	0.03	0.05
6	14.11	14.60	12.53	8.62	0.06	0.03	0.03	0.03
7	4.52	4.58	4.01	2.77	0.03	0.02	0.01	0.02
8	4.70	4.42	3.68	2.54	0.00	0.02	0.01	0.01
9	4.44	5.01	3.51	2.73	0.02	0.01	0.01	0.01
10	15.18	15.91	13.33	2.91	0.03	0.02	0.03	0.04
11	14.22	18.06	14.53	10.68	0.04	0.03	0.03	0.03
12	4.41	4.67	3.86	3.12	0.02	0.01	0.01	0.01
13	4.81	4.24	4.31	2.66	0.01	0.01	0.01	0.01
14	5.35	4.91	4.09	3.14	0.02	0.01	0.01	0.01
15	14.23	14.98	11.76	5.94	0.05	0.03	0.03	0.04
16	13.07	16.43	14.59	8.66	0.05	0.02	0.03	0.04

Table 7 CO and Smoke under different operating conditions

Power output, (kW)	1.06	1.87	2.94	3.7	0	1.06	1.87	2.94	3.7
Various Start of Injection & Duration	Carbon monoxide, (g/kW-h)				Smoke, (BSN)				
1	0.32	0.18	0.20	2.83	0.2	0.4	0.6	2	4.8
2	0.11	0.12	0.08	0.25	0.8	1	1.1	1.9	1.8
3	0.11	0.12	0.08	0.25	0	0.2	0.4	0.7	1.2
4	0.11	0.12	0.12	0.32	0.2	0.4	0.4	0.8	2.2
5	0.11	0.00	0.16	2.36	0	0	0.2	3.3	5.5
6	0.11	0.12	0.08	0.63	0	0	0.1	0.4	4.6
7	0.00	0.00	0.00	0.13	0	0	0.2	0.3	0.6
8	0.00	0.00	0.04	0.16	0	0.5	0.3	0.6	1.2
9	0.00	0.00	0.04	0.13	0.1	0.2	0.3	0.4	3
10	0.10	0.06	0.16	1.50	0.3	0.4	0.7	2.7	5.5
11	0.10	0.06	0.08	0.22	0.4	0.4	0.6	0.9	3.4
12	0.00	0.00	0.00	0.03	0.4	0.2	0.3	0.3	1
13	0.00	0.00	0.00	0.41	0.2	0.2	0.3	0.4	3.1
14	0.00	0.00	0.00	0.03	0.1	0.1	0.2	0.3	0.3
15	0.10	0.06	0.43	2.67	0.1	0.2	1.8	5	5.6
16	0.10	0.06	0.08	1.35	0	0	0.1	0.3	5

Table 8 CO_2 and Peak Pressure result under different operating conditions

Power output, (kW)	1.06	1.87	2.94	3.7	0	1.06	1.87	2.94	3.7
Various Start of Injection & Duration	Carbon di oxide, (g/kW-h)				Peak pressure,(bar)				
1	61.46	41.19	38.12	40.73	51.9	58.9	62.9	68.9	73.7
2	38.02	32.11	29.94	31.95	46.7	53.5	58.8	66.8	72.3
3	35.83	30.87	31.29	30.68	44.1	52.6	58.9	66	68.3
4	33.62	25.74	32.26	33.11	42.3	51.5	55.8	67	69.5
5	36.77	31.41	32.73	32.82	42.1	53.1	63.4	67.5	73.1
6	46.64	38.40	33.95	32.81	42.5	54.1	61.9	67.2	71.4
7	10.54	9.08	8.32	8.86	41.1	52.9	59.1	66.9	70.3
8	11.51	8.99	8.62	8.80	41.6	52.2	59.4	66.7	74.2
9	11.50	9.65	8.21	8.83	41.6	51.2	59.7	65.6	72
10	31.23	27.50	28.75	24.27	40.2	54.6	62.1	73.8	83.1
11	31.20	24.92	25.80	26.15	41.3	54.3	76.4	78.4	81.2
12	9.39	8.39	7.78	7.46	40.7	52.3	59.1	65.8	71
13	10.43	7.78	8.53	9.50	43.1	53.6	58.6	64.5	74.6
14	10.43	8.98	8.14	7.42	41	52.5	57.9	64.3	76.2
15	28.01	25.60	31.69	29.13	45.2	54.7	61.4	74.5	80.2
16	25.94	29.27	27.44	29.82	40.5	53.5	60.7	72.3	78.1