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Performance and Emission Characteristics of an IdI Diesel Engine Using Spark Assisted Technique with Diesel as Fuel

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Abstract

Multi cylinder IDI Diesel engine powered vehicle population in India will exist for another decade. The major exhaust exhaust emissions from these engines are NOx, smoke, HC and CO. Hence the present research work has been carried out to control the smoke, which contributes a major share as exhaust pollutant from the vehicle exhaust. The engine performance in specific fuel consumption and thermal efficiency have been improved at the optimized spark delay set at 800 µ seconds (17 º crank angle at 1500 rpm) and the duration of 5 mille seconds (46 º crank angle at 1500 rpm). The research work has been conducted using High Speed Diesel (D 100) at different loads of 85 %, 65 % and 45 % at corresponding speed ranges between 2000 rpm and 3500 rpm at a speed interval of 500 rpm. Smoke has been found reduced by 2-3 % at operating speeds of 2500 rpm-3000 rpm and 3 % increase in brake thermal efficiency and 3 % improvement in specific fuel consumption (SFC) at the same operating speed range.

Keywords: Electronic ignition, Smoke, Spark duration.

Introduction

The objective of this research work is based on the fact that IDI Diesel engine powered vehicles in India will continue to exist in the transport field for many more years due to Indian economical conditions. Hence the major pollutants like NOx, HC, CO and Soot which are emanated from these vehicles need to be controlled.

Main scope of this research work is , when a spark is triggered over the hot mixture of air and fuel inside the pre combustion chamber, the ignitable mixture readily get ignited and the flame propagation starts at a faster rate during the pre mixed and mixing controlled combustion stage (S.F.Ahemed)1. Because of this , soot formation rate become less (Dec)2 since oxidation rate of the Diesel is very fast and this soot burns out in the turbulent diffusion flame region. NOx level is increased due to high temperature in the main chamber where more Oxygen and Nitrogen are available to form NO and atomic Nitrogen (J.B.Heywood)4. Good combustion takes place at the regions where fuel air mixture maintains stoichiometric and the other regions are the source for the formation of HC emission (Richard Stone)7 .HC emission level is high which is due to flame quenching since the flame availability period in IDI Diesel engines is only for 40º ATDC and 75 % of this period is lost inside the pre combustion chamber and the flame quenching starts when this charge enters into the main chamber. Because of this dilution effect, with the air charge available in the main chamber HC emission level becomes more. (J.B.Heywood)4

Early combustion initiated by the spark, completes the combustion process a knock free smooth pressure rise inside the cylinder which is the main reason for smooth running of the engine and improvement in fuel consumptions. (R.G. Phatak)3 (Caroline E Bowen)8.

The air charge inside the pre combustion chamber is getting pre heated during the suction stroke in each cycle due to twin sparking effect since the two spark plugs are connected with each ignition coil and the pulse generation from each coil triggers the spark in two spark plugs simultaneously. Hence each cylinder is getting sparks twice, one during compression stroke and the other during suction stroke Brake Thermal efficiency is improved because of this effect in the combustion process. (G J I Abid Alla)5 and (J.D.Dale and J.Santiago)6 .Also, optimized Spark advance and spark duration reduce the emission and fuel consumption. A multi cylinder 4 stroke IDI Diesel engine has been taken for the research work and the glow plugs have been replaced by spark plugs with suitable adaptors in that engine and they are connected to an electronic pulse controlled ignition system where the spark duration can be adjusted. Two ignition coils are connected and trigger spark at the desired spark timing.

Experimental Setup

The engine used for the research work is a four cylinder automotive engine. The engine specifications and fuel injection specifications are given in Table.1 and Table. 2

Make	Bajaj Tempo
Model	E 301 D2
Number of cylinders	Four
Type of cooling	Water cooled
Ignition	Compression
Combustion chamber	Turbulence Prechamber
Bore	78 mm
Stroke	94 mm
Rated speed	3800 rpm
Brake Power	32.24 kW @ 3800 rpm
Maximum Torque	108 Nm @ 2500 rpm
Lubrication oil	SAE 30/SAE 40

Table. 1 engine specifications

Fuel Injection Pump	Inline
Governor Type	Pneumatic
Injector Opening Pressure	125 bar
Nozzle Type	Pintle
Nozzle Spray Angle	10 °

Table. 2 fuel injection system

Engine Modifications

Spark plug: The heater plugs in the engine cylinder head are replaced with spark plugs. Adaptors are made for accommodating the spark plugs in the heater plug location. The depth of the heater plug hole is increased, in order to expose the spark plug electrodes into the pre chamber. Here the spark plug protrusion in the chamber is kept minimum, so as to avoid the wetting of electrodes. This also reduces the possibility of spark being quenched due to very high turbulence generated in the pre chamber. The spark plug along with the adaptor is shown in Fig. 1.

Ignition Coil and Ignition System: A direct distributor less ignition (DDLI) system is used for the research work. Pulse controlled Electronic ignition coil having two high tension cables is used. High voltage discharge will be simultaneous from both the cables, when the pulse is applied from the control unit. The spark plug in cylinder 1 and 4 is connected to one coil and spark plug in cylinder 2 and 3 is connected to another coil.

Fig. 1 spark plug and adaptor

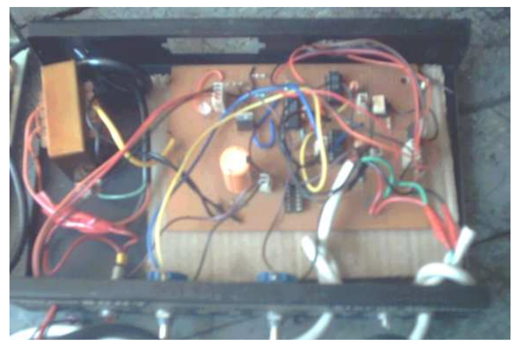

Fig. 2 electronic spark triggering circuit

As the heater plugs are removed for accommodating the spark plug, starting has become very difficult. So a provision is made for fumigating diethyl ether (DEE) in the intake manifold. This ensures quick starting of the engine.

The schematic view of the experimental set up is shown in Fig . 3. It Includes the engine instrumentation, emission measurement equipment, air metering system. Air flow rate is measured by means of an orifice meter. Infra Red (IR) sensors are used for sensing the TDC position. Two sensors are used for two coils. The signal is fed into the electronic triggering unit, where the spark timing and the duration can be varied manually. Here two triggering units are used for two coils instead of using a distributor. An exhaust gas analyzer (Qrotech) is used for measuring the exhaust pollutants, where NOx and Oxygen concentrations are measured in an electro chemical cell. Hydrocarbons, Carbon Monoxide (CO) and Carbon dioxide (CO2) are measured in NDIR analyser. Exhaust gas temperature is measured by means of a thermocouple. Smoke levels are measured using Bosch type smoke meter. The engine is loaded by means of a hydraulic dynamometer.

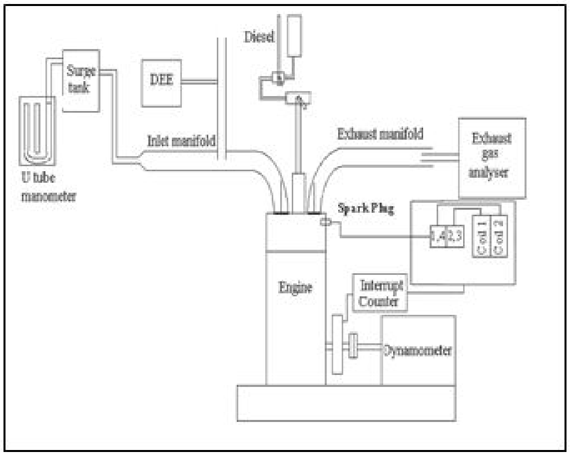

Fig. 3 experimental set up

Concept

The static injection timing is about 22° BTDC. The spark is set at 23° BTDC.

- Sparking during the ignition delay period, helps in reducing the delay period. This may also reduce the combustion noise
- Spark will be given even during the premixed and diffusion combustion period as the duration is increased.
- This helps in effective burning of the fuel vapours near the vicinity of the spark plug which in turn may reduce the fuel consumption.

Test Matrix

The engine speed is varied from 2000 to 3800 rpm with varying loads of 40 %, 60 % and 80 %. The work is conducted in the following phases

- In the first phase performance and emission characteristics were observed without spark for obtaining the baseline reading.
- In the second phase the spark timing is fixed at 23 ° BTDC for all the loads and speeds. The duration of spark in terms of milliseconds is varied for all the loads and speeds.

Results and Discussion

Brake Thermal Efficiency

The variation of brake thermal efficiency with speed at 40 % load is shown in Fig. 4. Maximum efficiency is obtained at 3000 rpm for all the cases. Increase in speed beyond this point leads to a decrease in brake thermal efficiency. This is probably because of the decrease in time availability for combustion in terms of crank angle. Also the volumetric efficiency is lower at high speeds, which results in incomplete combustion. The spark duration of 5 ms gives the maximum efficiency of about 21.6 % at the engine speed of about 3000 rpm. Even the spark duration of 3 ms and 4 ms is having better efficiency than that of the baseline. Here the spark intensity is proportional to the spark duration. This shows that some flame propagation is taking place in the vicinity of the spark plug. The case is similar at 60 % load which is shown in Fig. 5. Here the maximum efficiency observed is at 2500 rpm instead of 3000 rpm. Increase in fuel quantity in the pre-chamber due to increase in load and speed results in rich mixture combustion. This in turn results in some incomplete combustion at higher speeds. Once again the maximum efficiency obtained is higher for the spark duration of 5 ms .The values are about 26.4 %, 26 %, 25.5 % for the duration of 5, 4, 3 milliseconds respectively. The maximum efficiency for the diesel base line is about 25 % at 2500 rpm. Efficiency at the rated speed (3800 rpm) is in the range of 21.5 % for the duration of 4 and 5 milliseconds. It is about 20.8 % for the diesel baseline. Spark has a lesser significance at the rated speed. This is due to the increase in diffusion combustion period which is due to the result of increased injection duration. Since the spark plug is located in the pre-chamber it is not having as much significance as the products already forced to the main chamber.

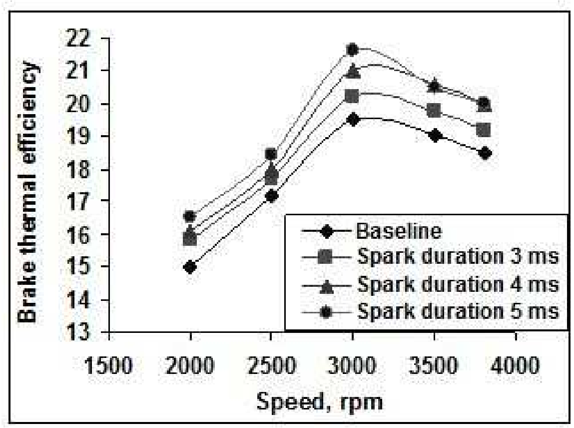

Fig. 4 variation of brake thermal efficiency with speed at 40 % load

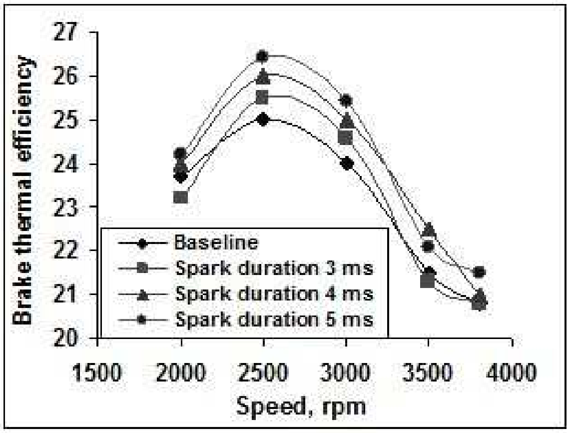

Fig. 5 variation of brake thermal efficiency with speed at 60 % load

The variation of brake thermal efficiency with speed at 80 % load is shown in Fig. 4. The maximum efficiency is obtained for the spark duration of 5 ms at the speed of 2500 rpm. The brake thermal efficiency is about 27 %, 27.5 % and 27.8 % for the spark duration of 3 ms, 4ms and 5ms respectively. The brake thermal efficiency at the rated speed is about 22 % for the spark duration of 4 ms and 5 ms. The brake thermal efficiency is about 21.5 % at the rated power for the diesel base line. This clearly shows that, spark has a lesser significance at higher loads and speeds.

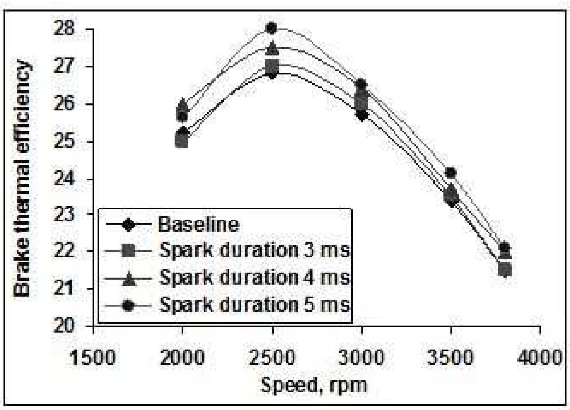

Fig. 6 variation of brake thermal efficiency with speed at 80 % load

Specific Fuel Consumption

The variation of specific fuel consumption with speed is shown in Fig. 7. The specific fuel consumption at 3000 rpm is lower for the spark duration of 5 ms compared to that of the other duration. This is attributed to better combustion with the spark. The specific fuel consumption is about 0.395, 0.406 and 0.415 kg/kWh for the spark duration of 5, 4 and 3 ms respectively. The specific fuel consumption for the base line reading at 3000 rpm is about 0.42 kg/kWh. The SFC at the rated speed is about 0.469 kg/kWh for the spark duration of 5 ms. Specific fuel consumption for the spark duration of 4 ms and 5 ms is about 0.48 and 0.475 kg/kWh respectively.

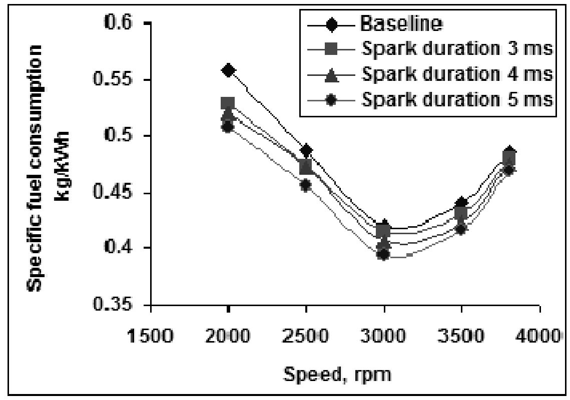

Fig7 Variation of Specific Fuel Consumption With Speed At 40 % Load

Fig. 8 and Fig. 9 shows the variation of specific fuel consumption with speed at 60 % and 80 % loads. The specific fuel consumption at 2500 rpm is minimum for the spark duration of 5 ms at both the loads and are about 0.32 and 0.3055 kg/kWh for 60 % and 80 % loads respectively. Specific fuel consumption increases as the speed is increased above 2500 rpm. For the rated power, SFC is about is 0.39 and 0.37 kg/kWh for 60 % and 80 % loads respectively. The specific fuel consumption of the diesel baseline for 60 % and 80 % loads are 0.4 kg/kWh and 0.38 kg/kWh. The optimum speed range of the engine is between 2500 to 3000 rpm. The trend of spark duration curve of 4 ms is closely following the 5 ms curve. Specific fuel consumption at 2500 rpm is about 0.327kg /kWh at 60 % load. This is slightly higher compared to that of spark duration 5 ms. The reason may be due to the spark intensity is more for longer spark duration. Specific fuel consumption at 80 % load at 2500 rpm is about 0.366 kg / kWh. This is very much closer to that of 5 ms duration. Decrease in the spark duration to 3 ms increase the specific fuel consumption to a certain extent for all the cases.

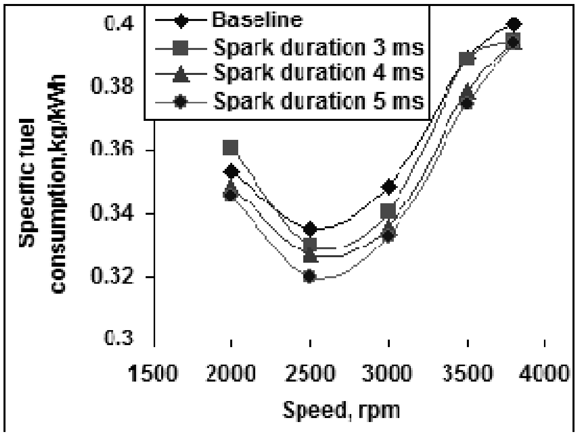

Fig. 8 variation of specific fuel consumption with speed at 60 % load

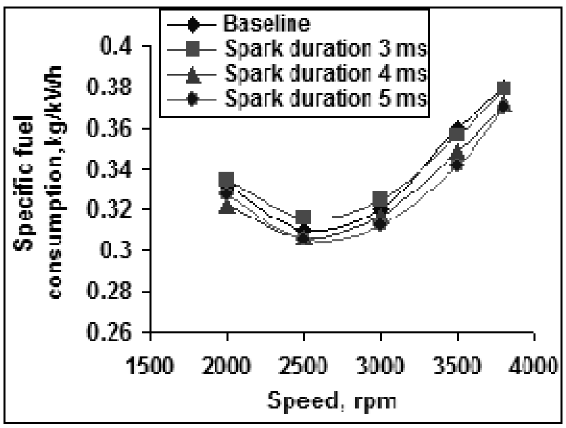

Fig. 9 variation of specific fuel consumption with speed at 80 % load

Exhaust Gas Temperature

The variation of exhaust gas temperature is linear with that of speed. Fig.10 shows its variation with speed at 40 % load. The maximum temperature is about 469° C for the diesel baseline at the rated speed. The exhaust temperature is about 450° C for the spark duration of 5 ms at the rated speed. The exhaust gas temperature is about 462° C and 455° C for the spark duration of 3 ms and 4 ms respectively. Late combustion or increase in combustion duration results in the shoot up of exhaust temperature. The exhaust temperature at 3000 rpm is about 393° C for the diesel baseline. It is about 369° C for the spark duration of 5 ms and about 375° C for the duration of 4 ms. This difference in temperatures for diesel baseline and spark assisted technique shows that combustion duration is shorter for the later.

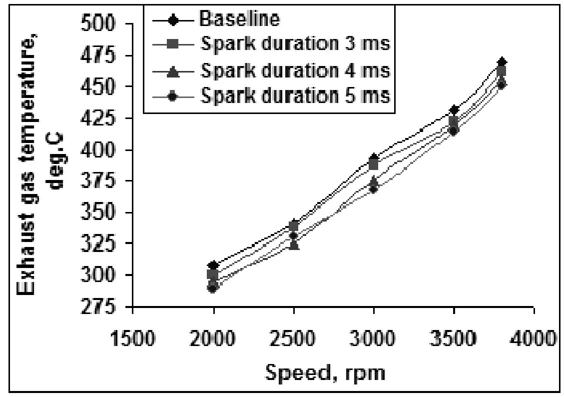

Fig. 10 variation of exhaust gas temperature with speed at 40 % load

Fig 11 shows the variation of exhaust gas temperature with speed at 60 % load. It is a well known fact that an increase in load increases the exhaust gas temperature. At the rated speed, the exhaust temperature is about 490° C for the spark duration of 3 ms. The exhaust gas temperature is about 488° C and 480° C for the spark duration of 4 ms and 5 ms respectively. As previously mentioned the intensity of spark is proportional to the duration. So increase in duration of spark enhances the combustion and reduces the late burning of fuel. At the engine speed of 2500 rpm the temperature difference between the diesel baseline and the spark duration of 5 ms is still larger. The exhaust gas temperature for the diesel baseline is about 437° C. The exhaust gas temperature is about 429° C, 420° C and 416° C for the spark duration of 3ms, 4ms, 5ms.

At 80 % load, the maximum temperature at the rated speed is about 540°c for the diesel baseline. The spark duration of 3 ms doesn't have any significance at the speed of 3800 rpm. The exhaust gas temperature is about 538° C. The exhaust gas temperature is about 530° C and 525° C for the spark duration of 4 ms and 5 ms. As the combustion products are forced to the main chamber quickly at higher speeds, sparking in prechamber will only have a small influence on diffusion combustion. At 2500 rpm the exhaust gas temperature is about 414° C, 408°c and 404° C for the spark duration of 3ms, 4ms and 5ms respectively. It is about 422° C for the diesel baseline at the speed of 2500 rpm.

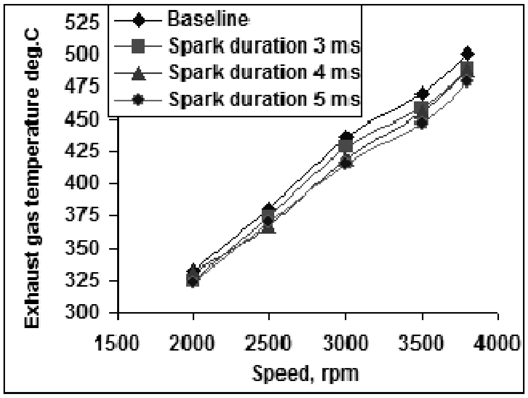

Fig. 11 variation of exhaust gas temperature with speed at 60 % load

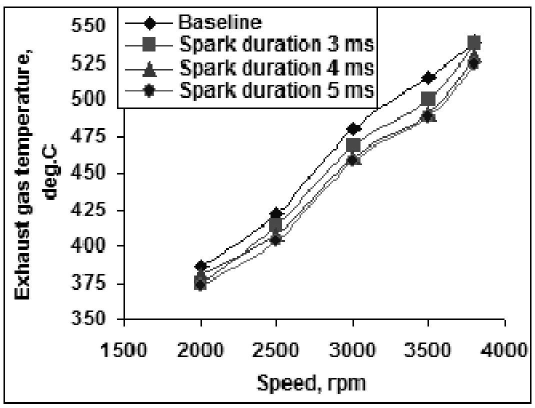

Fig.12 variation of exhaust gas temperature with speed at 80 % load

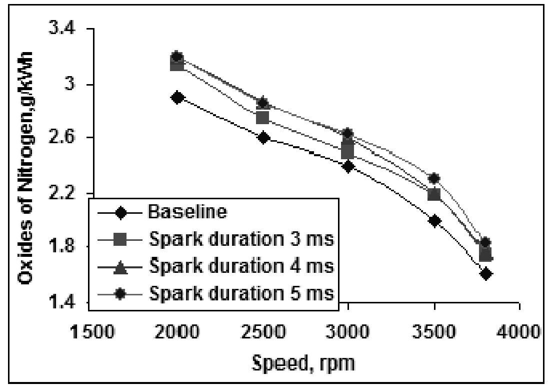

Fig. 13 variation of oxides of nitrogen with speed at 40 % load

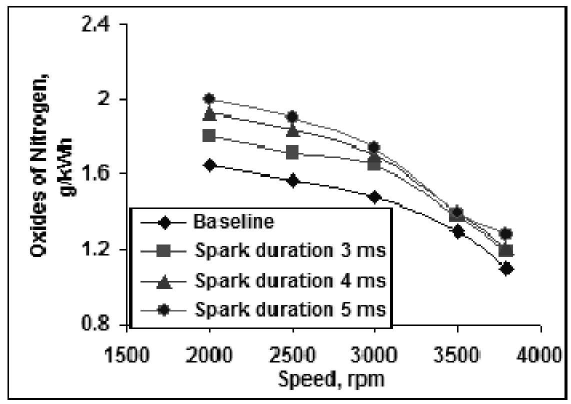

Fig. 14 variation of oxides of nitrogen with speed at 60 % load

Emissions

Oxides of Nitrogen

The variation of NOx with speed at 40 % load is shown in Fig. 13. It is clearly evident that the oxides of nitrogen levels are higher than that of the diesel baseline. The NOx level at the rated speed is 1.61 g/kWh for the diesel baseline. The NOx level at the rated speed is about 1.75, 1.77 and 1.83 g/kWh for the spark duration of 3 ms, 4ms and 5 ms respectively. Increase in spark duration has only a lesser significance on NOx emissions. Even though local temperature due to spark is higher, the oxygen availability and the rich mixture combustion in the prechamber decides the NOx formation rate. At all speeds the NOx, emissions are slightly on the higher side. The NOx at the speed of 3000 rpm are 1.31, 1.34 and 1.34 g/kWh for the spark duration of 3 ms, 4 ms and 5 ms.

Fig. 14 shows the variation of NOx with speed at 60 % load. The trend in NOx at the rated speed is approaching towards the diesel baseline. The effect of spark duration on NOx emissions is very minimal. The NOx level at the rated speed is about 1.19, 1.21 and 1.28 g/kWh for the spark duration of 3 ms, 4 ms and 5 ms respectively. The NOx level for the diesel base line is about 1.1g/kWh.The effect of spark duration is felt considerably at 2500 rpm. NOx level is about 1.9 g/kWh, while it is about 1.57 g/kWh for the diesel baseline. Since the air to fuel ratio is higher at 2500 rpm, the availability of oxygen for the fuel sprays is increased. So the increase in local temperature created by the spark may result in increase in NOx formation rate. The NOx level at 2500 rpm speed is about 1.71 and 1.84 g/kWh for the spark duration of 3 ms and 4 ms.

The variation of NOx with speed for 80% loads shown in Fig. 15. The NOx levels at the rated speed for the spark duration of 3 ms and 4 ms are almost closer to that of diesel. They are about 1.08, 1.11 g/kWh respectively. NOx level at the rated speed for the diesel baseline is 1.06 g/kWh. It is about 1.16g/kWh for the spark duration of 5 ms. The shortage of air availability in the prechamber at higher speeds suppresses the NOx formation, whatever be the spark duration. As the speed is reduced to 2500 rpm the volumetric efficiency is improved. The NOx level is about 1.42 g/kWh for the spark duration of 4 ms and 5 ms. The NOx level at this speed is about 1.2 g/kWh for the diesel baseline. For the spark duration of 3 ms NOx level is about is about 1.33 g/kWh.

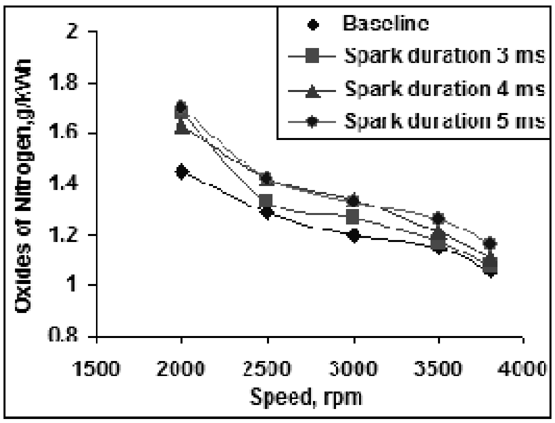

Fig. 15 variation of oxides of nitrogen with speed at 80 % load

Smoke Emissions

The variation of smoke with respect to speed at 40 % load is shown in Fig.16. The maximum smoke is obtained for the diesel baseline at the rated speed and it is about 3 BSN. The smoke level is about 2.6 BSN for the spark duration of 3 ms and 4 ms. For the spark duration of 5 ms the smoke level is about 2.2 BSN. Reduction in smoke may be due to spark, which assists in burning the diesel vapours in the prechamber. There are possibilities of wetting of diesel spray on the surface of the heater plug, which may be a reason for increase in smoke levels. The heater plugs are replaced by sparkplugs, whose protrusion is minimum in the prechamber. This helps in reducing the smoke levels. The smoke levels at 3000 rpm are also lower compared to that of baseline. The smoke level is about 2 BSN. smoke levels are about 1.6, 1.6 and 1.4 BSN for the spark duration of 3 ms, 4 ms and 5 ms respectively.

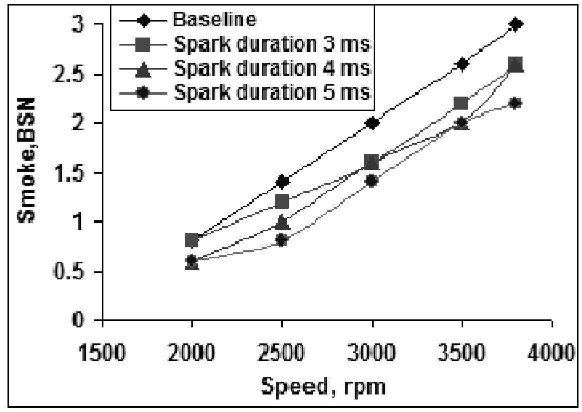

Fig. 16 variation of smoke with speed at 40 % load

As the load is increased the smoke level is also increased. Fig. 17 shows the variation of smoke with speed at 60 % load. Smoke level is maximum at the rated speed for all the cases. The smoke level is about 3.4 BSN for the spark duration of 5 ms. It is about 4 BSN for the diesel baseline. For spark duration of 3 ms and 4 ms the smoke level is about 3.8 and 3.6 BSN respectively. The influence of spark duration is very minimal at the rated speed. The time available for combustion is minimum and the gases immediately rush to the main chamber. As the spark plug is located in the pre-chamber, the spark during the later stages of combustion will be having only a little effect on Smoke. As the speed is reduced to 2500 rpm, the smoke is about 1.0 BSN for the spark duration of 5 ms. Smoke level is still higher for the diesel baseline and it is about 2 BSN. Since the intensity of spark is proportional to the duration, burning of diesel vapours near the vicinity of the spark plug may be effective in reducing the smoke levels. Smoke levels are about 1.6 and 1.4 BSN for the spark duration of 4 ms and 5 ms.

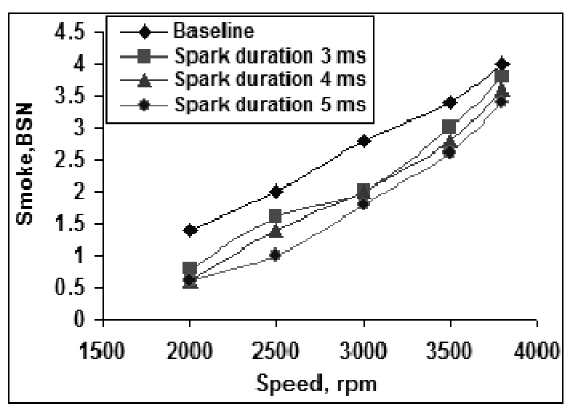

Fig. 17 variation of smoke with speed at 60 % load

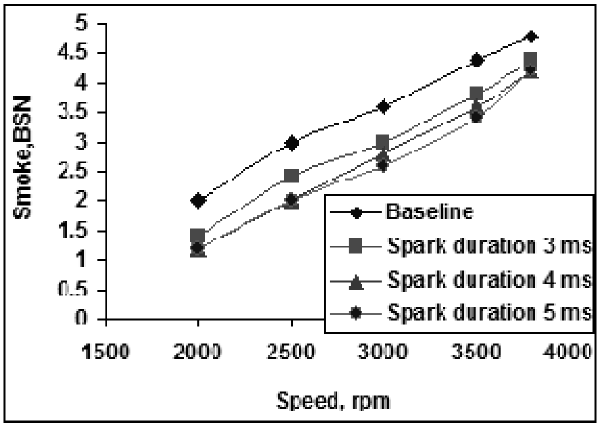

Fig. 18 variation of smoke with speed at 80 % load

Smoke levels are comparably higher as the load is increased from 60 % to 80 %. The smoke is about 4.4, 4.4 and 4.2 BSN for the spark duration of 3 ms, 4 ms and 5ms respectively. It is about 4.8 BSN for the diesel baseline. Spark duration has no influence on smoke emission at this point. Here it is clear that the reduction in smoke is only due to the spark at the earlier stages of combustion. At the speed of 2500 rpm, the smoke level is about 2 BSN for the spark duration of 4 ms and 5 ms. It is about 3 BSN for the diesel baseline. Thus it is clearly evident that smoke reduction is better at intermediate speeds than at the rated speed.

Hydrocarbons

The variation of Hydrocarbons (HC) with speed at 40 % load is shown in Fig. 19. The HC emissions are minimum for the spark duration of 5 ms at the rated speed compared to other duration. The same is about 0.014 g/kWh. The HC emission for the spark duration of 3 ms and 4 ms is about 0.015 g/kWh each. It is about 0.0155 g/kWh for the diesel baseline. The effect of spark on HC emissions is minimum. At high speeds the time available for combustion is very less which results in increased emission of unburned hydrocarbons. As the speed is reduced to 3000 rpm, the HC emissions with the spark duration of 3 ms and 4 ms are still closer to that of diesel baseline and observed as about 0.0225 and 0.022 g/kWh respectively. It is about 0.219 g/kWh for the spark duration of 5 ms. Since the HC emissions are lower at part loads for the IDI engines the effect of spark is less significant.

Fig. 19 shows the variation of hydrocarbons with speed at 60 % load. The HC emissions at the rated speed for the diesel baseline are about 0.0142 g/kWh. It is observed as about 0.014, 0.0136 and 0.0135 g/kWh for the spark duration of about 3 ms, 4 ms, 5 ms respectively. It is clearly evident that the spark duration has only a minimum influence on HC emissions. The influence of spark duration is felt at the speed of 2500 and 3000 rpm. The HC emission is about 0.0159 g/kWh for the spark duration of 5 ms at 2500 rpm. The maximum HC emission at this speed is about 0.017g/kWh for the diesel baseline. As the speed is reduced the time available for combustion in prechamber is increased. So the effect of spark is clearly felt at this speed.

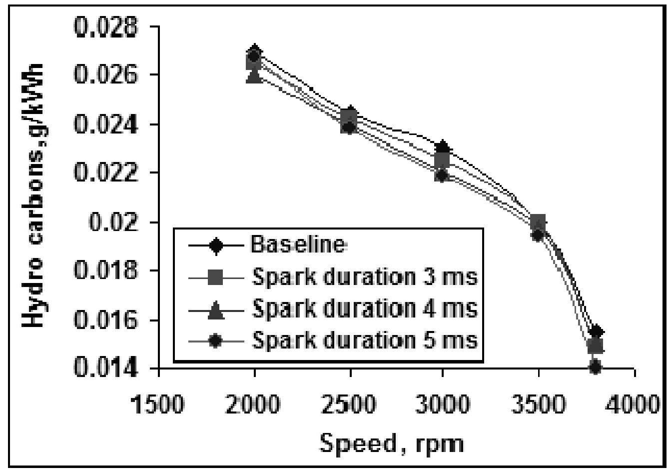

Fig. 19 variation of hydrocarbons with speed for load at 40%

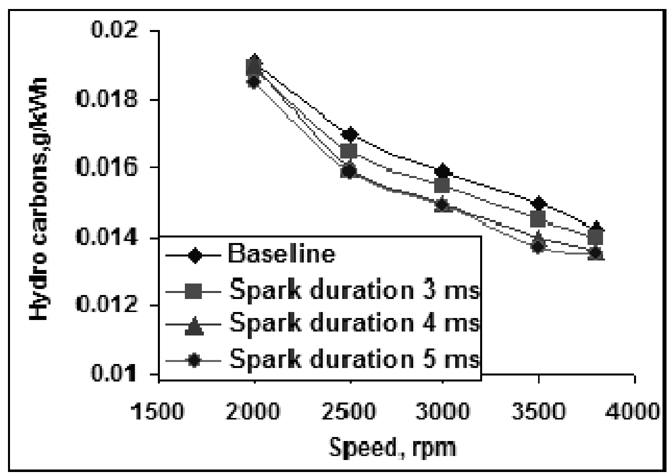

Fig. 20 variation of hydrocarbons with speed at 60 % load

As the load is increased the amount of unburned hydrocarbons are also increased. Fig. 20 shows the variation of hydrocarbons with speed at 80 % load. The spark duration has no effect on the HC emission .The HC emissions at the rated speed are 0.012, 0.0124, 0.012 g/kWh for the spark duration of 3 ms, 4 ms, 5 ms respectively. The HC emission for diesel baseline is exactly the same as 0.012 g/kWh. But at the speed of 2500 rpm the HC emissions are significantly reduced for the spark duration of 5 ms and it is about 0.0131 g/kWh. It is about 0.0141 and

0.0135 g/kWh for the spark duration of 3 ms and 4 ms respectively. Hydro carbon emissions are on the higher side for the diesel baseline and is about 0.0154 g/kWh. This clearly shows that the diesel vapors at the vicinity of the spark plug gets combusted which results in a reduction in the HC levels.

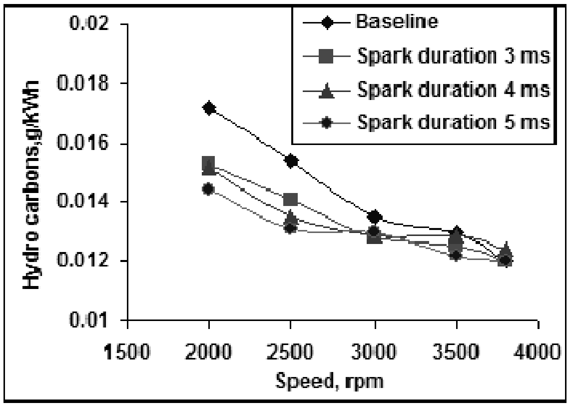

Fig. 21 variation of hydrocarbons with speed for load at 80 %

Conclusion

- Maximum efficiency is obtained at 2500 rpm at 80 % load for all the cases.
- The Brake thermal efficiency at 2500 rpm & 80% load is increased by 1.5 % for the spark duration of 5 ms. The brake thermal efficiency for spark duration of 4 ms is closer to that of diesel baseline.
- The performance at 60 % load and 2500 rpm is better than that of diesel baseline . Brake thermal efficiency is increased to 26.4 % from 25 % for the spark duration of 5 ms. No significant drop in efficiency is observed for the spark duration of 4 ms.
- Smoke levels are reduced by 1 BSN for both the spark duration of 4ms and 5 ms.
- Smoke levels are reduced by 0.6 and 1BSN for the spark duration of 4 ms and 5 ms respectively at 2500 rpm and 60 % load. Smoke levels at the rated speed are decreased by 0.4and 0.6 BSN for 4 ms and 5 ms spark duration respectively.
- Oxides of Nitrogen level at 2500 rpm and 80 % is about 1.29 g/kWh for the diesel baseline. NOx levels are increased by 10 % and 12 % for the spark duration of 4 ms and 5 ms.
- Oxides of nitrogen levels are increased by 17 % and 18 % for the spark duration of 4 ms and 5 ms at 60 % load and 2500 rpm. Increase in NOx levels at the rated speed is about 7 % for the spark duration of 5 ms and about 4.7 % for the spark duration of 4 ms.
- Hydrocarbon emissions are decreased by 12.5 % and 15 % for the spark duration of 4 ms and 5 ms respectively.
- Spark duration is only having lesser significance on emissions at the rated speed and 80 % load.
- On the whole it is concluded that the spark assisted technique is having the potential to reduce the specific fuel consumption, smoke levels and hydrocarbons.

Acknowledgements

The author wishes to thank Mr. Nagarajan, of IIT, Chennai for his valuable assistance in preparing the electronic circuit.

Nomenclature

HC	Hydrocarbon
NOx	Oxides of Nitrogen
DEE	Diethyl Ether
BSN	Bosch Smoke Number
SFC	Specific fuel consumption
ms	Milli seconds
g/kWh	grams per kilowatt hour
BTDC	before top dead center
rpm	revolutions per minute
º C	degree centigrade

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