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Experimental Investigation of Combustion, Performance and Emission in CI DI Spark Assisted Diesel Engine Using Ethanol as Dual Fuel

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Abstract

Multi cylinder IDI Diesel engine powered vehicle population in India will exist for another decade. The major 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

Vehicles which are powered by Diesel engines will exist for many more years in India even though many researchers are finding an alternative fuel to compensate the depletion of Diesel. Economical conditions in India may not be ready to accept the modifications in the engine which involves huge cost. Under the circumstances, the exhaust emissions like NOx, Particulate matters and HC from these engines will increase day by day and must be controlled to meet the trade off between efficiency and clean air.

Particulates from the Diesel emissions affect the respiratory systems. NOx and Hydrocarbon emissions combine to form smog under the sunlight which affects the visibility of the air traffic. NOx associates with global warming which leads to sea level rise due to ice melting at Arctic regions and may affect the low lying areas in the globe.

Spark assisted ethanol fumigation technique has been used to control the exhaust emissions in the present research work. Brake thermal efficiency, Smoke, HC and NOx have shown significant improvement. Miscibility of diesel with ethanol is totally eliminated in this technique since ethanol is fumigated through inlet manifold.

Experimental Setup

The experimental work was carried out in a single cylinder DI diesel engine. The engine specifications are given in Table 1. The engine is a Kirloskar TAF-1, single cylinder, air cooled, direct injection, four-stroke diesel engine. The dynamometer used to load the engine comprises of a three-phase AC generator with a load bank. A photo-interrupt counter connected to the engine flywheel determines the crank angle. The schematic view of the CI engine experimental set up is shown in Fig. 1. A small tube was fitted in the intake manifold for induction of ethanol which was inducted at a distance of 200 mm from the intake valve. The ethanol quantity was controlled by means of a flow control valve and the flow rate of ethanol was measured with a burette.

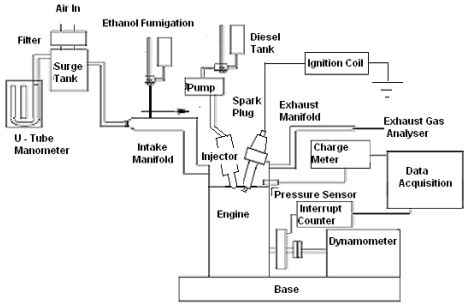

FIG. 1 Schematic Layout of CI Engine Setup

TABLE 1 Engine Specifications

Description	Specifications
Make of the engine	Kirloskar TAF 1
Number of cylinders	One
Combustion chamber	Hemispherical open type
Cycle	Four stroke
Injection	Direct Injection
Aspiration	Naturally aspirated
Cooling	Air cooled
Bore	85.5 mm
Stroke	110 mm
Displacement volume	661 cc
Compression ratio	17.5 : 1
Rated output	4.4 kW @ 1500 rpm
Injection nozzle	MICO BOSCH, 3 hole nozzle, 116º spray angle
Injection pressure	200 bar
Injection timing	23º b TDC
Connecting rod length	235 mm
Inlet valve opens	4.5º bTDC
Inlet valve closes	35.5º aBDC
Exhaust valve opens	35.5º bBDC
Exhaust valve closes	4.5º aTDC

Engine Modifications

Cylinder Head

The cylinder head of the DI diesel engine has been modified to accommodate two spark plugs inside the combustion chamber since the ignition coil produce two sparks simultaneously. Spark plugs are inclined at 30º to the axis of the cylinder bore and are positioned at equidistant of 18 mm from injector center. Two holes were drilled at equidistant from the centre of the bowl and are at the periphery of the combustion chamber. The spark plugs were located in the periphery to avoid flame quenching due to compression-induced turbulence and also to minimize wetting of the electrodes by diesel spray. The spark plugs location in the cylinder head is shown in Fig. 2 and Fig. 3.

FIG. 2 Spark Plugs Location on the Cylinder Head

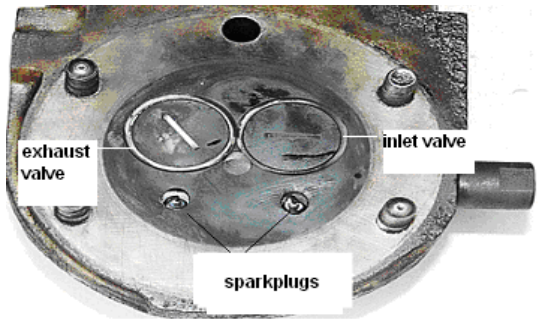

FIG. 3 View of the Cylinder Head

Test Matrix

Experiments were conducted at a constant engine speed of 1500 rpm by varying the engine loads from no load to full load.

- In the first phase, the performance, emission and combustion characteristics were studied in the ethanol fumigation mode for various flow rates of ethanol.
- In the second phase, the performance, emission and combustion characteristics were studied in the spark-assisted mode with ethanol fumigation for various flow rates of ethanol for different spark durations. The test matrix are given in Table 1

TABLE 2 Test Matrix

Injection fuel	Fumigated fuel	Fumigation flow rate cc/min	Spark time º CA	Spark duration º CA
Diesel	Ethanol	6	27	27
				36
				45
Diesel	Ethanol	9	27	27
				36
				45
Diesel	Ethanol	12	27	27
				36
				45

Result and Discussion

From the study it has been observed that the optimum fumigation flow rate of ethanol with and without the aid of spark is 9 cc/min. The optimum conditions are chosen on the basis of performance and emission characteristics. Since NOx, Smoke and hydrocarbon emissions are the major pollutant emissions from a

diesel engine only these pollutants are taken for determining the optimum conditions. The results at full load and 60 % load are discussed in the forth coming sessions.

Brake Thermal Efficiency

The variation of brake thermal efficiency with load is shown in Fig. 4. The brake thermal efficiency is higher for the spark assisted fumigation mode which is 30.65 %, while it is 28.4 % for diesel baseline. The efficiency for the ethanol fumigation mode is closer to that of spark assisted fumigation mode and it is 29.7 %.

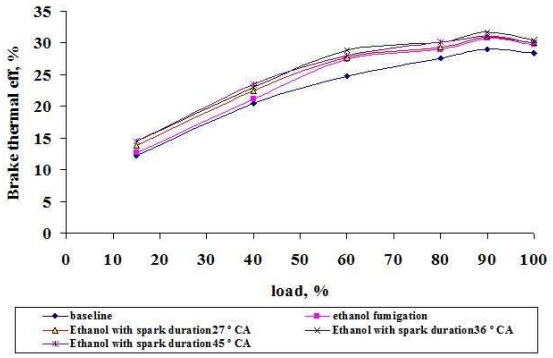

FIG. 4 Variation of Brake Thermal Efficiency With Load

The increase in efficiency is due to the increase in homogeneous combustion, in addition to that spark initiates the combustion and assists in burning the fuel effectively. At 60 % load the brake thermal efficiency is 28.3 %, 27.4 % and 24.7 % for the spark assisted fumigation mode, ethanol fumigation mode and diesel baseline respectively. At 60 % load, the quantity of diesel injected in ethanol fumigation is lower compared to diesel baseline which results in higher efficiency.

Diesel Fuel Consumption

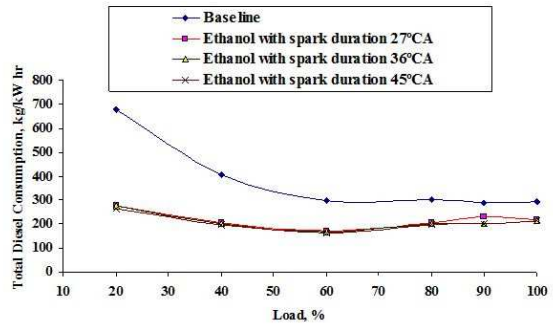

FIG. 5 Variation of Diesel Fuel Consumption With Load

Fig.5 illustrates the variation of Diesel consumption for the spark assisted Ethanol fumigation mode with load. At 20 % load conditions Diesel consumption is very much comparable as 265 kg/kW h with spark assisted ethanol fumigation mode and 680 kg/kW h with Diesel as sole fuel operation. Diesel consumption at 60% load is 165 kg/kW h for the spark assisted Ethanol fumigation mode with that of Diesel base line which is 296 kg/kW h. This is due to the effect of Ethanol fumigation which assists combustion and reduces the Diesel consumption by 45 % at that load. Similarly at full load operation, the diesel saving is 28% when the engine is operated under spark assisted Ethanol fumigation mode and with sole diesel as fuel.

Maximum Rate of Pressure Rise

The variation of maximum rate of pressure rise with load is illustrated in Fig. 6. At full load condition, the maximum rate of pressure rise is maximum for the spark duration of 45 º CA and it is 4.97 bar /deg CA when compared to ethanol fumigation and diesel baseline of 4.91 bar/deg CA and 4.37 bar/deg CA. This increase is due to the addition of ethanol with diesel, since ethanol is an oxygenated fuel which improves the combustion and increases the pressure.

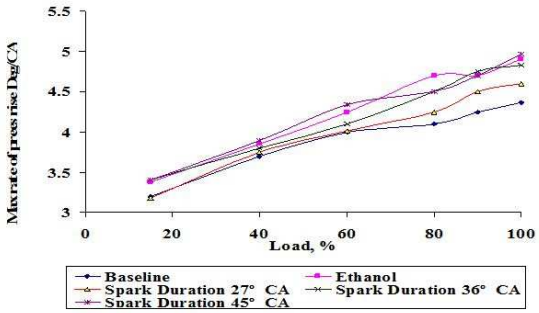

FIG. 6 Variation of Max Rate of Pressure Rise with Load

Optimal maximum rate of pressure rise is observed at full load for the spark duration at 45 º CA when compared to that of other two spark duration of 36º CA and 27º CA which is 4.83 bar/deg CA and 4.6 bar/deg CA respectively. This may be due to rapid vaporization of ethanol in the vicinity of the spark plug which assists the injected quantity of diesel for better combustion during the pre combustion phase.

Peak Pressure

Fig. 7 shows the variation of peak pressure with load. It can be observed that maximum peak pressure is 76 bar at full load condition for the spark duration of 45 º CA and for ethanol fumigation mode and baseline it is 76 bar and 72 bar respectively. Spark has a lesser significance at full load condition as the combustion flame duration is higher during the end of the pre combustion phase closure to TDC where the pressure

is maximum which again depends on the diesel ethanol - air mixture available for combustion.
At 60 % load condition, the peak pressure is 70 bar, 69 bar and 68 bar for the spark duration at 45º CA, 36º CA and ethanol fumigation respectively. Vaporization of ethanol in the vicinity of the spark plug assists rapid combustion through homogeneous mixture during the pre combustion phase and hence the peak pressure is closer to each other.

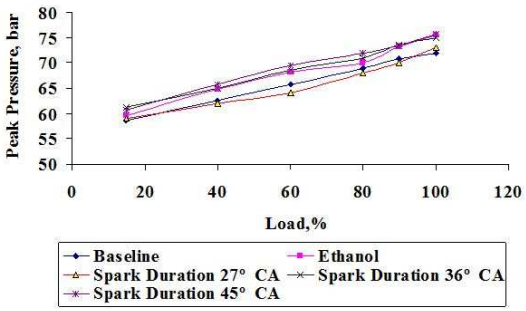

FIG. 7 Variation of Peak Pressure with Load

Heat Release Rate

Fig. 8 depicts the heat release rate with crank angle. The heat release rate at full load for the diesel baseline is 74.79 J/deg at 4° CA bTDC. The heat release rates during the pre mixed combustion phase for the spark assisted ethanol fumigation mode is 88 J/deg at 3° CA bTDC where as for the ethanol fumigation mode it is 83.1 J/deg at 3° CA bTDC.

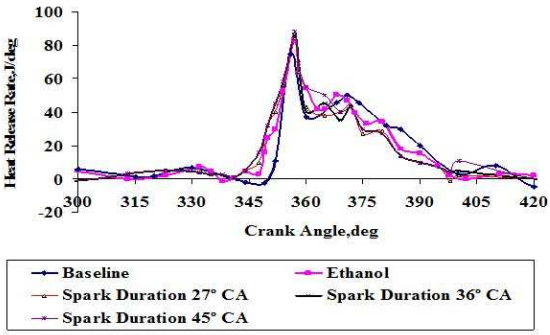

FIG. 8 Variation of Heat Release Rate with CA

The reason for the increase in heat release rate is due to rapid combustion of ethanol. Heat release rate is lower during the diffusion combustion phase for the fumigation mode when compared to that of diesel baseline. The heat release rate during the diffusion combustion phase for ethanol fumigation mode is 47 J/deg at 10° CA aTDC whereas for the spark assisted fumigation mode it is 50 J/deg at 10° CA aTDC . Since the quantity of diesel injected is lower compared to ethanol heat release rate at diffusion combustion phase is shorter.

Oxides of Nitrogen

The variation of oxides of nitrogen with load is depicted in Fig.9. The NOx emissions are higher for the diesel baseline at full load and it is 12.93 g/kWh whereas for spark assisted ethanol fumigation mode and ethanol fumigation mode it is 10.78 g/kWh and 11.8 g/kWh respectively. Since the latent heat of vaporization of ethanol is higher, the generation of cool flame suppresses the NOx emissions.

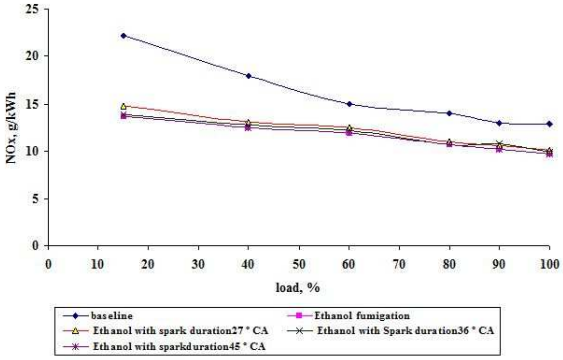

FIG. 9 Variation of NO_x with Load

At 60 % load condition the NOx emissions are 15 g/kWh, 9.24 g/kWh and 12.74 g/kWh for the diesel baseline, spark assisted ethanol fumigation mode and ethanol fumigation mode respectively. At part loads, the temperature inside combustion chamber is lower, in addition to that the ethanol present inside the cylinder produces the cooling effect which results in flame quenching.

Hydrocarbons

Fig. 10 shows the variation of hydrocarbon emission with load. The HC emissions is 1.12 g/kWh for ethanol fumigation mode, 0.8 g/kWh for spark assisted ethanol fumigation mode at 45 º CA and it is 0.53 g/kWh for diesel baseline at full load.

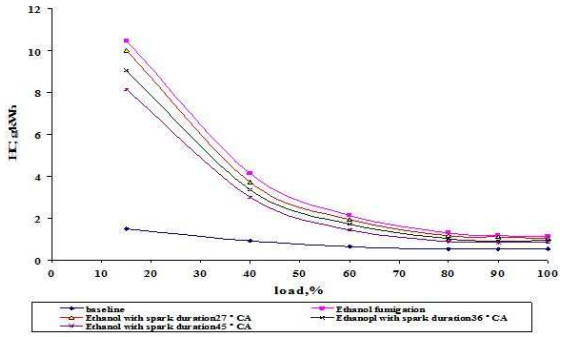

FIG. 10 Variation of Hydrocarbon with Load

The increase in HC emissions is because of flame quenching which is due to the cooling effect of ethanol. The HC emissions are higher for ethanol fumigation mode followed by spark assisted

fumigation ethanol mode at 45 º CA of 1.42 g/kWh at 60 % load condition.

Smoke

The variation of smoke with load is shown in Fig. 11. Smoke emissions are higher only at full loads and are of lesser significance at part loads and lower loads. The smoke emissions at full load is higher for diesel baseline which is 3.4 BSU whereas it is 1.6 BSU and 2.4 BSU for the spark assisted ethanol fumigation mode at 45º CA and ethanol fumigation mode respectively.

The increase in smoke at full load for diesel baseline is attributed to the diffusion combustion phase, which is reduced with ethanol fumigation. At 60 % load, the smoke emissions are 0.8 BSU, 0.2 BSU and 0.2 BSU for the diesel baseline, spark assisted ethanol fumigation mode at 45º CA and ethanol fumigation mode respectively and the reduction in smoke emissions is attributed to the oxygen present in ethanol which helps in effective combustion in homogeneous phase.

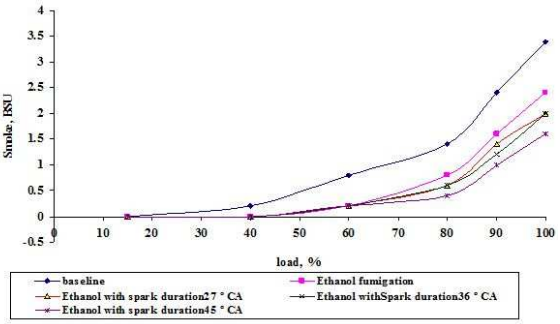

FIG. 11 Variation of Smoke with Load

Carbon Monoxide

Fig. 12 depicts the variation of CO with load. CO emission is minimum in spark assisted fumigation mode at 45 º CA and it is 0.058 g/kWh whereas it is 0.1 g/kWh and 0.044 g/kWh for the ethanol fumigation mode and diesel baseline respectively. Lower CO emission is due to more quantity of diesel injected at full load with vaporized ethanol when it flows to the vicinity of the spark plug for complete combustion under stoichiometric mixture condition. Spark duration assists ethanol for better vaporization and CO emission reduces as the spark duration increases. CO emission is 0.070 g/kWh and 0.066 g/kWh for the spark duration of 27º CA and 36º CA respectively.

At 60 % load condition, CO emission is minimum for spark assisted ethanol at 45º CA of 0.058 g/kWh and it is closer to each other for other spark duration of 36º CA and 27º CA and it is higher for ethanol fumigation and diesel baseline of 0.069 g/kWh and 0.028 g/kWh respectively. Lower CO emission at this load condition is due to spark assistance which combines with injected quantity of diesel which leads to homogeneous mixture combustion and thereby lower CO emissions. Only a marginal difference of 9 %, 5 % and 4 % can be noticed in CO emissions for the spark duration of 27° CA, 36° CA and 45° CA. From this it is inferred that CO emission is better controlled at 45° CA at this load.

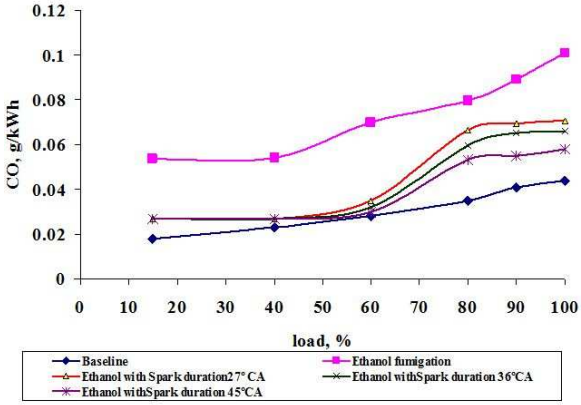

FIG. 12 Variations of CO with Load

To summarize, this research work has been carried out to optimize the engine performance and emissions by varying the spark duration and adjusting the ethanol fumigation flow rates. Spark has no significant influence in the combustion at higher loads due to more injected quantity of diesel at higher load conditions but it certainly assists the ethanol to get vaporized when ethanol air mixture moves to the vicinity of the spark plug . Ethanol fumigation flow rate replaces the diesel by energy share by 50 % at part load conditions and 30% at full load conditions which is the need of the hour to replace the diesel to some significant portion by controlling the emissions with improvement in the engine brake thermal efficiency. Hence in a nut shell, optimal results have been obtained in both engine performance and emissions for the ethanol fumigation flow rate at 9 cc/min with spark duration at 45º CA.

Conclusion

From the results obtained from the DI diesel engine, it is observed that the spark has no significance on diesel combustion. With ethanol fumigated through the intake manifold, the spark has a significant influence on performance and emission. Spark has a significant effect at lower and part loads and marginal effects at full load conditions. It was observed that the fumigation flow rate of 9 cc/min is found to be optimum from the performance and emissions point of view. The following conclusions are drawn from the experiments.

- Brake thermal efficiency at full load for the spark assisted fumigation mode is increased by 2 % compared to that of diesel baseline and by 0.9 % compared to that of ethanol fumigation mode.
- At 60 % load the efficiency increased by 3.6 % for the spark assisted mode compared to that of diesel baseline. Only a marginal increase of about 0.95 % was observed compared to that of ethanol fumigation mode. At 40 % load the brake thermal efficiency for spark assisted fumigation mode is increased by 2.6 % than that of diesel baseline.
- NOx emissions decrease by 20.7 % for the spark assisted fumigation mode at full load and 20.66 % at 60 % load compared to that of diesel baseline.
- NOx emissions increased by 5.2 % for the spark assisted fumigation mode at full load compared to that of ethanol fumigation mode. At 60 % load the increase in NOx emissions is about 7 % than that of ethanol fumigation mode.
- The smoke emissions at full load decreased by 1.8 BSU compared to that of diesel baseline and by 0.8 BSU than that of ethanol fumigation mode.
- HC emissions at full load conditions are higher in both spark assisted fumigation mode as well as ethanol fumigation mode. HC emissions increased by 33 % compared to that of diesel baseline at full load.
- The HC emissions are maximum for the ethanol fumigation mode at full load and it increased by 2.6 % than that of spark assisted fumigation mode.
- CO emission at full load is minimum in spark assisted fumigation mode at 45 º CA and it is 0.058 g/kWh whereas it is 0.1 g/kWh and 0.044 g/kWh for the ethanol fumigation mode and diesel baseline respectively.
- At 60 % load condition, CO emission is minimum for spark assisted ethanol at 45 º CA of 0.03 g/kWh and it is closer to each other for the spark duration of 36 º CA and 27 º CA and it is higher for ethanol fumigation and almost equal for diesel baseline of 0.089 g/kWh and 0.028 g/kWh.
- The peak pressure is higher for the spark assisted ethanol fumigation mode at full load compared to that of diesel baseline. No significant change in peak pressure is observed in the ethanol fumigation mode. It increased by 3.7 bar compared to that of diesel baseline.
- The peak pressure for the spark assisted ethanol fumigation mode at 60 % load increased by 3.4 bar and 1.1 bar compared to that of diesel baseline and ethanol fumigation mode respectively.

TABLE - COMPARISON OF THE RESULTS AT FULL LOAD

Operating Mode	Fumigation Flow Rate cc/min	NOx g/kWh	Smoke BSU	HC g/kWh	Brake Thermal Efficiency %
Baseline	NA	12.93	3.4	0.842	28.6
Ethanol Fumigation Mode	6	10.85	2.8	0.912	29
	9	**9.74**	**2.4**	**1.12**	**29.77**
	12	7.6	3	1.438	29.19
Spark Assisted Ethanol Fumigation Mode at 45 º CA	6	10.91	2.6	0.631	29.45
	9	**10.25**	**1.6**	**0.842**	**30.65**
	12	9.243	2	0.985	30.04
Spark Assisted Ethanol Fumigation Mode at 36 º CA	6	11.02	2.4	0.73	29.01
	9	**10.12**	**2**	**0.93**	**30.38**
	12	9.14	2.2	0.98	29.87
Spark Assisted Ethanol Fumigation Mode at 27 º CA	6	10.89	2.8	0.74	29
	9	**9.94**	**2.2**	**1.02**	**30**
	12	8.95	2.6	1.24	29.3

TABLE - COMPARISON OF THE RESULTS AT 60 % LOAD

Operating Mode	Fumigation Flow Rate cc/min	NOx g/kWh	Smoke BSU	HC g/kWh	Brake Thermal Efficiency %
Baseline	NA	15	0.8	0.555	24.74
Ethanol Fumigation Mode	6	13	0.2	1.65	26.37
	9	**11.9**	**0.2**	**2.1**	**27.4**
	12	10	0	2.93	27.8
Spark Assisted Ethanol Fumigation Mode 45 ° CA	6	13.76	2	1.16	27.24
	9	**12.74**	**0.2**	**1.428**	**28.34**
	12	10.75	0	1.747	28
Spark Assisted Ethanol Fumigation Mode 36 ° CA	6	13.95	0.4	1.35	26.7
	9	**12.51**	**0.2**	**1.69**	**28**
	12	10.67	0	1.77	27.9
Spark Assisted Ethanol Fumigation Mode 27 ° CA	6	13.66	0.2	1.5	26.7
	9	**12.17**	**0.2**	**1.94**	**27.8**
	12	10.36	0.2	2.23	28.1

Abbreviations and Nomenclature

aTDC	-	After Top Dead Center
bTDC	-	Before Top Dead Center
BSU	-	Bosch Smoke Unit
CA	-	Crank Angle
CC	-	Cubic Centimeter
CO	-	Carbon monoxide
CO_2	-	Carbon dioxide
DI	-	Direct Injection
g/kWh	-	grams per kilowatt hour
HC	-	Hydrocarbon
HRR	-	Heat Release Rate
kg	-	Kilogram
kW	-	Kilowatt
NO_x	-	Oxides of Nitrogen

References

[1] S.F.Ahmed,E.Mastorakos-"Spark Ignition of lifted turbulent jet flames-Paper – Elsevie Combustion flame -146(2006)-(215-231)-p229.

[2] R.G Phatak, K.Komiyama –spark assisted diesel start up SAE-paper 830588 (47-50)

[3] Heywood J.B (1988) internal combustion engine fundamentals, Newyork Mc Graw Hill

[4] G.HAbd Alla , Q.A.Badr and Soliman – "Exhaust emissions from an Indirect Injection dual engine – paper Institute of Mechanical Engineers ,Volume 243 part D –(333-340) ,p339.

[5] J.Santiago, P.Smy, J.D.Dale, J.D.Wilson Diesel cold start up - SAE-paper 850049 (pages 41-50)

[6] Richard Stone –Internal Combustion Engines- Text book p 265

[7] Caroline E Bowen, Graham T.Reader and Ian J.Potter- "The effect of exhaust gas recirculation on the combustion noise level of an IDI Diesel engine" – 97115-(2088-2093) p 2092.

[8] M. Abu-Qudais, O. Haddad and M. Qudaisat**,** "The effect of alcohol fumigation on diesel engine performance and emissions", Energy Conversion and Management, Volume 41, Issue 4, March 2000, Pages 389-399.

[9] E. M. H. Broukhiyan, S. S. Lestz, "Ethanol fumigation of a light duty automotive diesel engine", SAE paper 811209

[10] Qiqing Jiang, Pradheepram Ottikkutti, Jon Van Gerpen, Delmar VanMeter, "The effect of alcohol fumigation on diesel flame temperature and emissions", SAE paper 900386

[11] J. Chen, D. Gussert, X. Gao, C. Gupta, D. Foster, "Ethanol fumigation of a turbocharged diesel engine", SAE paper 810680

[12] L. D. Savage, R. A. White, S. Cole, G. Pritchett, "Extended Performance of Alcohol Fumigation in Diesel Engines Through Different Multipoint Alcohol Injection Timing Cycles", SAE paper 81068