EXPERIMENTAL INVESTIGATIONS ON PERFORMANCE EVALUATION OF DI DIESEL ENGINE WITH CRUDE JATROPHA OIL WITH VARYING INJECTION TIMINGS AND INJECTION PRESSURES

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Abstract : ***Alternate fuel research has been the topic of the highest priority in the context of depletion of fossil fuels at alarming rate. The high consumption of diesel fuel (DF) compels for the substitution of diesel fuel with suitable and renewable alternative fuels. Vegetable oils are the major alternative fuels for diesel fuel. They have comparable energy content and cetane number to diesel fuel. In the present work, the crude jatropha oil (CJO) is used as the alternative fuel for diesel. Experiments were conducted on the Conventional Diesel Engine (CE) to evaluate the performance and emissions with CJO operation, at different injection timings and injection pressures. The manufacturer's recommended injection timing is 27^0 bTDC (before top dead centre). Study was undertaken to match the injection timing which would bring in improved performance of the engine over that of manufacturer's recommended injection timing. The injection timing was varied from 27^0–34^0 bTDC. The injection pressure was varied from 190 bar to 270 bar (in steps of 40 bar). At the recommended injection pressure of 190 bar, the optimum injection timing was found to be 31^0 bTDC for diesel operation while it was 32^0 bTDC for CJO operation. At the optimum injection timing of 32^0 bTDC, CJO operation showed comparable performance when compared with diesel operation at recommended injection timing.***

IndexTerms - Crude jatropha oil, Performance, Exhaust Emissions, Injection Timing, Injection pressure

I. INTRODUCTION

Diesel fuel (DF) is consumed in many sectors like transport, agricultural etc. But due to depletion of fossil fuels and fluctuating fuel prices in International Market, there is strong necessity for alternative fuels. Vegetable oils are important substitutes for diesel fuel as they are renewable in nature. Vegetable oils have comparable cetane number (in the range of 40–45) and energy content as of diesel and therefore they can be effectively used in diesel engines. Smoke and NO_X are the main pollutants from diesel engine. When inhaled, they cause many health hazards like headache, nausea, increased susceptibility to infections, respiratory problems, lung cancer and skin cancers [1]. Hence control of these emissions is important.

The use of vegetable oils as diesel fuels dates back to several decades. The vegetable oils have comparable properties with those of diesel fuel. Edible oils cannot be considered as diesel engine fuels due to socio economic restrictions. However, non-edible vegetable oils can be conveniently used in CI engines. The researchers [2-9] conducted experimental investigations on diesel engine using vegetable oil and reported that the engine performance slightly deteriorated while the emissions increased, when compared with that of the diesel fuel. On the other hand, the researchers [10-14] reported improvement of engine performance, decrease of smoke levels and slight increase of NOx emissions.

Investigations were carried out by various researchers [15-16] on the influence of injection timing on the performance and emissions of diesel engine fuelled with vegetable oil. They reported that with the advancing of injection timing, the performance parameters improved, smoke levels reduced and NO emissions increased.

The researchers [17-19] have studied the influence of injection pressure on the performance of DI diesel engine with vegetable oil operation. An increase in injector pressure resulted in improved performance and reduced smoke emissions.

The present work consists of investigations on the performance and emissions with crude jatropha oil (CJO) operation at different injection timings (27-34 ^{0}bTDC). The injection pressure was varied from 190 bar to 270 bar. The results thus obtained were compared with that of the diesel operation.

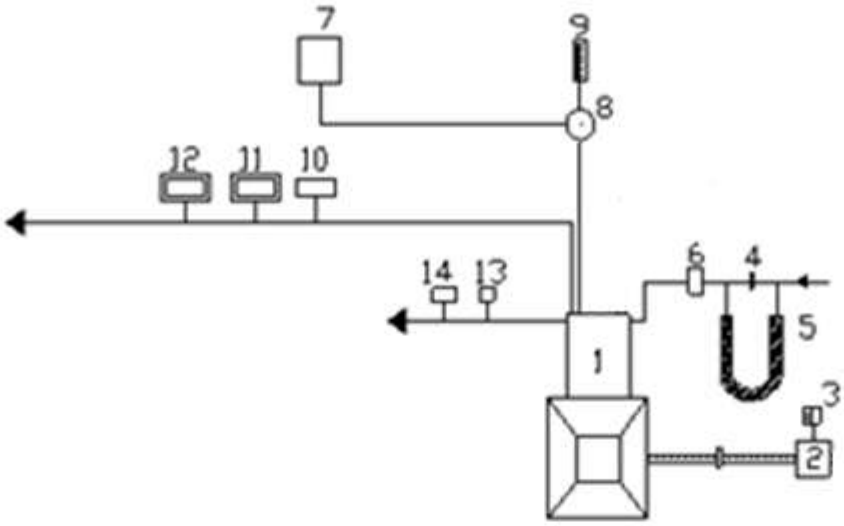
II. MATERIALS AND METHODS

Figure 1 shows the schematic diagram of the experimental set up for the diesel operation. The engine is a single cylinder, four stroke and direct injection type diesel engine with a rated output of 3.68 kW at a rated speed of 1500 rpm. The compression ratio is 16:1. The manufacturer's recommended injection timing and injection pressures are 27 bTDC and 190 bar respectively. The brake power was measured by an electrical dynamometer. The consumption of air and fuel by the engine were measured by air-box method and burette method respectively. The specifications of the engine are given in Table-1.

CJO was injected into the engine in the conventional manner, similar to that of diesel. The experimental set-up for jatropha oil operation will be same as that for diesel operation. Jatropha oil is non-edible. It can be obtained from *Jatropha curcus* plant, which can be grown in waste, arid lands and is not grazed by cattle. The seeds of the plant can be crushed to yield about 25% oil. The CJO has been found to be an attractive alternative fuel for diesel in C.I. engines. The properties of diesel and jatropha oil are given in Table-2.

The injection timing was varied from 27^0bTDC to 34^0bTDC, using the copper shims of suitable size between the engine frame and the pump body. A nozzle testing device was used to vary the injection pressure from 190 bar to 270 bar (in steps of 40 bar). Due to the practical difficulties involved, the maximum injection pressure was restricted to 270 bar. Effect of injection timing and injector pressure, on the performance of the engine was studied. A temperature indicator was used to measure the exhaust gas temperatures (EGT).

The smoke and NO_X are the main emissions from a diesel engine and they were measured by smoke meter and NO_X Analyzer respectively, at full load operation of the engine. The specifications of analyzers are given in Table-3.



1. Engine, 2.Electical Dynamometer, 3.Load Box, 4.Orifice meter, 5.U-tube water manometer, 6.Air box, 7. Diesel tank, 8.Three-way valve, 9.Burette, 10.Exhaust gas temperature indicator, 11.AVL Smoke meter, 12.Netel Chromatograph NOx Analyzer, 13.Outlet jacket water temperature indicator, 14.Outlet-jacket water flow meter

Fig.1 Experimental set-up

Table 1: Specifications of test engine

Description	Specification
Engine make and model	Kirloskar (India) AV1
Maximum power output at a speed of 1500	3.68 kW
Number of cylinders ×cylinder position×	One × Vertical position × four-
Bore × stroke	80 mm × 110 mm
Method of cooling	Water cooled
Rated speed (constant)	1500 rpm
Fuel injection system	In-line and direct injection
Compression ratio	16:1
Aspiration	Natural
BMEP @ 1500 rpm	5.31 bar
Manufacturer's recommended	27^0 bTDC × 190 bar
Dynamometer	Electrical dynamometer
Number of holes of injector and size	Three × 0.25 mm
Type of combustion chamber	Direct injection type
Fuel injection nozzle	Make: MICO-BOSCH No. 0431 202 120/HB
Fuel injection pump	Make: BOSCH: NO- 8085587/1

Table-2: Properties of test fuels

Test Fuel	Kinematic Viscosity at 40^0C (mm^2/s)	Specific gravity at 15^0C	Cetane number	Lower Calorific value (kJ/kg)
Diesel	3.07	0.84	55	42000
CJO	31.05	0.92	48	36000

Table-3: Specifications of analyzers

Name of the analyzer	Principle of operation	Measuring Range	Precision	Resolution	Accuracy
AVL Smoke meter	Opacity	0-100 HSU	1 HSU	1 HSU	±1 HSU
Netel Chromatograph NO_X Analyser	Chemilucency	0-2000 ppm	2 ppm	1 ppm	±5 ppm

III. RESULTS AND DISCUSSIONS

The experiments were carried out on Conventional Diesel Engine (CE) with diesel operation and with CJO operation with varied injection timings and injection pressures. Study was undertaken to match the injection timing which could bring in improved performance of the engine over that of manufacturer's recommended injection timing. The investigations for evaluating the performance of the engine was categorized into two parts – (i) evaluation of performance parameters and (ii) measurement of exhaust emissions. The results obtained for CJO operation were compared with that of diesel operation.

A. Performance Parameters

The performance of the CE was studied varying the injection timing by introducing copper shims between the pump body and the crankcase. Injection timing was varied from 27^0–34^0bTDC and the performance evaluation was carried out for CE at the injection timing where maximum brake thermal efficiency (BTE) was observed at all loads. The variation of BTE with brake mean effective pressure (BMEP) with diesel operation, at various injection timings at an injection pressure of 190 bar, is shown in Fig.2. BTE increased up to 80% of the full load operation (4.2 bar) at all injection timings. Increase of fuel conversion efficiency and mechanical efficiency might have improved the performance of the engine. Beyond that load, BTE decreased due to reduction of air-fuel ratio, volumetric efficiency and mechanical efficiency [20]. This was accepted trend in all engines. With the advancing of injection timing, BTE increased, which might be due to the early initiation of combustion with an increase of peak pressure. This might also be due to the more contact period between fuel and air leading to improved atomization and hence better combustion. Higher BTE was observed when the injection timing was advanced to 31^0 bTDC. Beyond that, the performance deteriorated, which might be due to the increase of ignition delay. So 31^0 bTDC is considered as the optimum injection timing with diesel operation.

Figure 3 gives the variation of brake thermal efficiency (BTE) with brake mean effective pressure (BMEP) in CE with CJO operation at different injection timings, at an injection pressure of 190 bar. From the figure, it is observed that the CJO operation showed the deterioration in the performance at all loads when compared with diesel operation at recommended injection timing. This might be because of the non-volatility, high viscosity of the CJO. Moreover, due to the larger droplet diameter (expressed as Sauter mean), the CJO has lower heat release rates than diesel fuel [21]. From the figure, it is also evident that BTE increased with the advancement of injection timing, which might be due to the early initiation of combustion and attainment of higher peak pressures. The increase of BTE at all loads with advancing of injection timing proceeded up to 32^0 bTDC and later on decreased. So the optimum injection timing with CJO operation is 32^0 bTDC. The higher value of BTE at optimum injection timing over the recommended injection timing was due to its longer ignition delay and combustion duration, which are essential to burn the highly viscous fuel like CJO.

The part load variations of the parameters with respect to BMEP were small; hence bar charts were drawn for the performance parameters at full load operation of the engine with diesel operation and CJO operation at recommended and optimum injection timings at an injection pressure of 190 bar.

The Fig.4 shows the bar chart, giving the variation of peak BTE with test fuels at recommended and optimum injection timings at an injection pressure of 190 bar. CE with CJO operation gave lower BTE when compared with diesel operation because of low volatility, high viscosity and low calorific value of CJO. From the same figure, it is noticed that with CJO operation, the peak BTE is lower by 11% at recommended injection timing and lower by 10% at optimum injection timing when compared with diesel operation. Increase of ignition delay with CJO operation might have contributed for the inferior performance. The CJO operation at optimized injection timing gave performance comparable to diesel operation at recommended injection timing.

Table 4 shows the comparative data on peak BTE at different injection timings and injection pressure. At recommended injection timings, peak BTE increased with an increase of injection pressure with test fuels. This was due to improved spray characteristics of the fuel with increased injection pressure.

As fuels with different calorific values were used in the investigations, brake specific energy consumption, (BSEC) defined as energy supplied through the fuel per unit power output of the engine was used instead of brake specific fuel consumption (BSFC), defined as fuel consumed per unit brake power. Figure 5 shows the bar chart, giving the variation of BSEC at full load with test fuels in CE at optimum and recommended injection timings at an injection pressure of 190 bar.

CE with CJO operation gave higher BSEC when compared with CE with diesel operation both at recommended and optimum injection timings. Low volatility, high viscosity and low heating value of vegetable oil might be the reason for higher BSEC values with CJO operation. BSEC decreased with advanced injection timing with test fuels which might be due to the early initiation of combustion.

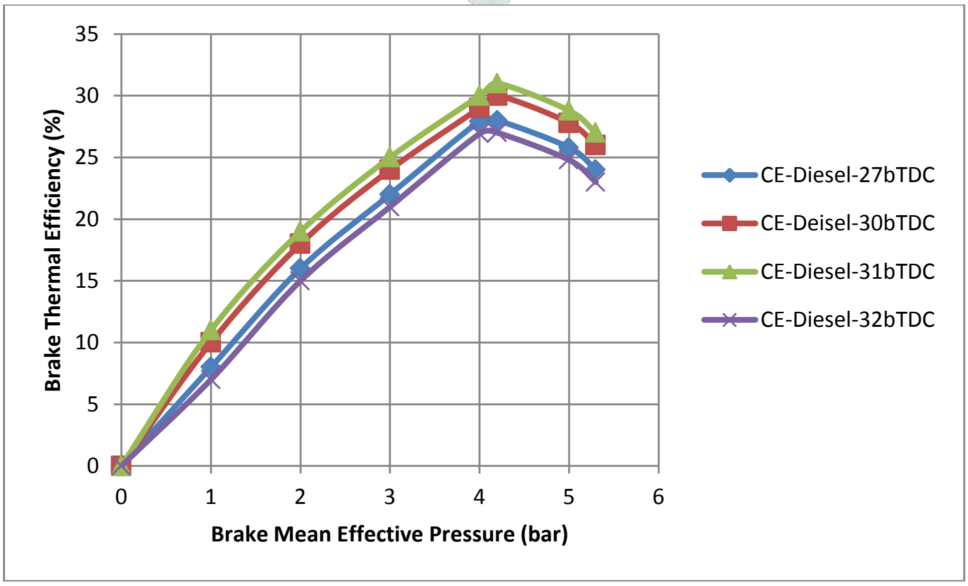


Fig.2 Variation of BTE with BMEP with diesel operation

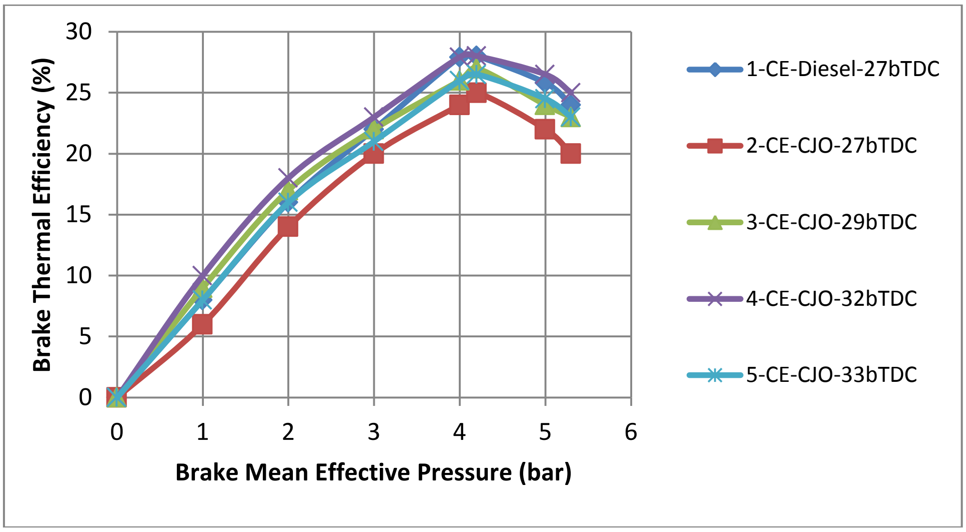


Fig.3 Variation of BTE with BMEP with CJO operation

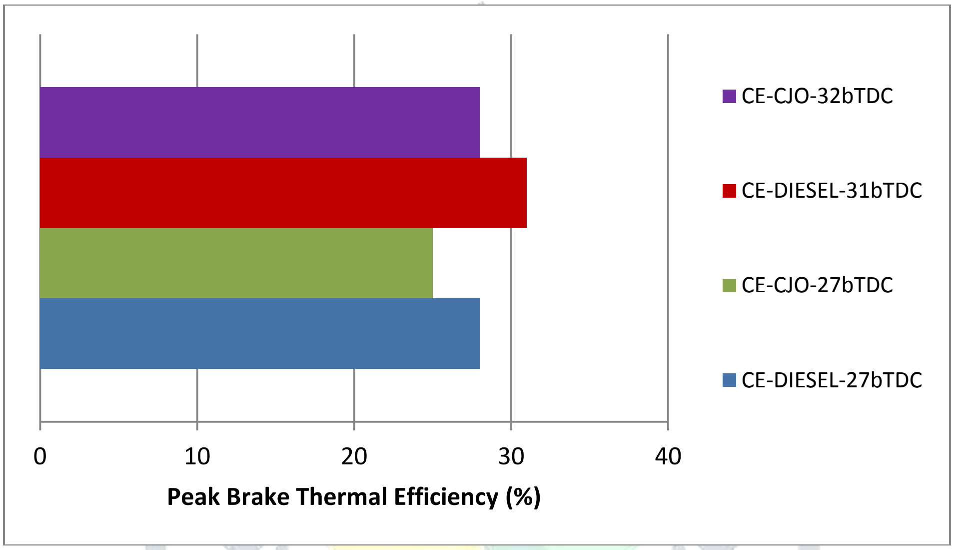


Fig.4 Bar chart showing the variation of peak BTE

Table-4: Data of peak BTE

Injection Timing (^{0}bTDC)	Fuel	Injection pressure (bar)		
		190	230	270
27	DF	28	29	30
	CJO	25	26	27
31	DF	31	30.5	30
32	CJO	28	27	26

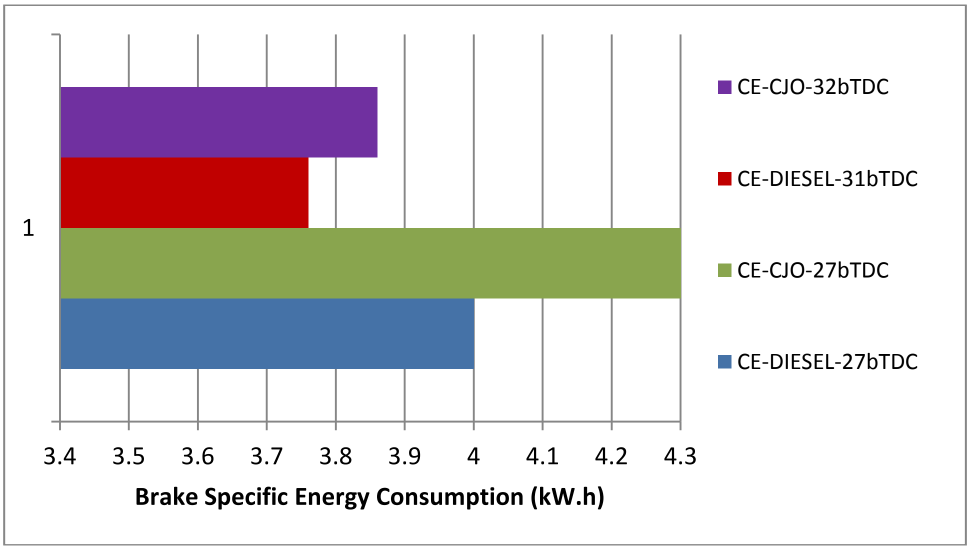


Fig.5 Bar chart showing the variation of BSEC at full load operation

Table-5 shows the comparative data on BSEC at full load operation at different injection timings and injection pressures. It is evident from the Table-5, that BSEC at full load with CJO operation is higher than that of diesel operation. At an injection pressure of 190 bar, the BSEC for CJO operation was higher by 7.5% at recommended injection timing and 2.66% at optimum injection timing in comparison with diesel operation. Poor volatility, high viscosity and low calorific value of the CJO lead to deterioration in performance. BSEC at full load operation decreased with an increase of injection pressure and advanced injection timing in with test fuels. This was due to decrease of mean diameter of the droplet with increased injection pressure.

Figure 6 gives the bar chart, showing the variation of exhaust gas temperature (EGT) with test fuels at recommended and optimum injection timings at an injection pressure of 190 bar. EGT decreased with advanced injection timing with test fuels as seen from Fig.6. This was because, when the injection timing was advanced, the work transfer from the piston to the gases in the cylinder at the end of the compression stroke was too large, leading to reduce exhaust gas temperatures. CE with CJO operation gave higher value of EGT compared with Diesel operation both at recommended and optimum injection timings. Though the calorific value of CJO was less than that of diesel, the density of the vegetable oil was higher and therefore, greater amount of heat was released in the combustion chamber leading to higher EGT with CE, which confirmed that performance deteriorated in CE with CJO operation in comparison with diesel operation. This might also be because of high duration of combustion of vegetable oil causing retarded heat release rate.

The Table 6 shows the comparative data on EGT at full load operation at different injection timings and injection pressures. CJO operation gave higher values of EGT when compared with diesel operation. Though the calorific value of CJO was less than that of diesel, the density of the vegetable oil was higher and therefore, greater amount of heat was released in the combustion chamber leading to higher EGT, which confirmed that performance deteriorated with CJO operation in comparison with diesel operation. This was also because of high duration of combustion of vegetable oil causing retarded heat release rate. From the Table, it is noticed that, with CJO operation, the EGT at full load increased by 23% at recommended injection timing and by 15% at optimized injection timing in comparison with diesel operation.

The Fig.7 gives the bar chart, showing the variation of volumetric efficiency with test fuels at recommended and optimum injection timings at an injection pressure of 190 bar. Diesel fuel at optimized injection timing showed higher volumetric efficiency. This might be due to high cetane number and clean combustion at optimized injection timing with diesel fuel in the diesel engine.

With the advanced injection timing, the volumetric efficiency increased due to the decrease of combustion wall temperatures with improved oxygen-fuel ratios. From the Fig.7, it is also observed that, with CJO operation, volumetric efficiency decreased in comparison with diesel operation.

Table-5: Data of BSEC at full load operation

Injection Timing (^{0}bTDC)	Fuel	Injection pressure (bar)		
		190	230	270
27	DF	4.0	3.92	3.84
	CJO	4.30	4.26	4.22
31	DF	3.76	3.80	3.84
32	CJO	3.86	3.90	3.94

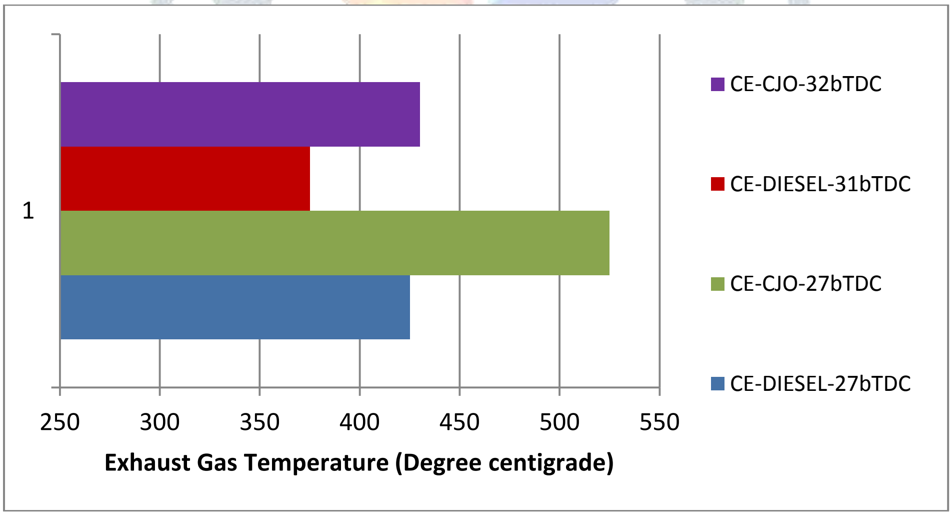


Fig.6 Bar Chart Showing The Variation Of EGT

Table-6: Data of EGT at full load operation

Injection Timing (^{0}bTDC)	Fuel	Injection pressure (bar)		
		190	230	270
27	DF	425	410	395
	CJO	525	500	475
31	DF	375	400	425
32	CJO	430	450	470

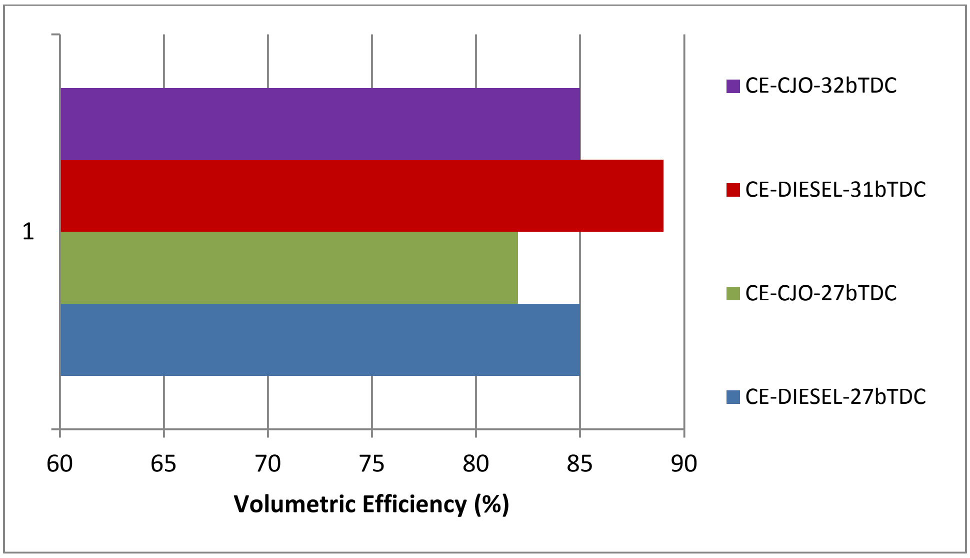


Fig.7 Bar Chart Showing The Variation Of Volumetric Efficiency

The Table 7 shows the comparative data on volumetric efficiency at full load operation at different injection timings and injection pressures. From the same Table, it is observed that, volumetric efficiency was lower with CJO operation than with diesel operation. This might be because of higher cylinder temperatures with CJO operation. At recommended injection timing, the volumetric efficiency increased marginally with an increase of injection pressure.

Table-7: Data of VE at full load operation

Injection Timing (^{0}bTDC)	Fuel	Injection pressure (bar)		
		190	230	270
27	DF	85	86	87
	CJO	82	83	84
31	DF	89	88	87
32	CJO	85	84	83

B. Exhaust Emissions

The Fig.8 gives the bar chart showing the variation of smoke in Hartridge Smoke Unit (HSU) with test fuels in CE at recommended and optimum injection timings at an injection pressure of 190 bar.

From the figure, it is observed that CE with CJO operation gave higher values of smoke emissions both at recommended and optimized injection timing when compared with CE with diesel operation. Smoke levels increases linearly with density of the fuel and increase of carbon to hydrogen atoms (C/H) ratio provided the equivalence ratio is not altered. The density of diesel and CJO are 0.84 and 0.92 respectively. High value of C/H ratio would lead to more concentration of carbon dioxide, which would be further reduced to carbon. The C/H values of diesel and CJO are 0.44 and 0.53 respectively. So the CJO operation gave higher smoke values compared to diesel operation. Smoke levels decreased at optimum injection timing with test fuels. Initiation of combustion at early period, increase of air entrainment at the advanced injection timings might have caused the lower smoke levels.

The Table 8 shows the comparative data on smoke levels at peak load operation at different injection timings and injection pressures.

Smoke levels further decreased with an increase of injection pressure, due to efficient combustion at higher injection pressures, which improved the atomization with the reduction of mean diameter of the fuel particle.

The Fig.9 gives the bar chart showing the variation of nitrogen oxide (NO_X) with test fuels in CE at recommended and optimum injection timings at an injection pressure of 190 bar.

The presence of higher temperatures and the availability of oxygen are factors for the NO_X formation. From the figure, it was observed that NOx emissions increased with increase of injection timing. This might be due to the higher combustion temperatures and increase of resident time, with increase of injection advance.

The Table 9 shows the comparative data on NO_X at peak load operation at different injection timings and injection pressures. NO_X emissions increased with increase of injection timing and with increase of injector pressure. From same Table, it was observed that NOx emissions decreased with CJO compared when compared with diesel operation, both at recommended and optimized injection timings.

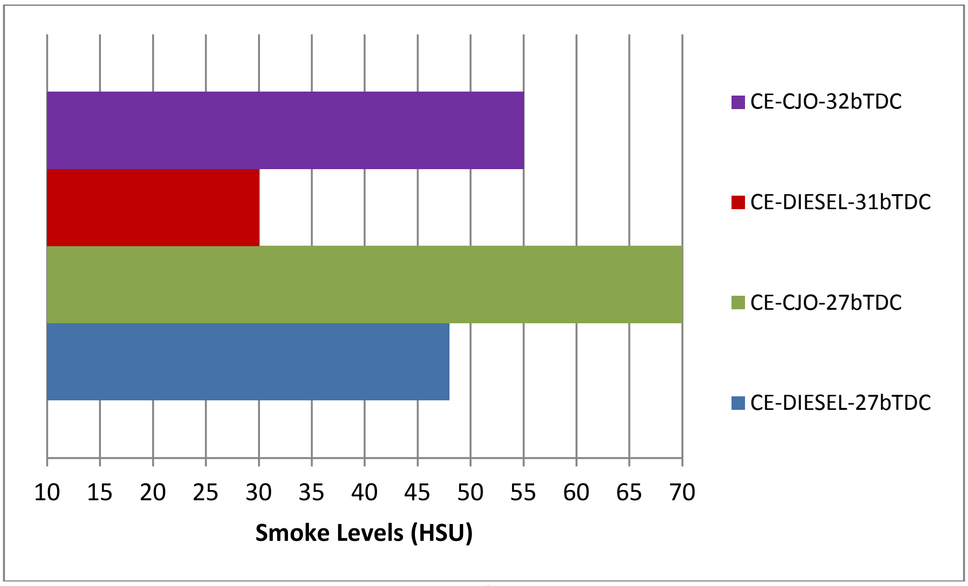


Fig.8 Bar Chart Showing The Variation Of Smoke Levels

Table-8: Data of Smoke Levels in Hartridge Smoke Units (HSU) at full load operation

Injection Timing (^{0}bTDC)	Fuel	Injection pressure (bar)		
		190	230	270
	DF	48	38	34
27	CJO	70	65	60
31	DF	30	30	35
32	CJO	55	60	65

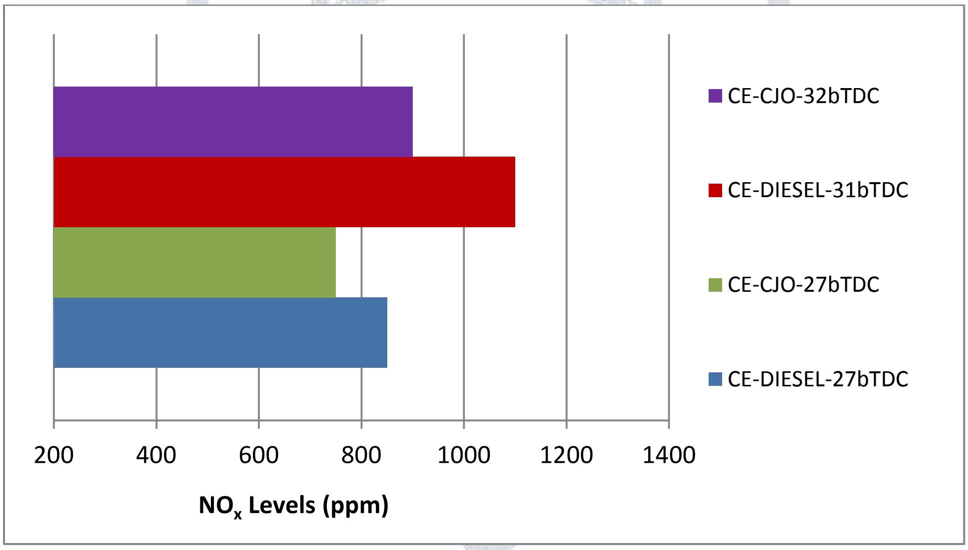


Fig.9 Bar Chart Showing The Variation Of NO_X Levels

Table-9: Data of NO_x levels at full load operation

Injection Timing (^{0}bTDC)	Fuel	Injection pressure (bar)		
		190	230	270
	DF	850	900	950
27	CJO	750	800	850
31	DF	1100	1150	1200
32	CJO	900	950	1000

IV. CONCLUSIONS

1. The optimum injection timing was found out to be 31^0 bTDC for the diesel operation while it was 32^0 bTDC for the CJO operation.
2. The CJO operation showed the deterioration in the performance when compared with diesel operation. It gave lower BTE, higher BSEC, higher EGT, lower volumetric efficiency at both recommended and optimum injection timings.
3. At the optimum injection timing of 32^0 bTDC, CJO operation showed comparable performance when compared with diesel operation at recommended injection timing.
4. With the advancing of injection timing- BTE increased, BSEC decreased, EGT decreased, volumetric efficiency increased, smoke levels decreased and NOx emissions increased~~, PP increased, TOPP decreased and MRPR increased~~ with test fuels.

5. CJO operation gave higher values of smoke emissions and lower values of NOx emissions at both recommended and optimized injection timings when compared with diesel operation.
6. The performance increased with increase of injection pressure with test fuels.

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