EXPERIMENTAL INVESTIGATIONS ON PERFORMANCE, EMISSIONS AND COMBUSTION CHARACTERISTICS OF CONVENTIONAL DIESEL ENGINE WITH NON-EDIBLE VEGETABLE OIL OPERATION AT VARYING INJECTION TIMINGS

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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 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, emissions and combustion characteristics with CJO operation, at different injection timings at the manufacturer's recommended injector opening pressure of 190 bar and the results were compared with that of the diesel operation. 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 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 vegetable oil, Performance, Exhaust Emissions, Combustion characteristics**

I. INTRODUCTION

Diesel fuel 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.

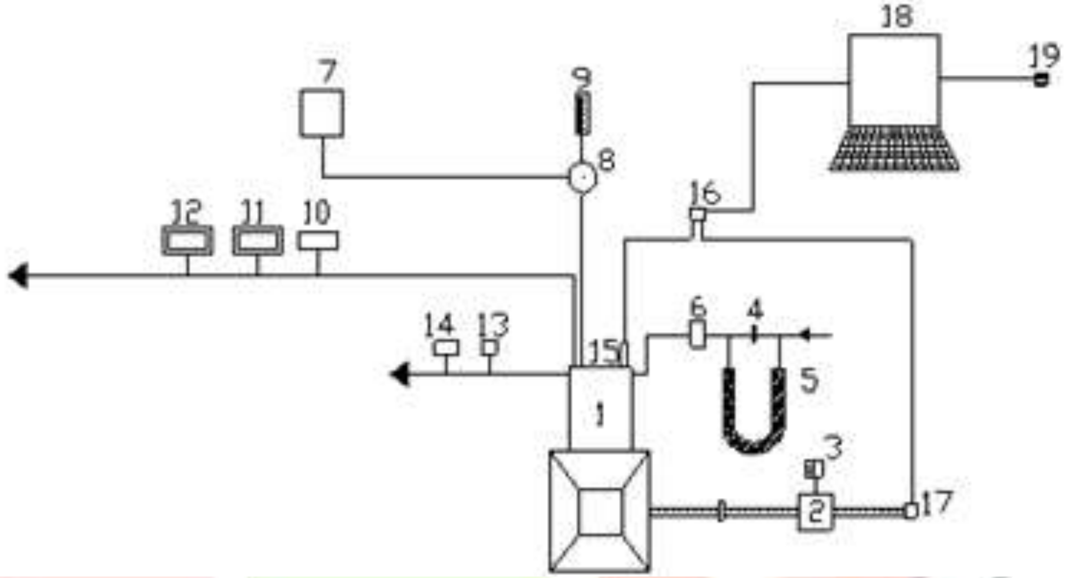
Investigations were carried out by various researchers [15-16] on the influence of injection timing on the performance and emissions of diesel engine fuelled with vegetable oil. They reported that with the advancing of injection timing, the performance parameters improved, smoke levels reduced and NO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

The present work consists of investigations on the performance, emissions and combustion characteristics with crude jatropha oil (CJO) operation at different injection timings (27-34 ^{0}bTDC) at recommended injector opening pressure of 190 bar. The results thus obtained were compared with that of the diesel operation.

II. MATERIALS AND METHODS

Fig.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 injector opening 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.



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, 15.Piezo-electric pressure transducer, 16.Console, 17.TDC encoder, 18.Personal Computer and 19. Printer

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 rpm	3.68 kW
Number of cylinders ×cylinder position× stroke	One × Vertical position × four-stroke
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 injection timing and pressure	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

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. Effect of injection timing 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.

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

The pressure in the combustion chamber was measured by a water-cooled piezoelectric pressure transducer and the crank angle was measured with the help of a TDC encoder provided at the extended shaft of the dynamometer. The transducer and encoder were connected to a computer. The combustion characteristics such as peak pressure (PP), time of occurrence of peak pressure (TOPP) and maximum rate of pressure rise (MRPR) were evaluated at full load operation of the engine with the help of a P-θ software package.

III. RESULTS AND DISCUSSIONS

The experiments were carried out on Conventional Diesel Engine (CE) with diesel operation and with CJO operation with varied injection timing at an injector opening pressure of 190 bar. 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 engines were categorized into three parts – (i) evaluation of performance parameters, (ii) measurement of exhaust emissions and (iii) evaluation of combustion characteristics. 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 injector opening pressure of 190 bar, is shown in Fig.2.

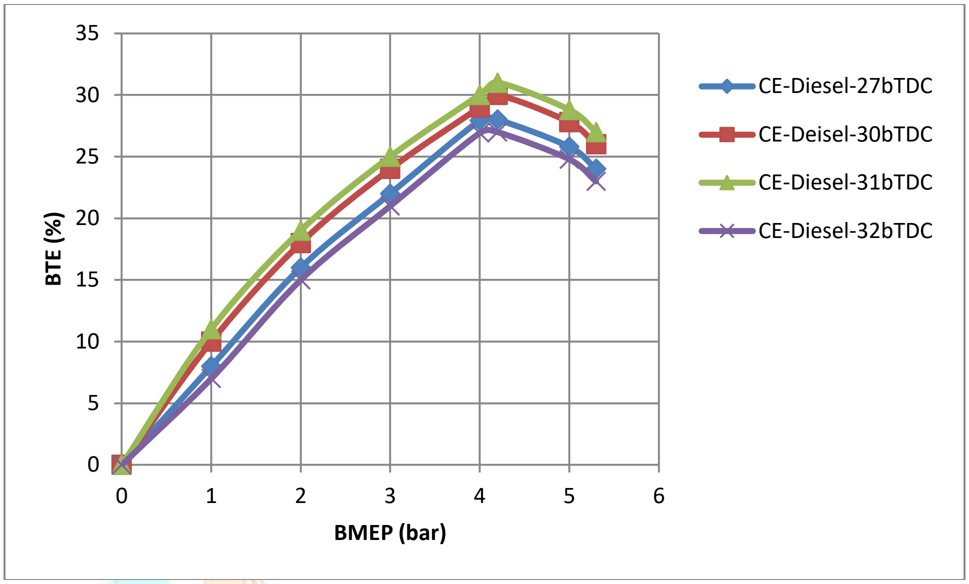


Fig.2 Variation of BTE with BMEP with diesel operation

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 [17]. 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.

Fig.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 injector opening pressure of 190 bar.

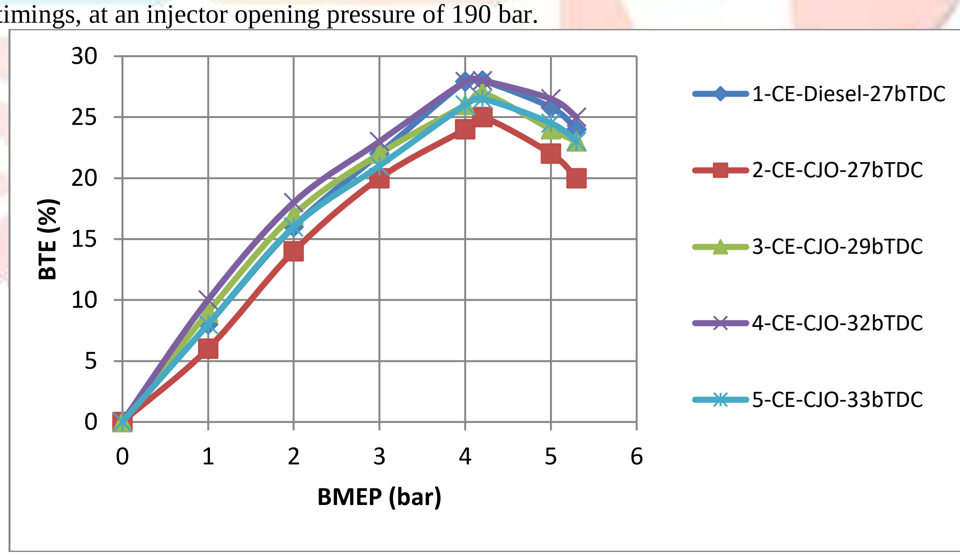


Fig.3 Variation of BTE with BMEP with CJO operation

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 [18]. 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 at full load operation on with diesel operation and CJO operation at recommended and optimum injection timings at an injector opening 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 injector opening pressure of 190 bar.

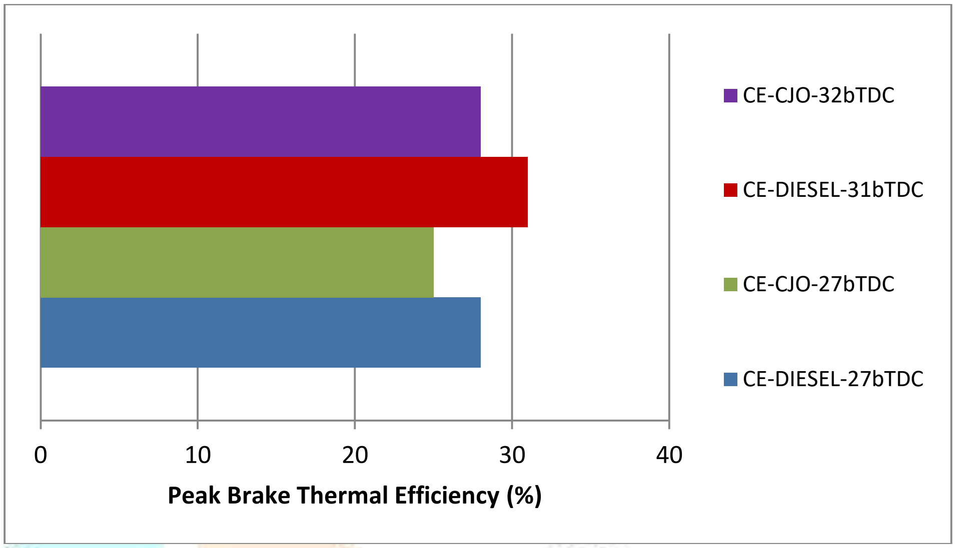


Fig.4 Bar chart showing the variation of peak BTE

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.

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. Fig.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 injector opening pressure of 190 bar.

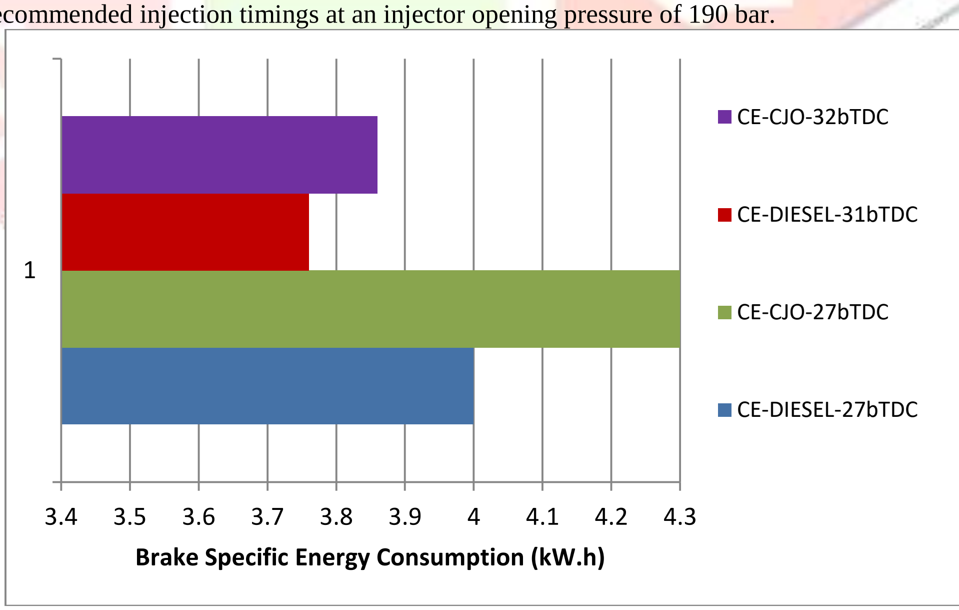


Fig.5 Bar chart showing the variation of BSEC at full load operation

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 due to the early initiation of combustion.

The Fig.6 gives the bar chart, showing the variation of exhaust gas temperature (EGT) with test fuels at recommended and optimum injection timings at an injector opening pressure of 190 bar.

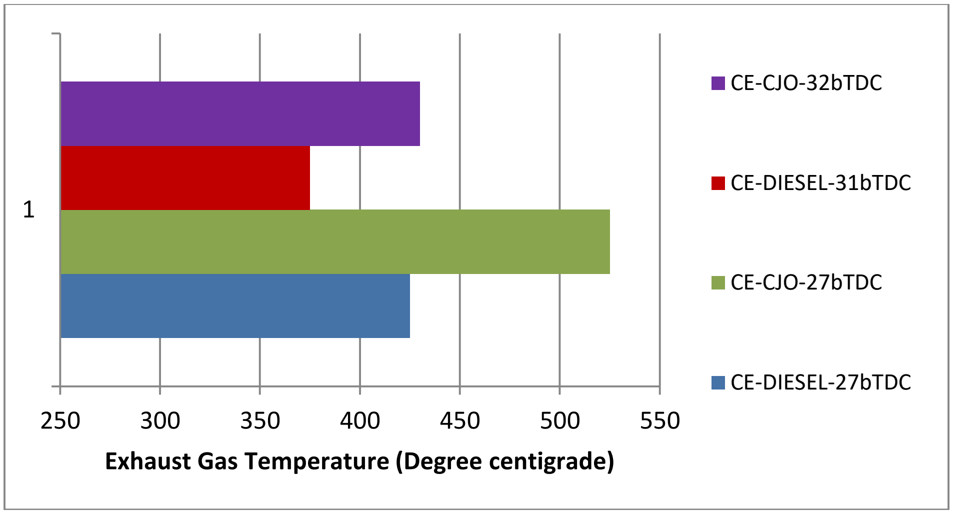


Fig.6 Bar Chart Showing The Variation Of EGT

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 Fig.7 gives the bar chart, showing the variation of volumetric efficiency with test fuels at recommended and optimum injection timings at an injector opening 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.

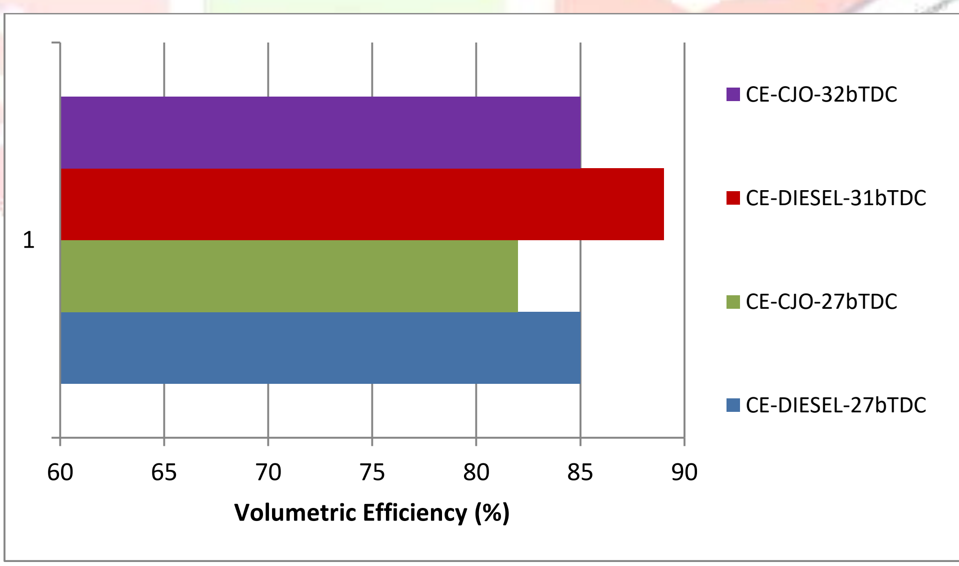


Fig.7 Bar Chart Showing The Variation Of Volumetric Efficiency

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.

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 injector opening pressure of 190 bar.

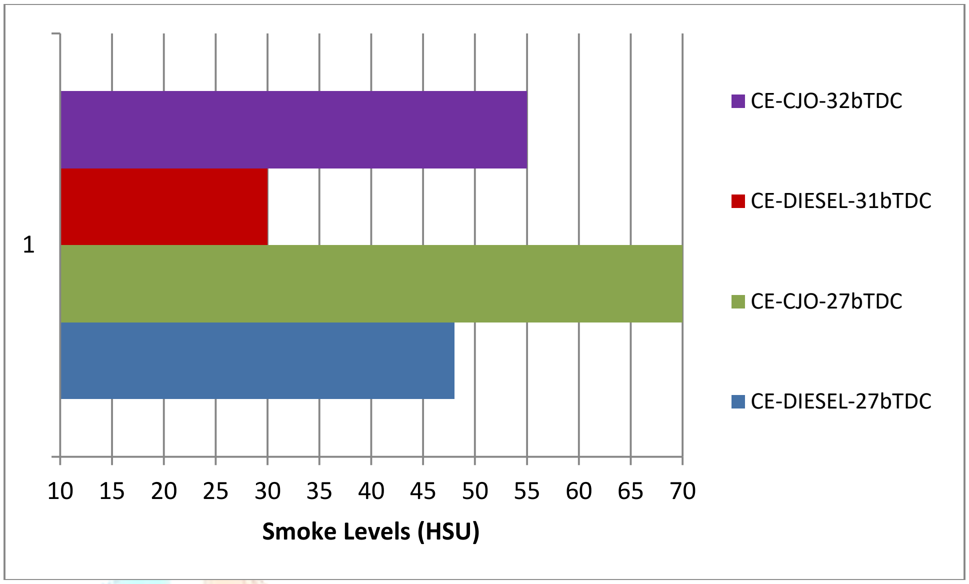


Fig.8 Bar Chart Showing The Variation Of Smoke Levels

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 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 injector opening pressure of 190 bar.

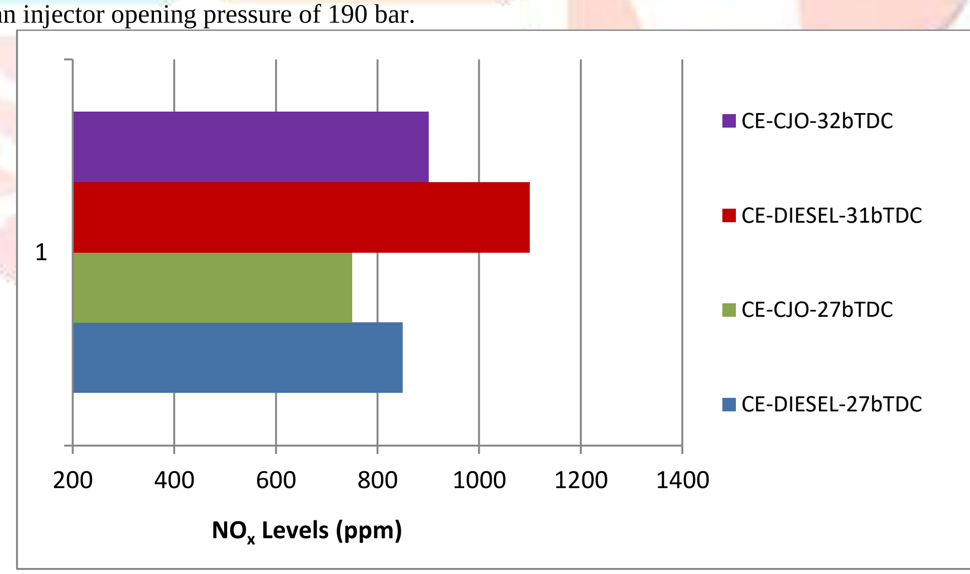


Fig.9 Bar Chart Showing The Variation Of NO_X Levels

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. From same figure, it was further observed that NOx emissions decreased with CJO compared to diesel operation, might be due to low temperatures in the combustion chamber with CJO operation.

C. Combustion Characteristics

The combustion characteristics like PP, TOPP and MRPR were determined for the CE from pressure-crank angle diagrams obtained with piezoelectric pressure transducer, TDC encoder and a pressure-crank angle (p-θ) software package.

The Fig.6 gives the bar chart, showing the variation of peak pressure with test fuels in CE at recommended and optimum injection timings at an injector opening pressure of 190 bar. CJO at recommended injection timing gave lower value of PP when compared with other operating conditions. Low calorific value of the fuel with retarded heat release rates might have been the reason for lower PP with CJO operation. PP decreased with CJO operation when compared with diesel operation both at recommended and optimized injection timing. This might be due to increase of ignition delay, as vegetable oil requires large duration of combustion, meanwhile the piston started making downward motion thus increasing volume when the combustion takes place in CE.

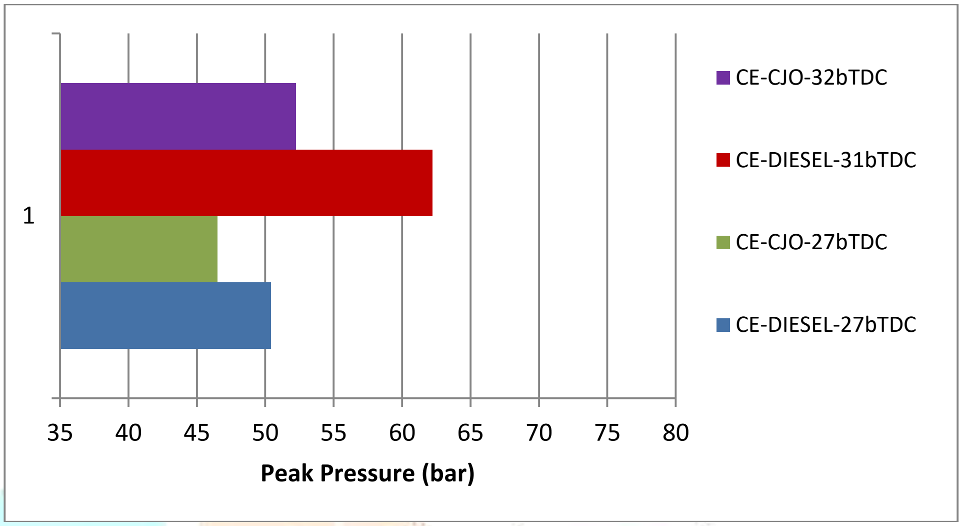


Fig.6 Bar Chart Showing The Variation Of Peak Pressure

The value of peak pressure increased with advancing of the injection timing with CE with test fuels. This might be due to accumulated and sudden explosion of the fuel with advanced injection timing with CE.

The Fig.7 presents the bar chart, showing the variation of TOPP with test fuels in CE at recommended and optimum injection timings at an injector opening pressure of 190 bar.

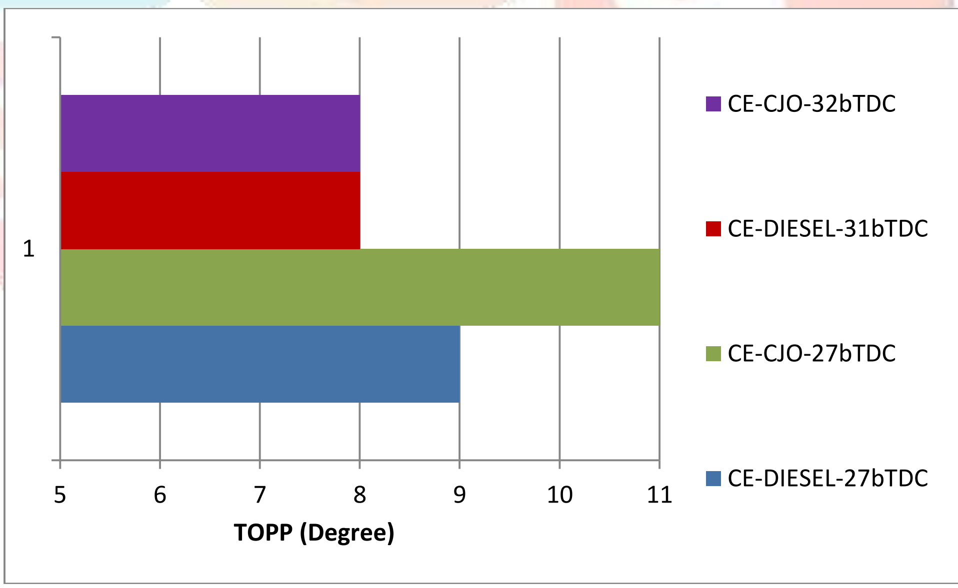


Fig.7 Bar Chart Showing The Variation Of TOPP

TOPP decreased with advancing of the injection timing with the test fuels. CJO operation at recommended injection timing gave higher TOPP in comparison with other operating conditions. Increase of combustion duration and retarded heat release rate might be the reason.

MRPR exhibited similar trends of peak pressure in both version of the engine. Fig.8 presents the bar chart, showing the variation of MRPR with test fuels in CE at recommended and optimum injection timings at an injector opening pressure of 190 bar.

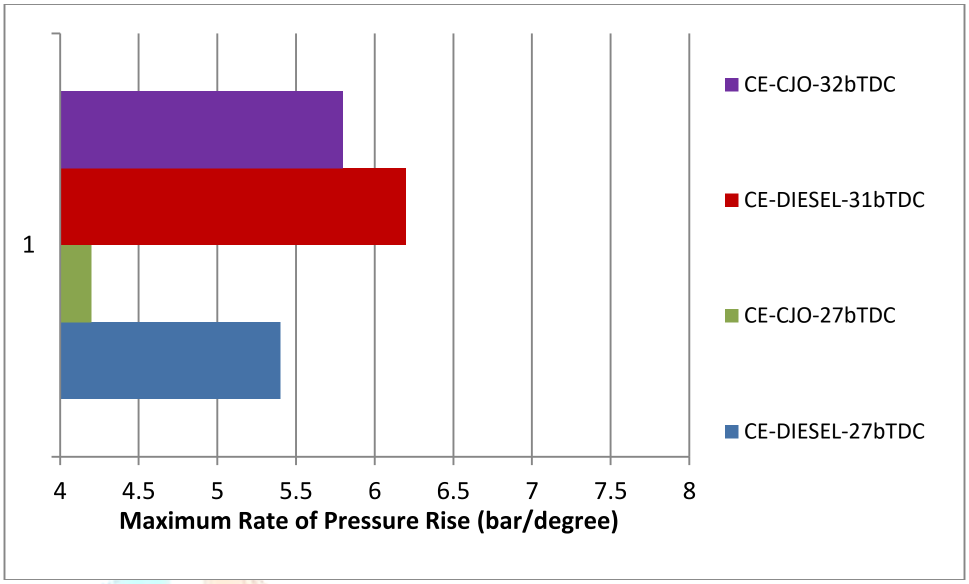


Fig.8 Bar chart showing the variation of MRPR

CE with CJO operation at recommended injection timing gave lower MRPR in comparison with other operating conditions. Retarded heat release rate, higher duration of combustion of CJO in addition to its lower calorific value might have contributed for the lower MRPR with CJO operation at recommended injection timing. MRPR increased with advanced injection timing with test fuels, which might be because of initiation and continued combustion at early period.

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. PP decreased with CJO operation when compared with diesel operation both at recommended and optimized injection timing.

V. ACKNOWLEDGEMENTS

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References

[1] Fulekar, M. H. 1999. Chemical pollution – a threat to human life. Indian Journal of Environmental Technology, 1, 353-359.

[2] Rehman, A. and Singhai, K.C. 1995. Vegetable oils as alternate fuels for diesel engine. Proceedings of IV Asian –Pacific International Symposium on Combustion and Energy Utilization, pp: 924-928, Hong Kong.

[3] Srinivasa Rao, S., Rama Mohan, P. and L.S. Rao, T. 1997. Jatropha oil as alternate fuel for diesel engines. Proceedings of National Conference on Alternate & Renewable Energy Technologies, pp:15-20, Hyderabad.

[4] Sudhakar Babu, S., Ramachandra, G., Nagamalleswara Rao, V., Naga Prasad Naidu. 2001. Investigations on the suitability of rapeseed oil in CI engine. Proceedings of National Conference on Advanced Trends in Mechanical Engineering Research & Development, JNT College of Engineering, pp: 593-596, Anantapur.

[5] Deepak Agarwal and Avinash Kumar Agarwal. 1982. Performance and emissions characteristics of Jatropha oil (preheated and blends) in a direct injection compression ignition engine. Applied Thermal Engineering, Elsevier Publications, Volume 27, Issue 13, 2314-2323.

[6] Fort, T. 1982. Evaluation of cotton seed oil as diesel fuel. SAE Paper No. 820317.

[7] Madhur, R.D. and Das, G. 1985. Utilization of non-edible wild oils as diesel engine fuels. Proceedings of Bio-energy Society II Convention, pp: 198-202, I.I.T., Madras.

[8] Kiannejad, F., Crookes., R.J. and Nazha, M.A.A. 1993. Performance and emissions of a 1.5 litre single cylinder diesel engine with low cetane number vegetable oil fuel and emulsification with water. Proceedings of IV International Conference on Small Engines and Fuels, pp: 32-39, Chang Mai, Thailand.

[9] Naga Prasad. Ch.S, Vijaya Kumar Reddy. K, Kumar. B.S.P, Ramjee. E, Hebbel.O.D and Nivendai. M.C. 2009. Performance and Emission Characteristics of a Diesel Engine With Castor Oil. Indian journal of science and technology,Vol 2(10), Oct, 25-31.

[10] K.Pramanik. 2003. Properties and use of jatropha curcas oil and diesel fuel blends in compression ignition engine. Renewable Energy, Elsevier Publications, Volume 28, Issue 2, 239-248.

[11] R.D.Misra, M.S.Murthy. 2010. Straight vegetable oils usage in a compression ignition engine - A review. Renewable and Sustainable Energy Reviews, Elsevier Publications, Volume 14, Issue 9, 3005-3013.

[12] D.C.Rakopoulos, C.D.Rakopoulos, E.G.Giakoumis, A.M.Dimaratos and M.A.Founti. 2011. Comparative environmental behavior of bus engine operating on blends of diesel fuel with four straight vegetable oils of Greek origin: Sunflower, cottonseed, corn and olive. FUEL, Elsevier Publications, Volume 90, Issue 11, 3439-3446.

[13] Soo-Young No. 2011. Inedible vegetable oils and their derivatives for alternative diesel fuels in CI engines: A review. Renewable and Sustainable Energy Reviews, Elsevier Publications, Volume 15, Issue 1, 131-149.

[14] Avinash Kumar Agarwal, K. Rajamanoharan. 2009. Experimental investigations of performance and emissions of Karanja oil and its blends in a single cylinder agricultural diesel engine. Applied Energy, Elsevier Publications, Volume 86 (1), 106-112.

[15] Bari S., Yu C.W. and Lim T.H. 2004. Effect of fuel injection timing with waste cooking oil as a fuel in a direct injection diesel engine. Proceedings of the Institution of Mechanical Engineers, part-d: Journal of automobile engineering, Part D, Vol. 218, Pg93-104.

[16] J.Narayana Reddy, A.Ramesh. 2006. Parametric studies for improving the performance of a Jatropha oil-fuelled compression ignition engine. Renewable Energy, Elsevier Publications, Volume 31, Issue 12, 1994-2016.

[17] Heywood, J.B. 1988. Internal Combustion Engine Fundamentals. Thermo-chemistry of fuel air mixtures, Properties of working fluids, pp: 85-96 and 130 –140, McGraw-Hill Book Company, New York, Edn.

[18] Hiroyasu, H. and Masataka, A. 1980. Development and use of a spray combustion modeling to predict diesel engine efficiency and pollutant emissions. Proceedings of V International Symposium of Automotive Propulsion Systems, April.