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OPTIMIZATION OF THE COMPRESSION RATIO AND THE INJECTION TIMING OF A COMPRESSION IGNITION ENGINE RUNNING ON BIODIESEL

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ABSTRACT

This study investigated the effect of compression ratio (CR), injection timing (IT) on the performance and combustion characteristics of a compression ignition (CI) engine running on diesel fuel, and biodiesel (25%, 50%, 75% and 100%) blended-diesel fuel. Tests were carried out using four different CRs (14, 15, 16 and 17:1) and ITs (17.8^o, 20.1 ^{o}, 23 ^{o}, 25.9 ^{o}, 28.8^o), with engine load varying from 3kg to 8kg, and at constant engine speed of 1500 rpm. The results showed that the brake thermal efficiency (BTE) increased with CR, and the best results for specific fuel consumption (SFC) and brake thermal efficiency were observed at the manufacturer recommended CR of (16) and IT (23 ^{o} CA BTDC). The engine efficiency was higher in biodiesel and biodiesel fuel blends, and the most appropriate fuel blend was found to be B75, for optimum performance when the engine is running at 1500 rpm and at a CR of 16.

Keywords: Biodiesel, Compression Ignition Engine, Compression Ratio, Injection Timing, Optimization, Performance.

1. INTRODUCTION

To sustain the ever growing need for energy ensuing from escalating demand and waning supply, alternative sources of fuel, majorly biodiesels, have received more attention in the recent past. Moreover, the increase in global concern has resulted in more emphasis on the use of oxygenated fuels diesel fuel due to environmental pollution from Internal Combustion engines. These pertinent issues have elicited intensive research and studies to substitute petroleum based diesel fuel with biofuel [1]. The biofuels that attain the required performance standards have been utilized by various academic researchers [2] who have reported that biodiesel exhibit similar and close engine performance characteristics to diesel fuel, and reduces exhaust emissions from diesel engines.

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2. METHOD

Experimental Setup

The experiments were conducted on a four-stroke, naturally aspirated, single cylinder, and multi-fuel engine. The engine was connected to an eddy current dynamometer for loading. The operation mode of the engine is such that it can be changed from diesel to ECU (electronic control unit) petrol and vice versa. This is done by use of a specially designed tilting cylinder block arrangement, without having to alter the combustion chamber geometry. The engine specifications and operating conditions used in this study are shown in Table 1, and the setup of the test bench is shown in Figure 1.

Table 1: Test Engine specifications

Engine Manufacturer	Kirloskar Oil Engines (India)
Engine Type	1 Cylinder, 4 stroke
Bore and Stroke	87.5mm by 110mm
Capacity	661cc
Fuel	Multi-fuel Diesel mode: power 3.5kw, speed 1500rpm, CR range 12:1-18:1, Injection variation 0-25 Deg BTDC
Dynamometer	Eddy Current Type, water cooled with loading unit
Propeller Shaft	With universal joints
Fuel Tank	Capacity 15lit, Type: Duel compartment, with fuel metering pipe of glass
Crank Angle Sensor	Resolution 1 Deg, speed 5500 RPM with TDC pulse
Piezo Powering Unit	Make-Apex, Model AX-409
Engine Control Hardware	Fuel injector, Fuel pump, ignition coil, idle air
Digital Voltmeter	Range 0-20V, panel mounted
Temperature Sensor	Type RTD, PT100 and thermocouple, type K.
Temperature transmitter	Type two wire, Input RTD

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	PT100, Range 0-1000^{o}C, Output 4-20 Ma and type two wire, Input thermocouple, Range 0-1200^{o}C, Output 4-20 Ma.
Load indicator	Digital, Range 0-50Kg, Supply 230VAC
Load sensor	Load cell, type strain gauge, range 0-50Kg
Fuel Flow Transmitter	Pressure transmitter, Range 0-500mm WC
Air Flow Transmitter	Pressure transmitter, Range (-) 250 mm WC
Software	"Enginesoft" Engine performance analysis software

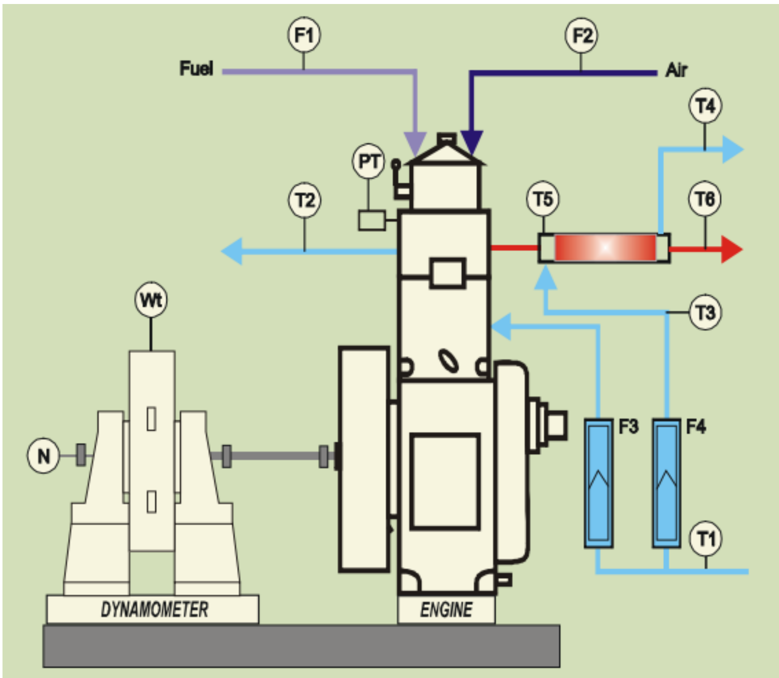

Fig. 1: Experimental set up.

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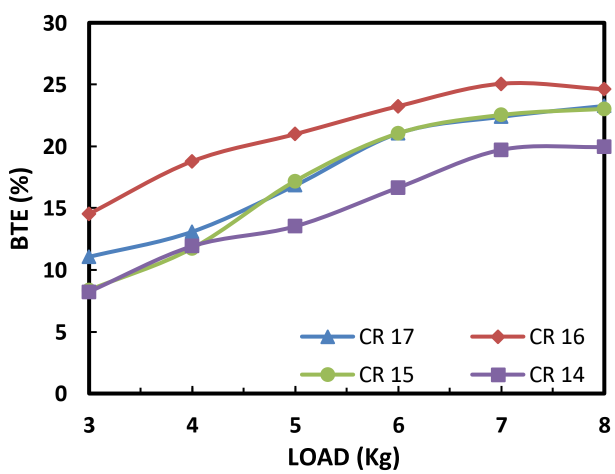
Procedure

The experiments were carried out at three different modes. The original compression ratio (CR) and injection timing (IT) of the engine are 16:1 and 20^{o}CA BTDC. In the first step, the experiments were carried out at four different CRs (14, 15, 16 and 17), with original IT, and the engine running on base fuel at 1500rpm. To change from one CR to another, the bolts clamping the tilting block were loosened, followed by the loosening of the lock nut on the adjuster. The adjuster was then turned to the desired CR, then the lock nut tightened, and afterwards all the bolts were tightened. The tests were then repeated with varying load from 3kg to 8kg. After obtaining the values of the performance and combustion characteristics of the engine using "Enginesoft" program, the remaining fuel was drained through the drain port, then fuel tank was filled with a diesel-biodiesel fuel blend (B25). The values of performance and combustion characteristics were also recorded, then the procedure was repeated using fuel blends B50, B75 and B100.

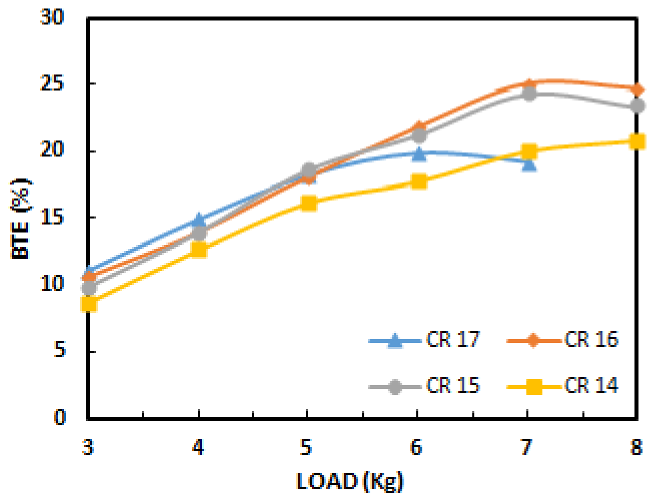
In the second set of experiments, the tests were performed at five different ITs (17.8^{o}, 20.2 ^{o}, 23 ^{o}, 25.9 ^{o}, 28.8^{o}) with original CR and engine speed at 1500 rpm. The values of engine performance and combustion characteristics were recorded when the engine is running on base fuel, and fuel blends (B25, B50, B75 and B100), with varying load from 3kg to 8kg.

3. RESULTS AND DISCUSSIONS

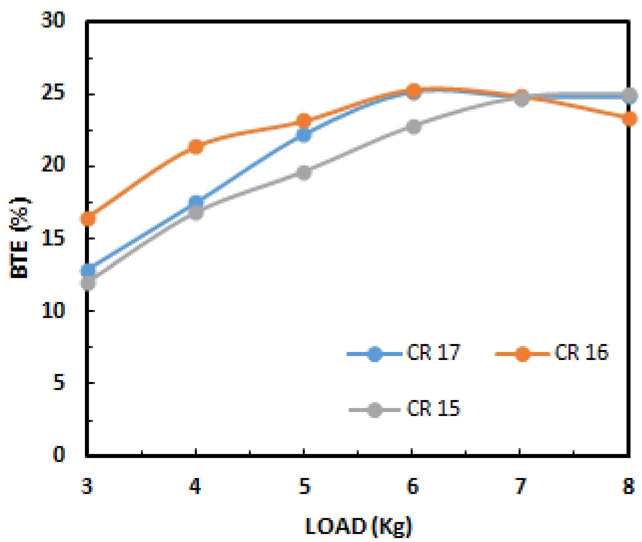
In these section the results will be presented and discussed. The effect of compression ratio, injection timing and blend composition will be analyzed in depth and presented as follows.



(a)



(b)



(c)

Fig. 2: (a-B75), (b-B50) and (c-B25) Variation of brake thermal efficiency with load, at different CR

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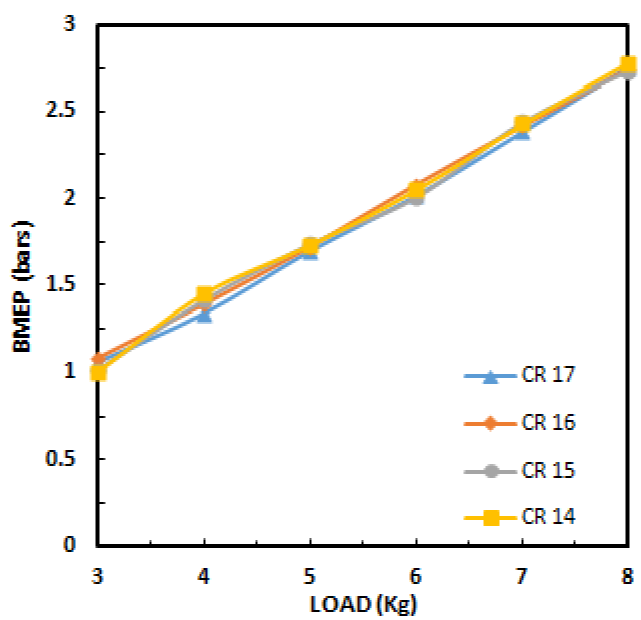
Brake thermal efficiency (BTE) is the ratio between the power output and the energy introduced through fuel injection, the latter being the output product of the injected fuel mass flow rate and the lower heating value [1].

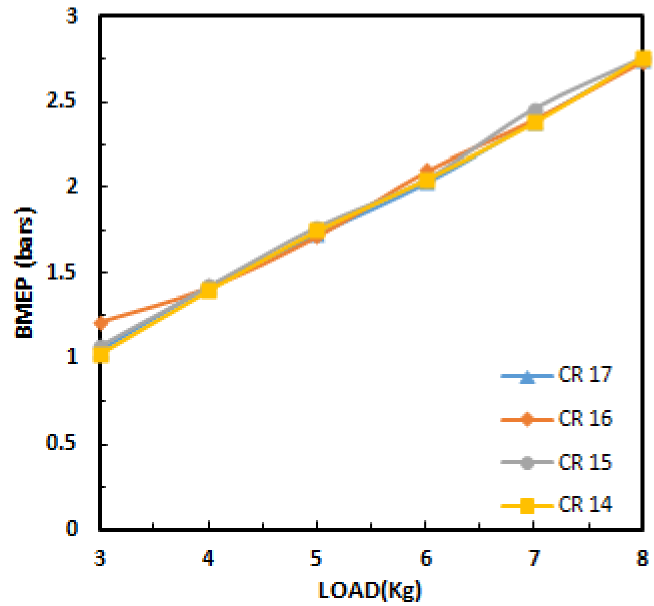
Generally, BTE increases with the value of the compression ratio (CR) from 14 to 16, beyond which it begins to drop. This is illustrated in Figures 1 (a), (b) and (c). From the graphs, a CR of 14 has the lowest BTE while CR16 has the best brake thermal efficiency. The BTE of CR17 is lower than that of 16 implying that optimum CR has been exceeded. At CR16 the peak performance occurs at a load of about 6-7kg. At lower CR, there is insufficient heat of compression which leads to delay in ignition hence the lower BTE. As the CR is increased, there is a rise in the air temperature inside the cylinder which reduces the ignition lag, hence results in a better and more complete burning of the fuel [2].

The effects of variation in CR on the BTE indicate that at higher CRs the engine efficiency is improved. This may attributed to better combustion and lubricity of biodiesel [5]. Increased CR enhances density of air charge in the cylinder. Increased density results in a higher amount of air entrainment in the spray.

Brake mean effective pressure (BMEP)



(a)



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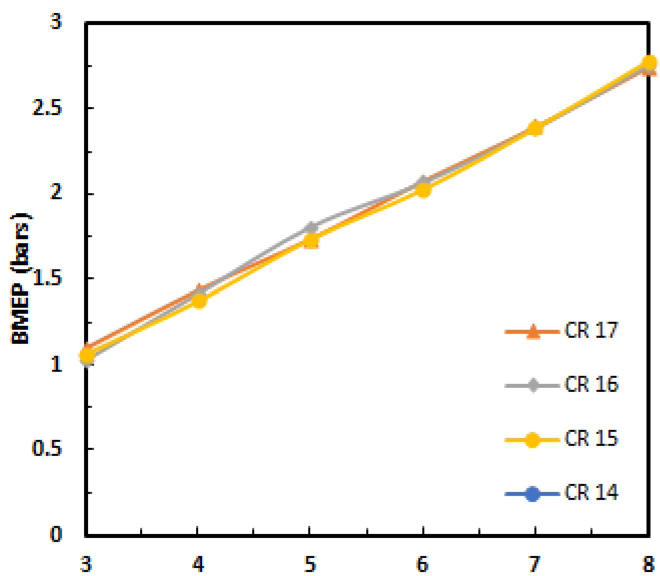

(c)

Fig. 3: (a-B75), (b-B50) and (c-B25) Variation of BMEP with load at various compression ratios.

Figures 3 (a), (b) and (c) shows the variation of BMEP with load at various compression ratios. It can be noted that BMEP increases with increasing load. For all the compression ratios, the BMEP curves compare well. At the load range of 5-7 kg, CR16 has a better BMEP in comparison to other CR, when the engine is running at a constant speed of 1500 rpm.

At low engine loads, the engine temperatures are low which makes it difficult to atomize the fuel blends which have high density, viscosity and molecular weight [7]. As the engine loads increase, there is a corresponding increase in the engine temperature which results in a faster atomization of the fuel and combustion, hence an increased brake mean effective pressure.

The efficiency of biodiesel and diesel-biodiesel blends is higher than that of diesel fuel due to better combustion because of higher oxygen content in the blends. The result indicate that biodiesel blends are better than diesel at low load condition since the inherent oxygen of biodiesel can enhance combustion at low load/low temperature conditions.

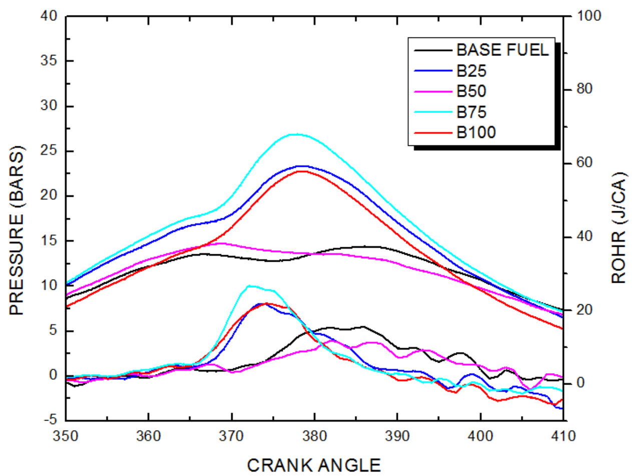

Fig. 4: Cylinder pressure and rate of heat release variation of fuel blends with respect to crank angle.

Combustion Analysis

Cylinder Pressure and rate of heat release

From Fig. 5 it can be noted that the ignition of fuel starts earlier for biodiesel based fuels in comparison to diesel fuel. In spite of higher viscosity and lower volatility of biodiesel, the ignition delay period seems lower than for diesel fuel. This could be a result of complex and rapid pre-flame

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chemical reaction that takes place at high temperature. As a result of the high cylinder temperature existing during fuel injection, biodiesel may undergo thermal cracking which leads to production of lighter compounds that might have reacted earlier, hence the shorter ignition delay [3].

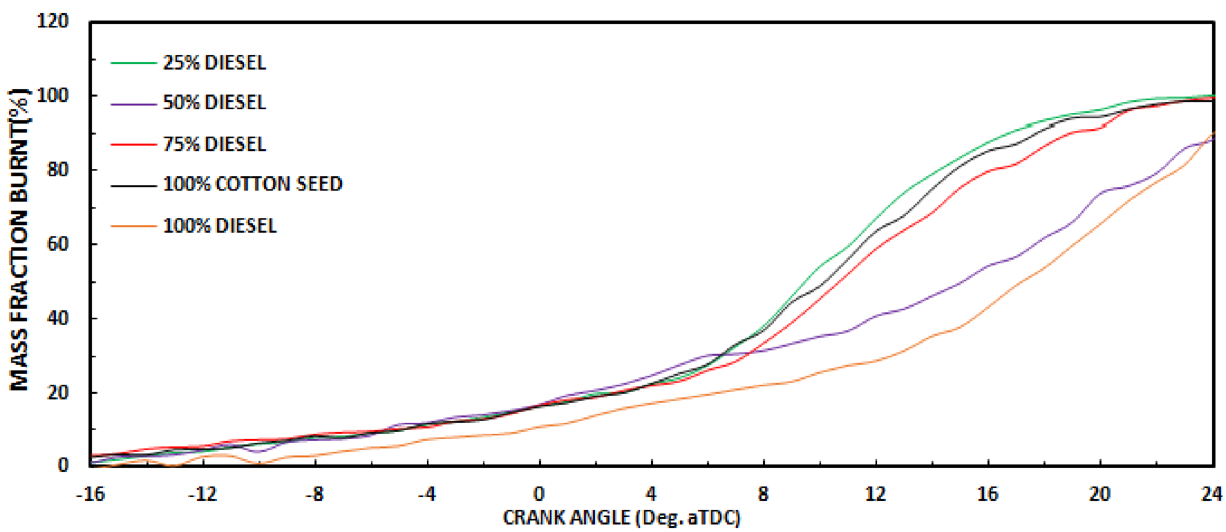


Fig. 5: Variation of MFB aTDC for various diesel-biodiesel blends with respect to crank angle.

Similarly, maximum cylinder gas pressure was found to be higher for all biodiesel blends as compared to the diesel fuel. The cylinder pressure depends on the burnt fuel fraction during the premixed phase (initial stage of combustion). It characterizes the ability of the fuel to mix well with air and burn. Therefore, the high peak pressures in biodiesel-diesel blends may be attributed to the high oxygen content in the biodiesel molecules, which lead an increase in the rate of combustion, peak temperature and pressure. The position of maximum pressure for diesel fuel is more delayed ATDC as compared to the biodiesel blends as a result of the lowest cetane number and long ignition delay period for the diesel fuel [4].

The high viscosity and low volatility of biodiesel and biodiesel fuel blends lead to poor atomization and mixing with air, and also shorter ignition delay which cause more fuel to be burnt in diffusion stage.

After peak pressure points, the rate of decreasing pressure for diesel fuel is higher than for biodiesel and biodiesel-diesel fuel blends. This is a result of the presence of oxygen in biodiesel molecules.

Comparing the various diesel-biodiesel fuel blends, it can be noted that B75 attains the highest peak cylinder pressure, and its rate of heat release confirms the same. Therefore, it can be concluded that at a CR of 16, B75 fuel blend is the most appropriate to run the engine for optimum performance.

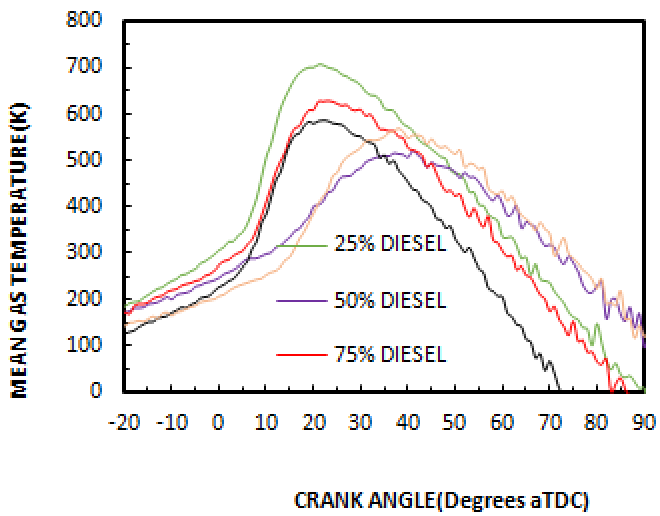


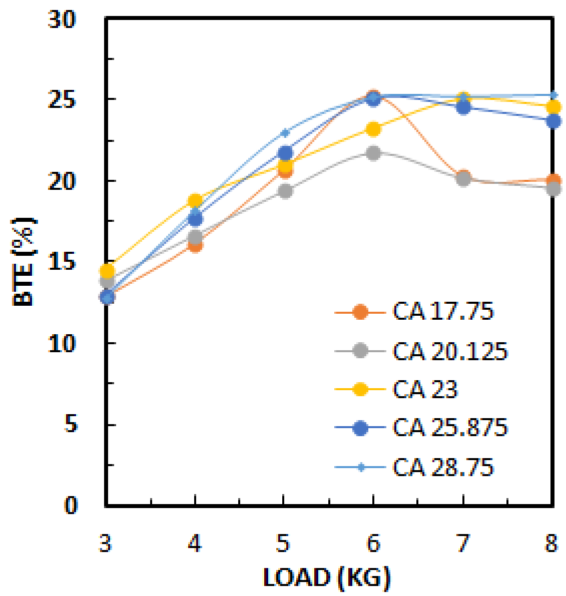
Fig. 6: Variation of MGT various diesel-biodiesel fuel blends with respect to crank angle.

Figures 5 and 6 shows the variation of MFB and MGT with respect to the crank angle for various diesel-biodiesel blends. It can be noted that in both cases, B75 (25% diesel-75% bio-diesel) had the highest mass fraction burnt and attained the highest mean gas temperature. The ignition of B75 starts earlier for all the fuel blends, which is accompanied by an early rise in its mean gas temperature with respect to the crank angle, in comparison to other fuel blends.

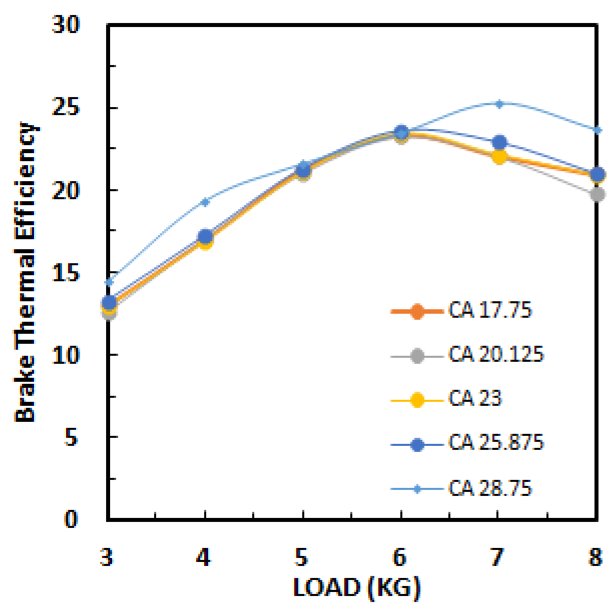
This is consistent with the peak cylinder pressure and rate of heat release in Figures 3. This leads to an informed conclusion that B75 diesel-biodiesel blend is the most suitable to run the engine at 1500rpm and CR16.

INJECTION TIMING

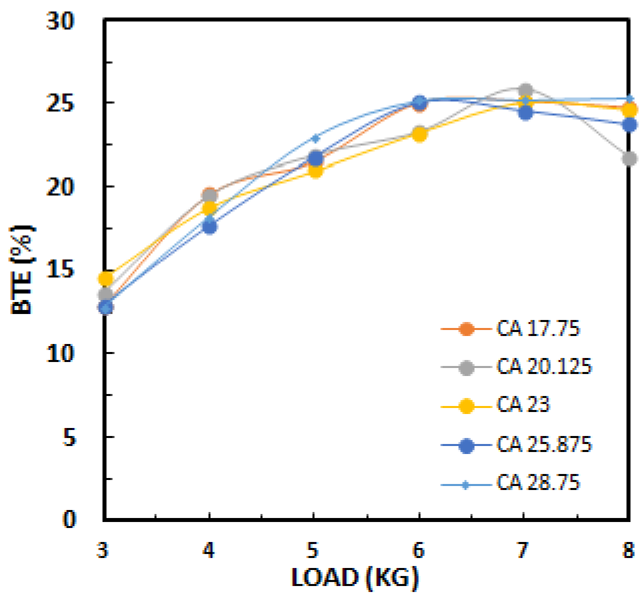
Performance Analysis


30
25
20
15
10
5
0
BTE (%)
CA 17.75
CA 20.125
CA 23
CA 25.875
CA 28.75
3
4
5
6
7
8
LOAD (KG)

(a)


30
25
20
15
10
5
0
Brake Thermal Efficiency
CA 17.75
CA 20.125
CA 23
CA 25.875
CA 28.75
3
4
5
6
7
8
LOAD (KG)

(b)

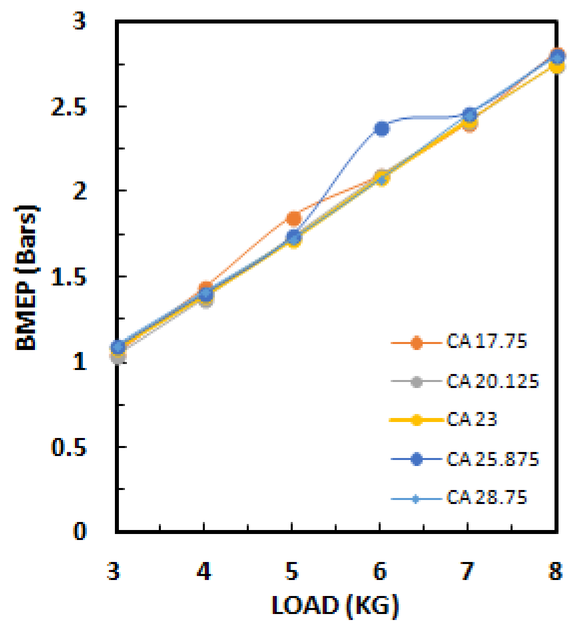


(c)

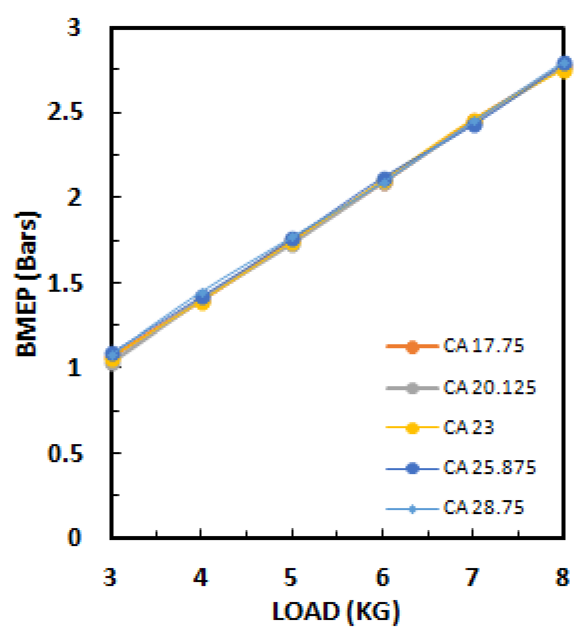
Fig. 7: (a-B75), (b-B50) and (c-B25) Variation of Brake Thermal Efficiency with respect to load for various crank angles.

From Figures 7 (a), (b) and (c) it can be noted that the BTE increases with increasing load, to a load of 6-7kg, beyond which it evens off. For the three diesel-biodiesel sample fuel blends, the crank angle of 28.8^{o} has the best BTE. This can be attributed to the fact that an increased CA aTDC causes a higher cylinder temperature and an increase in oxidation process between the fuel and oxygen molecules. This results in a more complete combustion of the fuel hence more energy is converted in to useful work, resulting in better BTE [9].

Brake Mean Effective Pressure


3
2.5
2
1.5
1
0.5
0
BMEP (Bars)
3
4
5
6
7
8
LOAD (KG)
CA 17.75
CA 20.125
CA 23
CA 25.875
CA 28.75

(a)


3
2.5
2
1.5
1
0.5
0
BMEP (Bars)
3
4
5
6
7
8
LOAD (KG)
CA 17.75
CA 20.125
CA 23
CA 25.875
CA 28.75

(b)

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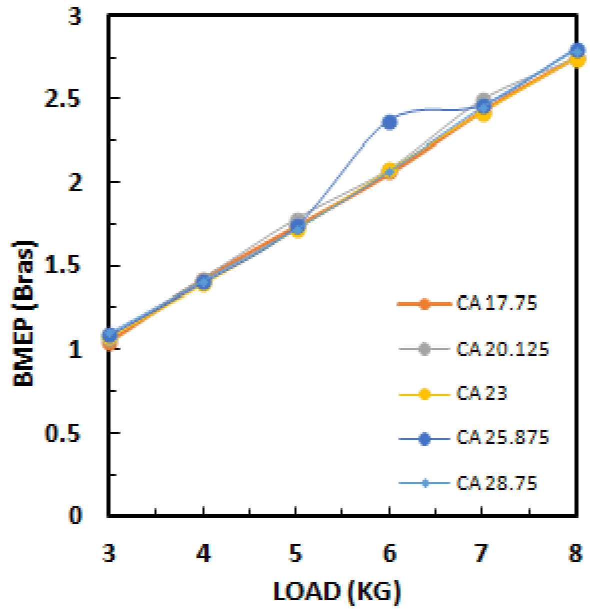

Fig. 8: (a-B75), (b-B50) and (c-B25) Variation of BMEP with load at various crank angles.

From the Figures 8 a, b and c it can be noted that BMEP increases with increasing load. At low engine loads, the engine temperatures are low which makes it difficult to atomize the fuel blends which have high density, viscosity and molecular weight. As the engine loads increase, there is a corresponding increase in the engine temperature which results in a faster atomization of the fuel and combustion, hence an increased brake mean effective pressure.

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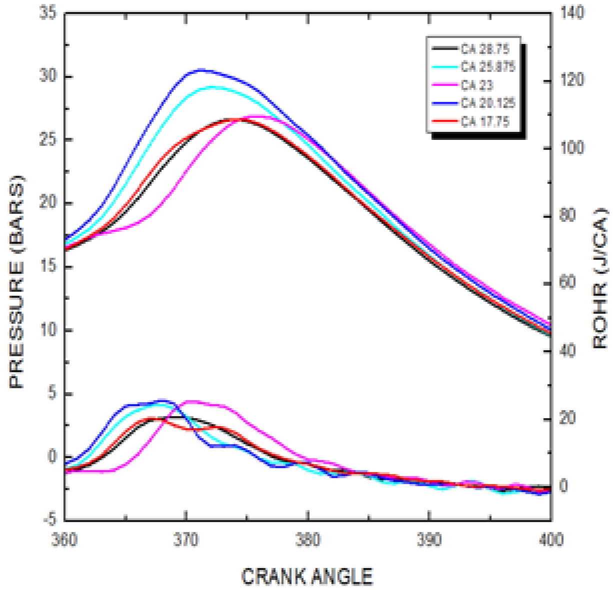
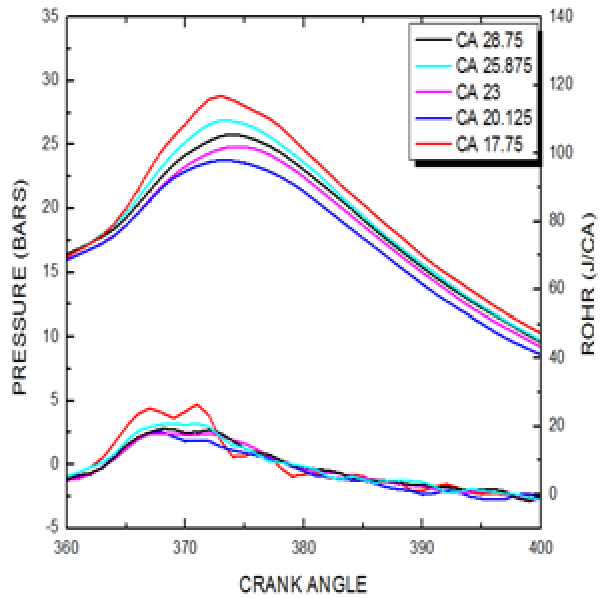


(a)



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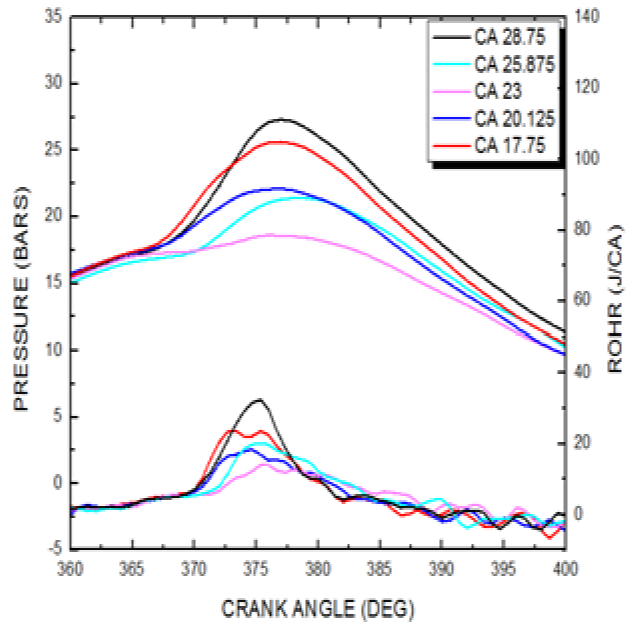

(c)

Fig. 9: (a-B75), (b-B50) and (c-25) Variation of cylinder pressure and rate of heat release with respect to crank angle in degrees.

For B75 blend, the CA of 20.1° has the highest peak cylinder pressure and corresponding rate of heat release. For the B50 blend, the best performance is obtained at a CA of 17.8° while for the B25 blend the best performance is attained at a CA of 28.3°.

To arrive at the optimum injection timing of the test engine when running on biodiesel, it has to be a combination of optimum CR and biodiesel-diesel fuel blend.

From previous discussions, it was found out that the optimum CR is 16, and B75 blend had the best performance at this CR. Therefore, it implies that the optimum injection timing is determined from the performance of the various crank angles when the engine is running with B75 fuel blend. Therefore, the optimum CA that meets this criteria is 20.2°.

Mass Fraction Burnt (MFB)

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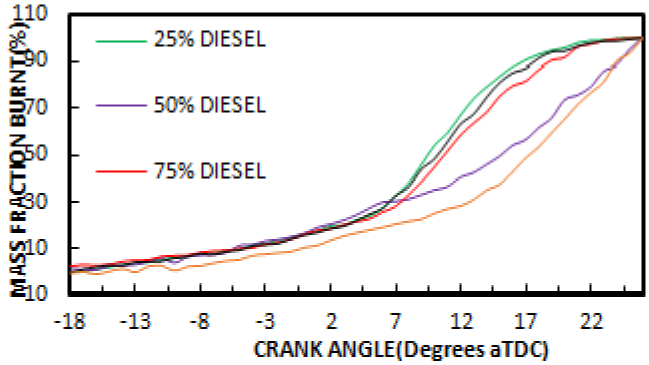

Fig. 10: Variation of MFB aTDC for various diesel-biodiesel blends with respect to crank angle.

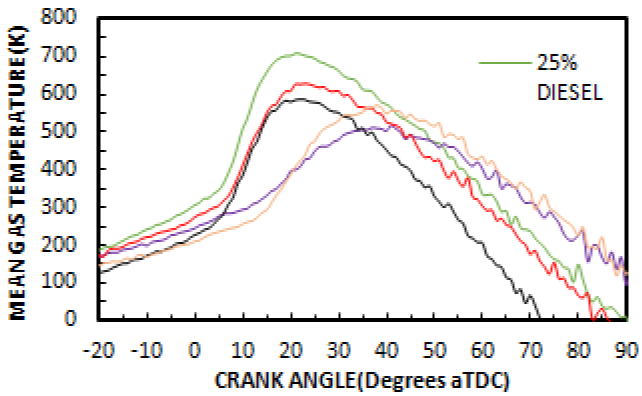

Fig. 11: Variation of MGT various diesel-biodiesel fuel blends with respect to crank angle in degrees.

Fig. 11 shows the variation of MFB and MGT with respect to the crank angle for various diesel-biodiesel blends. It can be noted that in both cases, B75 (25% diesel-75% bio-diesel) had the highest mass fraction burnt and it reached the highest mean gas temperature. The ignition of B75 starts earlier for all the fuel blends, which is accompanied by an early rise in its mean gas temperature with respect to the crank angle, in comparison to other fuel blends.

Comparing the biodiesel-diesel fuel blends

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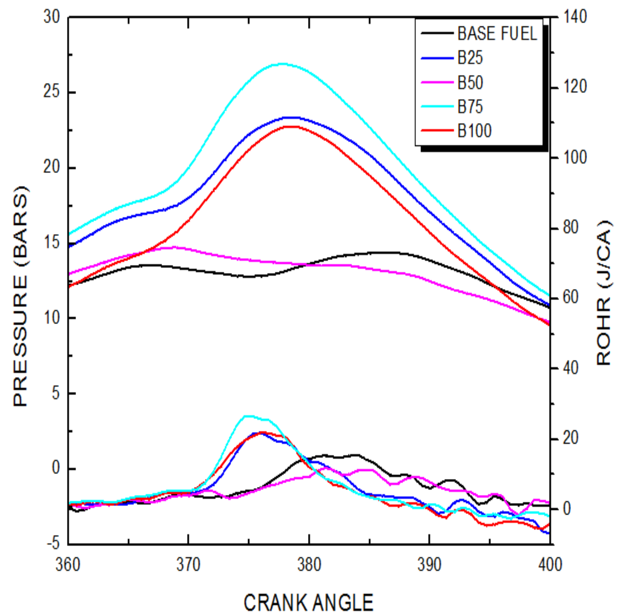

Fig. 12: Variation of the cylinder pressure and rate of heat release with respect to crank angle.

The cylinder pressure and rate of heat release variation with respect to crank angle for blends, in comparison with the diesel fuel, is shown in Figure 11. It is evident that ignition of biodiesel-diesel blends starts earlier as compared to diesel fuel, as discussed earlier.

From the figure, it can also be observed that B75 fuel blend attains the highest peak cylinder pressure corresponding rate of heat release. This is an indicator that this biodiesel-diesel fuel blend is the most appropriate when the engine is running at a constant speed of 1500rpm, and at a compression ratio of 16.

4. CONCLUSION

In this study, the effects of operating conditions such as CR and IT on the engine performance and combustion characteristics of a single cylinder diesel engine running on diesel-biodiesel fuel blends have been experimentally investigated, and compared to those of diesel fuel. Based on the results of this study, the conclusions can be drawn as follows:

BTE is considerably improved with the increase in CR as compared to the baseline compression ratio and decreased CRs. Increasing the CR enhances density of air charge into the cylinder. The more density in the higher angles of spray cone results in increase in amount of air entrainment in the

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spray. Sufficient air in the fuel spray contributes to the complete combustion.

BMEP increases with increased load. At low engine load there is difficulty in atomizing fuel blends that have high density and viscosity. With increasing engine load, there is an increase in engine temperature which results in a faster atomization of the fuel and enhanced combustion, which increases the BMEP.

The IT of 28.8^o CA BTDC gave better results for BTE and BMEP as compared to other ITs. The increased IT resulted in increase in the oxidation time which leads to higher temperatures during the expansion stroke, hence the increase in BTE and BMEP.

The engine efficiency when running on biodiesel and diesel-biodiesel fuel blends is higher as compared to its performance on diesel fuel, due to the higher oxygen content in biodiesel. Biodiesel fuel performs better at low load conditions since the entrained oxygen molecules in the biodiesel enhances combustion at low load/temperature conditions [10].

A comparison of the performance of the diesel-biodiesel blends indicate that B75 attains the highest peak cylinder pressure and has a higher rate of heat release. Therefore, at a CR of 16, B75 fuel blend is the most appropriate to run the CI engine for optimum performance.

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