Available online at www.sciencedirect.com

ScienceDirect

Materials Today: ProceedingsXX (2016) XXX–XXX

www.materialstoday.com/proceedings

PMME 2016

Effect of Compression Ratio, Injection Pressure and Injection Timing on Performance and Smoke Emissions of CI engine Fuelled with Waste Fried Oil Methyl Esters - Diesel Blend☆

Jagannath Hirkude[a]*, Vivek Belokar[b], Jisa Randhir[a]

[a]*Padre Conceicao College of Engineering, Verna, Goa, 403722*
[b]*Goa College of Engineering, Farmagudi, Goa,403401*

Abstract

Objective of this paper is to investigate the effect of Compression Ratio (CR) and injection parameters such as Injection Pressure (IP), Injection Timing (IT) on the performance and emissions of diesel engine. Biodiesel, produced through transesterification from waste fried oil, blended with diesel was used as fuel. Necessary modifications were carried out to achieve variation in input parameters such as Compression ratio, Injection pressure and injection timing. Tests were carried out using different CRs (16, 17, 18, and 19), ITs (24°, 27° and 30° BTDC) and IPs (200, 225 and 250 bar) at 3 kW engine load and 1500 rpm. The results showed that Brake Thermal Efficiency increased (BTE) and Brake Specific Fuel Consumption (BSFC) decreased with increase in CR from 16 to 18. While minor reduction in BTE with increase in BSFC was observed for further increase in CR from 18 to 19. Exhaust Gas Temperature (EGT) found decreased with reduction in smoke opacity (OP) with increase in CR. The best results for BSFC, and BTE were observed at CR of 18, IP of 250 bar and original IT of 27° BTDC. For tested fuel, an increase in IP, IT and CR leaded to increase in EGT and reduction in OP.

Selection and Peer-review under responsibility of International Conference on Processing of Materials, Minerals and Energy (July 29th – 30th) 2016, Ongole, Andhra Pradesh, India.

*Keywords:*Compression ratio, Injection parameters, Performance, Smoke opacity.

* Corresponding author. Tel.: +91-982-234-7923; fax: +91-082-279-1268.
E-mail address: jhirkude@yahoo.com

Selection and Peer-review under responsibility of International Conference on Processing of Materials, Minerals and Energy (July 29th – 30th) 2016, Ongole, Andhra Pradesh, India.

1. Introduction

Alternate fuel like biodiesel for compression ignition engines are earning popularity due to the depleting nature of fossil fuels and adverse environmental effect of exhaust emissions from petroleum fueled diesel engines. Currently elevated cost of biodiesel produced from edible and non-edible oil is main obstruction for its commercialization. Since cost of vegetable oil is increasing rapidly it is major worry for biodiesel producers as feed stock consists of 70% of cost of biodiesel [1]. Depending on source and availability the cost of waste cooking oil is about 60% less than fresh vegetable oil. Waste cooking oil is one of the major wastes generated in hotels and other public eateries [2]. Hence biodiesel from waste fried oil can be used as a suitable alternate for mineral diesel in CI engine after modification of fuel properties [3-6]. Many authors confirmed from their primary experimental investigations that fuel with blend of B40 have better performance over other blend ratios [8-11].

Laguitton et al. studied the effect of reduction in compression ratio (18.4 to 16) on the emissions of a diesel engine [12]. It was found that, either reducing the CR or decreasing IT greatly reduced OP and Nitrogen Oxides (NOx) emissions, although there was a small Carbon Monoxide (CO) and Unburned Hydrocarbon (HC) penalty. Raheman and Ghadge analyzed the performance of diesel engine using biodiesel by varying compression ratios (18, 19 and 20). The results depicted that BTE increased and EGT increased and BSFC decreased with the increase in CR [13].

Puhan et al. examined the effect of variation in IP (20, 22 and 24 MPa) on the performance and emissions characteristics of a diesel engine by using a high linolenic linseed oil methyl ester [14]. It was found that the optimum IP, the BSFC and BTE were found similar to those when using diesel and a reduction in OP, CO, and HC emissions with an increase in NOx emissions was observed compared to diesel.

Bakar et al. [15] investigated the effect of IP on the performance of a Direct Injection (DI) diesel engine at 1600 rpm and they found that the best performance was at 22 MPa IP. Pandian et al. investigated effect of injection systems parameters (IT, IP and nozzle tip protrusion) on performance and emission of twin cylinder diesel engine fuelled with pongamia biodiesel–diesel blend. The results demonstrated that the BSEC, CO, HC and OP were lesser, and BTE and NOx were higher at 2.5 mm nozzle tip protrusion, 225 bar of IP and at 30^0 BTDC of IT [10]. Hyun KyuSuh conducted experimental analysis for a better understanding of the combustion stability and reduction of exhaust emission in low CR engine It was observed that two pilot injections improves combustion efficiency, and these injection strategies operate engine more stably in low CR engine[16].

Suryawanshi and Desphande studied the effects of decreased fuel IT (by 4^o CA) on the emissions and performance of a pongamia oil methyl ester (PME) fueled DI diesel engine [17]. They observed that the addition of PME to diesel fuel caused a significant reduction in OP, HC and CO emissions but a slight increase in NOx emissions with standard IT. Sayin et al. studied the influence of CR and injection parameters such IT and IP on the performance and emissions of a DI diesel engine using biodiesel (5 %, 20 %, 50 %, and 100 %) blended-diesel fuel. Tests were carried out using three different CRs (17, 18, and 19/1), ITs (15^0, 20^0, and 25^0 Crank Angle (CA) Before Bottom Dead Centre (BTDC)) and IPs (18, 20 and 22 MPa) at 20 N m engine load and 2200 rpm. Their results revealed the best results for BSFC, BSEC and BTE were observed at increased the CR, IP, and original IT. For the all tested fuels, an increase in IP, IT and CR lead to decrease in OP, CO and HC emissions while increase in NOx emissions [18].

The effects of operating parameters such as CR and injection parameters like IT and IP on the performance and smoke emissions of CI engine using Waste Fried Oil Methyl Esters (WFOME)-blended with diesel fuel have not been clearly studied. Therefore this study highlights on the effect of CR, IT, IP on the engine performance and smoke emissions of the DI diesel engine by using WFOME-diesel blend. The objective of the present work is to investigate individual effect of IP, IT and CR on performance and smoke emissions of compression ignition engine fuelled with B40 (40 % WFOME + 60 % mineral diesel) at 3 kW electrical load (75 % of full load).

2. Equipment and Materials

2.1 Fuel Preparations

As confirmed by initial investigation carried out by the different authors through literature review, Blend of B40 was selected because of its better performance over other blend ratios. The biodiesel produced through transesterification process from waste fried oil was blended with diesel, procured from the nearby commercial vendor, in a volume ratio of 40:60 to get the biodiesel diesel blend fuel of B40. To ensure homogeneous mixture, blend was prepared just before beginning of experiments. The properties of the fuel blend of B40 and diesel have been determined as per the ASTM standards in an industrial testing and analytical laboratory, established at Goa, India. The properties of B40 are tabulated in Table 1.

Table 1 Properties of B40

Properties	**B40**	**Diesel(No. 2)**	**Method**
Viscosity at 40 ^{o}C (cSt)	5.56	4.320	ASTM D445
Specific Gravity	0.846	0.830	ASTM D941
Calorific Value (kJ/kg)	41400	43000	ASTM D240
Flash Point (^{o}C)	120	70	ASTM D93

2.2 Engine Set Up

This is a single cylinder, direct injection, water cooled, portable diesel engine of 4 kW rating with an alternator coupled to it. The engine was provided with suitable arrangements, which permitted wide variation of controlling parameters. This unit is manufactured by Ind Labs Equipments Bangalore, India. The major specifications of the engine used for investigations are presented in Table 2.

Table 2 Engine Specifications

Make	Kirloskar (India)
Rated Power	3.78 kW at 1500 rpm
Rated Speed	1500 rpm
Number of cylinders	1
Compression ratio	16.5:1
Standard injection timing	27 ^{o} CA BTDC
Standard injection pressure	190 bar
Loading	single phase, 230 V AC alternator

CR of engine was varied from 16 to 19. CR of the engine was increased by (16.5 to 19) removing shims below cylinder block (lowering the cylinder block) and by reducing clearance volume by carrying out piston surface machining to reduce piston cavity. CR was reduced (16.5 to 16) by inserting shims by raising the cylinder block to increase clearance volume. The thickness of the shim was measured using the digital verniercaliper which was having accuracy of 0.01 mm. The fuel IP was varied from 200 to 250 bar. The variation in IP was achieved by adding and removing shims under spring of nozzle. The pressure setting of nozzle was carried out at local BOSCH centre. The IP of each injector was measured by standard BOSCH nozzle tester. The fuel IT was advanced from 27^{o} to 30^{o} BTDC and retarded from 27^{o} from 24^{o} BTDC.

The engine was coupled with a single phase, 230 V AC alternator. The alternator was used for loading the engine through a resistive load bank. The load bank consists of eight heaters of 500 W each. The engine was loaded gradually from 0.5 kW to 3 kW in step of 0.5 kW. All tests are carried out at 3 kW (75%) electrical loading. The engine was first tested with diesel fuel for no load condition for 20 min at rated speed of 1500 rpm until lubricating oil temperature rose to around 80°C. The same conditions were maintained throughout the experiments for different test runs. The specific fuel consumption was computed by measuring the time taken for a fixed volume of fuel that flows into the engine. The current and voltage was measured by using ammeter and voltmeter. The alternator was calibrated to find out its conversion efficiency. The brake power was calculated by taking help of electrical power produced and alternator efficiency. The engine speed (rpm) was measured by electronic digital counter. The readings were taken three run times for each run and the average value was used to calculate performance and emission parameters. The performance parameters, BTE and BSFC were calculated from measured data. OP was measured by using smoke meter (Make :Netel, India; Model Name: NPM-SM-111B). OP was measured in HSU (Hartridge Smoke Unit). Accuracy of smoke meter is +/- 1 %.

All tests were conducted at electrical loading of 3 kW (75 % of full load capacity). All together 36 tests were conducted by varying CR at four levels,IP at three levels andIT at three levels. All tests were conducted for fuel blend of B40. In this study performance and smoke emission analysis at fixed blend and load were discussed. Uncertainty analysis of measured and calculated parameters is presented in Table 3.

Table 3 Uncertainty analysis.

Quantity	Accuracy	Quantity	Uncertainty
Viscosity	± 0.2 cSt	Brake power	± 2 %
Time	± 0.1 S	BTE	± 2.15 %
EGT	± 1 °C	BSEC	± 2.15 %
Smoke Opacity	± 1 HSU	Specific Gravity	±1.5 %
Calorific value	± 0.15 MJ/kg	-	-
Speed	± 10 rpm	-	-
Current	± 0.1 A	-	-
Voltage	± 5 Volts	-	-
fuel measurement	± 1 cc	-	-

3. Results

3.1 Brake Thermal Efficiency

BTE at different CRs, IPs and ITs is depicted in Fig. 1 and 2. As seen in figure 1, for all IPs, the BTE increases with increase in CR (from 16 to 18) and decreases marginally from 18 to 19. At IT of 27^0 BTDC, increase CR from 16 to 17 and from 17 to 18 increased BTE by 2.61 %, and 3.54 % respectively. Further, increase in CR from 18 to 19, leads towards decrease in BTE by 0.384 %. At injection pressure of 250 bar increase in compression ratio 16 to 17 increased BTE by 2.7 %, from 17 to 18 by 3.78 % and from 18 to 19 by - 0.98 %. Initial increase in BTE with increase in CR could be attributed to enhancement of density of intake air and reduction in ignition delay associated with it. Minor reduction in BTE beyond compression ratio of 18 could be endorsed to insufficient combustion space because of further reduction in clearance volume. Best compression ratio in terms of BTE was found to be 18.

As seen in figure 2, for all injection timings the BTE increases with increase in IP. This could be because of improved spray characteristics, better atomization and good mixing with air at higher injection pressures. This will improve efficiency because of enhancement in combustion process. Too high IP leads to finer diameter of fuel droplet; this affects the spray pattern and penetration. Therefore only minor increase in BTE was observed from 225 to 250 bar IP for B40 for all ITs and CRs. Other reason for negligible improvement in efficiency (beyond 225 bar of IP) could be faster velocity of fuel jets caused most fuel particles to hit wall of combustion chamber where fuel particles got cooled which would result in incomplete combustion. At 27° BTDC, with increase in IP from 200 to 225 bar average BTE increased by 3.41 %. Further, increase in IP from 225 to 250 leads to increase in BTE just by

0.88 %. At CR of 18, with increase in IP from 200 to 225 bar average BTE increased by 4.87 % and with increase in pressure from 225 bar to 250 bar average BTE increase was just by 0.95 %.

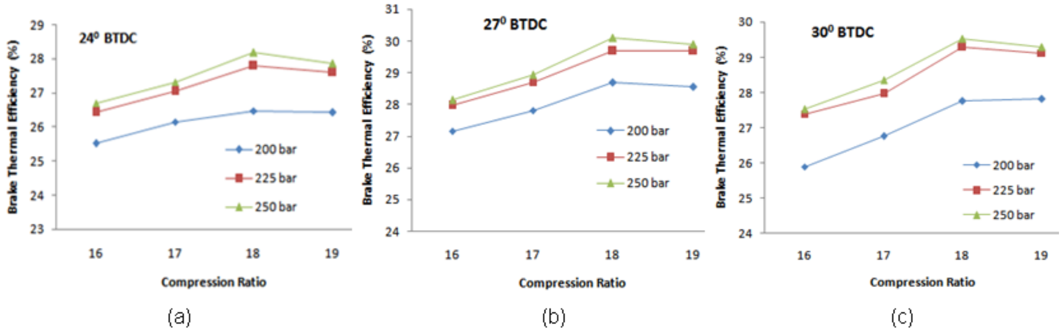

Fig. 1 Brake thermal efficiency Vs Compression ratio at varying IP

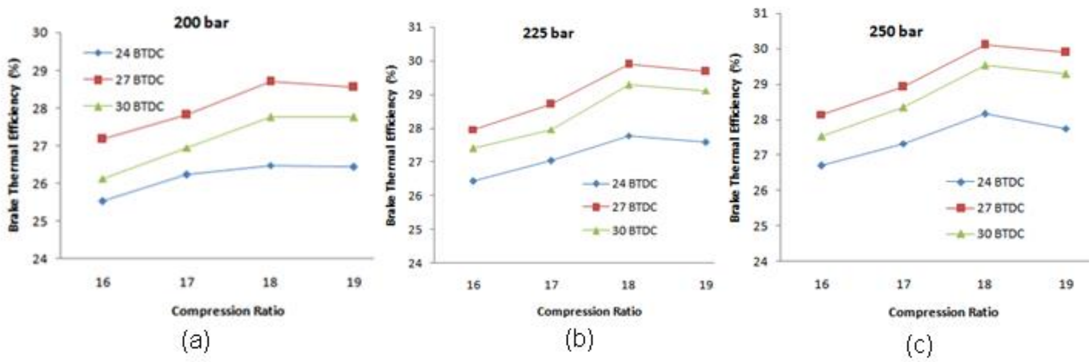

Fig. 2 Brake thermal efficiency Vs Compression ratio at varying IT

3.2 Brake Specific Fuel Consumption

The change in BSFC at different CRs, IPs and ITs is observed in Figures 3 and 4. As illustrated in Figures the BSFC generally decreased with increase in CR from 16 and 18 for all IPs and ITs. This could be attributed to higher brake effective pressure and temperature with increase in CR which leads to higher effective power and hence lower BSFC. From compression ratio 18 onwards minor increase in BSFC was observed. The possible reason for this trend could be insufficient combustion space (because of very less clearance volume at higher CR), which leads towards slight reduction in effective power. At, 250 bar with increase in CR from 16 to 17 and 17 to 18, reduced BSFC by 2.6% and 3.6% respectively. Whereas further increase in CR from 18 to 19 leads towards increase in CR by 1.01%. At IT of 27^0 BTDC, increase CR from 16 to 17 and from 17 to 18 decreased average BSFC by 2.44 % and 3.7% respectively. Average BSFC increased by 0.68% with increases in further CR from 18 to 19.

With advancement of IT from 27^0 BTDC to 30^0 BTDC the ignition delay would be longer and flame speed may be lower. These cause reduction in brake power. But retardation of IT from 27^O BTDC to 24^O BTDC leads later combustion and therefore pressure rises at later stage of expansion stroke. These leads in reduction in effective pressure which could be responsible for reduction in brake power. Reduction in brake power results in increase in BSFC. At IP of 250 bar, with decrease in IT from 27 to 24O BTDC average BSFC decreased by 6%. Advancing IT from 27 to 30O BTDC increased BSFC by 2.01%. At CR of 18 with decrease in IT from 24 to 27^o BTDC leads towards decrease in average BSFC by 6.95% While further increase in IT from 27 to 30O BTDC resulted in increase in BSFC by 2.37%. Figure 6 demonstrates change in BSFC at different injection pressures for all CRs and ITs. The reduced BSFC values were obtained with increase in IP (from 200 to 225 bar). This would be because of finer atomization and improved mixing. Marginal decrease in BSFC was observed with increase in IP from 225 to 250 bar because of minor increase in BTE. At CR of 18 with increase in IP from 200 to 225 bar, average BSFC decreased by 4.45% and with increase in pressure from 225 bar to 250 bar average BSFC reduced just by 0.99%. At IT of 27^0 BTDC increase in IP from 200 bar to 225 bar and from 225 bar to 250 bar average BSFC reduced by 3.46% and 0.66% respectively.

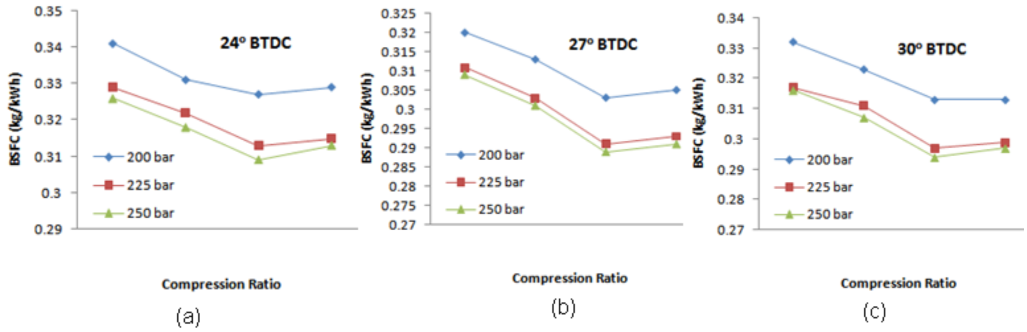

Fig. 3 Brake specific fuel consumption Vs Compression ratio at varying IP

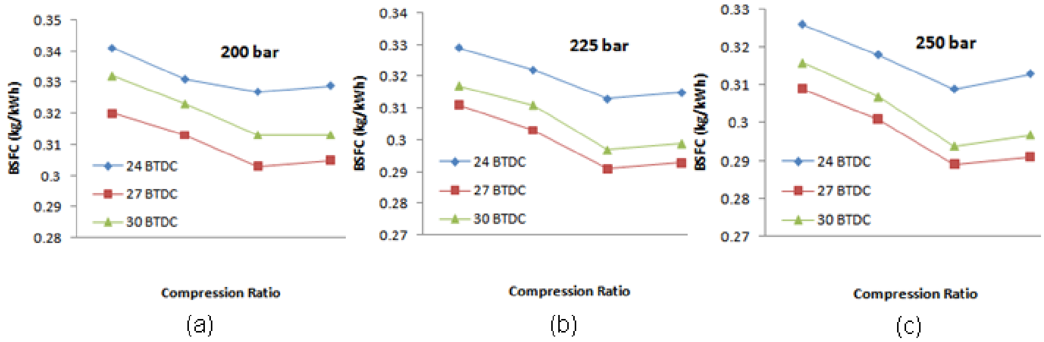

Fig. 4 Brake specific fuel consumption Vs Compression ratio at varying IT

3.3 Exhaust Gas Temperature

The variation of EGT for different CR, IP and IT are shown in figure 5 and 6. At higher CRs increase in EGT were observed, the possible reason for this could be higher operating temperature at elevated CRs. As illustrated in Figure 8, at all IPs decrease in EGT was observed with increase in IT. This could be because of advancement of injection timings may cause earlier start of combustion relative to TDC which increases chances of complete combustion and reducing the EGT. As illustrated in Figure 6, there was increase in EGT with increase in IP (from 200 to 250 bar). The increase in EGT with increase in IP may be attributed to the increased cylinder pressure due to improved combustion of fuel as a result of better atomization.

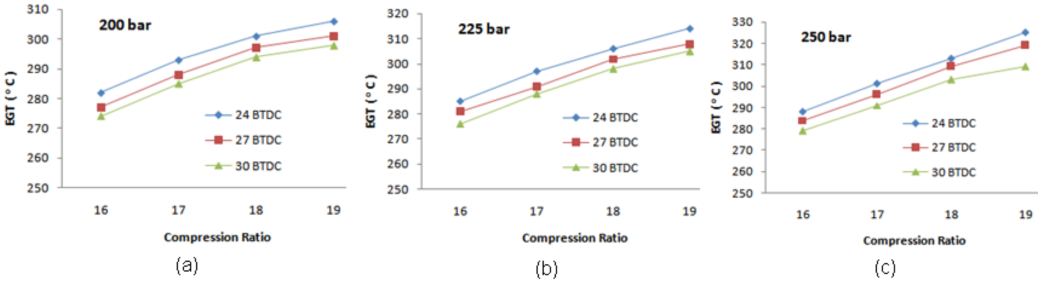

Fig. 5 Exhaust gas temperature Vs Compression ratio at varying IT

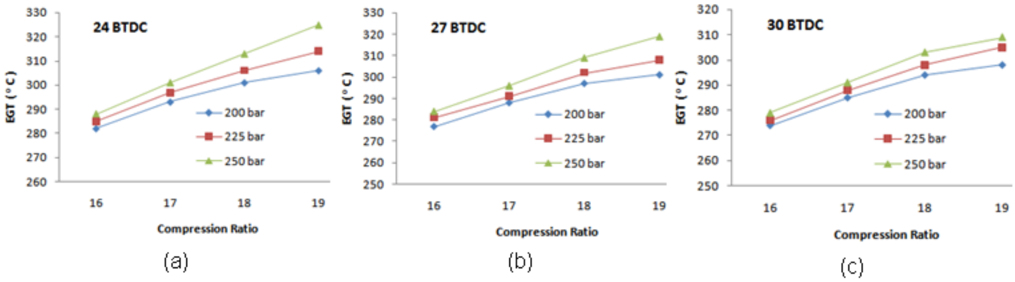

Fig. 6 Exhaust gas temperature Vs Compression ratio at varying IP

3.4 Smoke Opacity

The interactive effect of CR, IP and IT on smoke opacity are depicted in Figures 7 and 8 respectively. For all IPs and ITs, smoke opacity at higher CRswere observed lesser than at lower CR. This could be because of better combustion efficiency due to higher temperature and pressure at higher CRs. At IP of 250 bar, with increase in CR from 16 to 18 reduced average smoke emissions by 6.55 %. At IT of 27^{o} BTDC with increase in CR from 16 to 18 reduced average OP by 6.85 %. Figure 10 explains variation OP with IP for different ITs and CRs. Decrease in OP with increase in IP was observed. This could result of finer particle diameter because of increase in IP. Therefore, fuel-mixture would become better through combustion period which leads towards less smoke emission. At IT of 27^{o} BTDC, increase in IP from 200 bar to 250 bar reduced OP by 7.23 %. At CR of 18, increase in IP from 200 bar to 250 bar reduced smoke emission by 6.55 %.

Because of advancement of ITs from 24^{o} BTDC to 30^{o} BTDC,OPwere reduced for all IPs (Figure 8). This could be attributed to the following facts: advancement of injection timing means extended ignition and decrease in charge temperature and pressure. At CR of 18, advancement of injection timing from 27 to 30^{o} BTDC reduced smoke emission by 3.39 %. While retarding IT by 27 to 24 ^{o} BTDC increased OP by 3.38 %. At injection pressure of 250 bar, advancement of injection timing from 27 to 30 ^{o} BTDC reduced smoke emission by 3.03 %. While retarding IT by 27 to 24 ^{o} BTDC increased OP by 3.34 %.

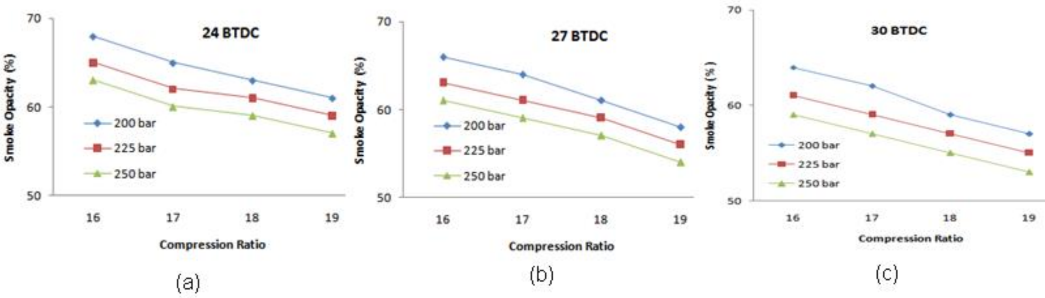

Fig. 7 Smoke opacity Vs Compression ratio at varying IP

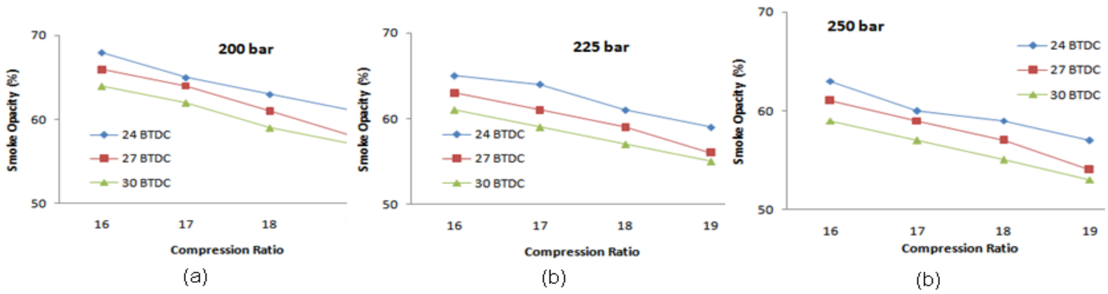

Fig. 8 Smoke opacity Vs Compression ratio at varying IT

4. Conclusions

In this study biodiesel from waste fried oil blended with mineral diesel (B40) was used to investigate effect of significant operating parameters like compression ratio, injection timing and injection pressure on performance and emission of compression ignition engine. Based on the results of this study the following conclusion can be drawn.

1. Increase in CR increases (form 16 to 18) BTE with B40 for all IPs and ITs. Beyond CR of 18 decrease in trend in BTE was observed. BTE found increases with increase in IP. Maximum BTE was observed with engine original IT of 27^{O} BTDC.
2. Initial decrease in BSFC was observed with increase in CR (from 16 to 18) and then starts decreasing (From 18 to 19). Minimum BSFC was observed at original injection timing of 27^{O} BTDC. With increase in IP there was decrease in BSFC. The intensity of decrease in BSFC was substantial from 200 bar to 225 bar. Intensity of decrease in BSFC from 225 bar to 250 bar injection pressure was marginal.
3. EGT found increasing with increase in CR and IP while EGT observed decrease with increase in ITs.
4. Smoke emissions were reduced at higher CRs. For advancement of IT these emissions found reduced. Decrease in OP with increase in IP was observed.
5. Best results in terms of performance were found at a CR of 18, IP of 250 bar and IT of 27^{o}BTDC. Best results in terms of smoke emissions were observed at CR of 19, IP of 250 bar and IT of 30^{o}BTDC.
6. By properly controlling compression ratio, injection timing and injection pressure performance can be improved and smoke emissions can be controlled by using blend of alternate fuel like biodiesel from waste fried oil.

References

[1] J. B. Hirkude, A. S. Padalkar, Applied Energy. 90 (2010) 68–72.
[2] P. Shivakumar, B. R. SrinivasaPai, R. Shrinivasa,Applied Energy.88 (2011) 2344–2354.
[3] S. Zheng, S. M. Khates, M. A.Dube, Biomass Bioenergy. 30 (2006) 267–272.
[4] A. V. Tomasevic, S. S. Siler-Marinkovic, Fuel Process Technology. 81 (2006) 1–6.
[5] M. Canakci,N. Ozsezen, G.U. Journal of Science. 18 (2005) 81–91.
[6] Z. Utlu, M. S. Kocak,Renewable Energy. 33 (2008)1936–1941.
[7] A. K. Agarwal,A.Rajamanoharan, Applied Energy. 86 (2009) 106–112.
[8]J. B. Hirkude, A. S. Padalkar, Fuel. 119(2014) 266–273.
[9] H. Raheman, A. G. Phadatare, Biomass Bioenergy. 27, (2004) 393–397.
[10] K. Sureshkumar, R. Velraj, R. Ganesan, Renewable Energy. 33 (2008)2294–2302.
[11] M. Pandian, S. P. Sivapirakasam, M. Udayakumar, Applied Energy. 88 (2011) 2663–2676.
[12] C. Laguitton, T.Crua, T. Cowell, M. R. Gold, Energy Conversion and Management. 48 (2007) 2918-2924.
[13] H. Raheman, S.V. Ghadge, Fuel. 87 (2008) 2659-2666.
[14] S. Puhan, R. Jegan, K. Balasubbramanian, G. Nagarajan,Renewable Energy. 34 (2009) 1227-1233.
[15] R.A. Bakar,S. Ismail, A.R. Ismail, American Journal of Applied Science. 5 (2008) 197-202.
[16] Hyun KyuSuh,Applied Energy. 88 (2011) 5013–5019.
[17] J.G.Suryawanshi, N.V. Desphande, SAE Technical Paper. 01(2005)3677.
[18] CenkSayin,MetinGumus,Applied Thermal Engineering. 31 (2011) 3182-3188.