Assessment of Effect of Load and Injection Timing on the Performance of Diesel Engine Running on Diesel-biodiesel Blends

Rajesh Kumar Saluja *[‡], Vineet Kumar**

* Department of Mechanical Engineering, IKG Punjab Technical University, Jalandhar, Punjab, India.

** Department of Mechanical Engineering, Rayat & Bahra Institute of Engg. & Biotech., Kharar, Punjab, India

(rksaluja@amity.edu, prabhakarvineet@yahoo.com)

[‡] Corresponding Author; Rajesh Kumar Saluja, Amity School of Engineering & Technology, 580, Bijwasan, New Delhi. India.
Tel: +91 28062106,

rksaluja@amity.edu

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Abstract- The present work was undertaken to analyze the performance and emission characteristics of the biodiesel produced from Jatropha curacs (JB100) and Pongammia (Karanja) (KB100) and their respective blends(JB20, JB50, KB20 and KB50) and to compare with those of the diesel. Tests were performed on constant speed, air cooled, single cylinder DI diesel engine that is commonly used in agricultural sector. The effect of blending biodiesel with diesel, load variations and variation of injection timings were studied on the Brake thermal efficiency (BTE), Brake specific fuel consumption (BSFC), smoke emissions, NOx emissions, HC emissions and exhaust gas temperatures (EGT). The maximum BTE of 28.6% was recorded for JB20 for advanced injection timing, however BTE of diesel was highest at low loads where as JB20 had highest efficiency at high loads and all injection timings. BSFC consumption for JB100 and KB100 was noticed to be about 20% and 28% than that of diesel at normal injection. Smoke emissions were found to be reduced by upto 47% for JB100 and 44% for KB100 when compared to diesel for advanced injection timing. EGT of diesel were lower than those with the 20% and 50% blends but higher than those of pure biodiesels. Advancing the injection timing increased BTE and decreased BSFC, Smoke and HC emissions. NOx emissions, however, increased due to advanced injection timing.

Keywords Jatropha biodiesel, Karanja biodiesel, Engine emissions, Engine performance, Injection timing.

1. Introduction

The most widely used engines in transportation, agricultural and industrial sectors are diesel engines. The research is going worldwide to enhance the performance and to lower the harmful exhausts of the diesel engines. The fear of shortage of crude petroleum, the fluctuations in the crude oil prices and the sensitive politico-economic conditions of the petroleum exporting nations is further fuelling the research for the alternative to petroleum diesel fuel. One of the most researched alternatives to the diesel fuel for the diesel engine is biodiesel. Biodiesel is usually prepared by the reaction of vegetable oil with ethanol or methanol in presence of an alkaline catalyst known as transesterification reaction [1, 2]. The biodiesel so formed has properties similar to the petroleum diesel.

Lot of research has been done [3-8] to prove the utility of biodiesels in the diesel engine. Combustion, performance and emission studies have been conducted and concluded that biodiesel is a good replacement to the conventional diesel fuel. Various sources of the biodiesel are mainly the tree based oils usually derived from the crops such as cotton, sunflower, neem, soybean, peanut, jatropha, palm, coconut, karanja, rape, mustard, linseed, caster, etc. [9]. In Indian scenario, the focus is more on non edible oils produced from jatropha and karanja [10]. A lot of studies have been performed on Jatropha and Karanja biodiesels and their blends with petroleum diesel [11-19]. In these studies, it was found that there is significant role of the various factors in performance of biodiesel. These factors are the chemical structure of biodiesel, blend ratio, speed, load, injection pressure, injection timing, and compression ratio.

Sayin C et al. [20] conducted experiments and reported in their experiments that while CO, smoke and unburnt HC reduced due to advancing the start of injection, the value of NOx increased. Similar results were found by Sayin C et al. [21] in yet another experiment using ethanol blended diesel. Habibullah [22] studied the effects of palm and coconut biodiesel combination blends, with conventional diesel. In their results, they reported the increasing trend of BSFC and NOx emissions showed when proportion of biodiesel in the blend was increased whereas Brake Thermal efficiency (BTE) showed decrease for the same. They also concluded that adding palm oil biodiesel to coconut oil biodiesel further improves the performance and emissions. Chauhan et al. [23] conducted comparative analysis of Karanja biodiesel with the conventional diesel. They reported that karanja biodiesel has efficiency 3-5% lower than the conventional diesel. Their study also recorded lower HC emissions and higher NOx emissions while using biodiesel. Gaurav Paul et al. [24] compared both experimentally and numerically jatropha biodiesel and conventional diesel and found that, both, in simulations and experiments diesel was having better thermal efficiency than Jatropha biodiesel. They too reported increase in NOx and CO_2 and reduction in smoke and while using Jatropha blends.

Elango and Senthil Kumar [25] investigated the effect of blending the jatropha biodiesel with petroleum diesel. They reported that upto 20% blending of biodiesel with normal diesel does not require any engine modification. Also in their studies, the B20 showed maximum efficiency of all the blends tested but lesser than that of the diesel. They also reported increase in NOx as well as smoke opacity while using the blends. In a study, Chiatti et al. [26] considered the outcome of blending biodiesel with petro-diesel on a small car engine. Their results pointed the same performance and reduced emissions could be obtained upto 20% blends of biodiesel with diesel. They also studied the effect of various injection strategies and found that slight delay in the injection timings helps to reduce the NOx.

Palash et al. [27] conducted experiments to find the influence of speed as well as blending on a CI engine using upto 20% blends of jatropha biodiesel. It was found that the NOx increases by 12% for JB20 (jatropha biodiesel 20% + 80% diesel) blend. EGT also increased with each of the blends when compared to diesel. Altaie et al. [28] performed tests using palm oil biodiesel blends with methyl oleate . The effects of speed and load were calculated. They reported that high viscosity and low calorific value had quite an influence on BSFC and torque. They also concluded that reduction in CO and HC emissions were caused due to higher value of cetane number of biodiesel and the oxygen content in it. Increment in NOx was also reported in their work.

Dhar and Agarwal [29] tested 10%, 20% and 50% blends of biodiesel on a CRDI engine using multiple injections. They reported that advancing the timing of injection had a positive influence on the BTE. They concluded that upto 20% blends of the biodiesel can improve the performance and emission characteristics of the diesel engine. Mohite et al. [30] calculated the emissions and performance of diesel engine using upto 30% blends of karanja biodiesel with petroleum diesel. They studied the effect of blending and varying the load and found B20 blend caused reduced smoke and was more efficient.

This study aims to find out:

1. The effect of blending diesel with biodiesel derived from Jatropha and Karanja to compare the performance of the two biodiesels.
2. To study the combined effect of load and injection timing on the performance parameters (BSFC and BTE) and emission parameter (Smoke, NOx, EGT and unburnt HC) of diesel engine.

It was decided to carry over the study on the biodiesels and their blends produced from second generation sources, Jatropha and Karanja, which have been recognized as the potential sources of biodiesel in Indian biodiesel mission[10]. The outcomes of varying the load applied and injection timing were studied on BSFC, BTE, smoke opacity, exhaust gas temperature (EGT), NOx emissions and unburnt hydrocarbons (HC) for each of the blend.

2. Materials and Methods

2.1. Biodiesels and blends

The biodiesel samples were produced from jatropha oil and karanja oils by catalytic transesterification reactions using KOH as a catalyst. The commercial diesel was purchased and the blends were prepared with 20% and 50% proportion of each biodiesel in the blend. The following samples were tested: *Diesel, KB20, KB50, KB100, JB20, JB50 and JB100*. The important properties of all the blends and biodiesel were tested as per the available standards and are given in table 1.

2.2. Experimental Setup and procedure

The engine selected for the experiments was Kirloskar make CAF1 Constant speed (1500 rpm), single cylinder DI engine having rated power of 4.5 kW. Table 2 shows the specifications of the engine and fig.1 shows the schematic of the set-up. The engine was connected to two storage tanks, one each for diesel and biodiesel. The engine was also connected to the alternator whose supply was connected to a control panel consisting of total 4.5 kW load lamps. The control panel also consisted of a digital temperature indicator, a digital voltmeter and a digital ammeter. The digital temperature indicator was connected to the sensor at exhaust manifold of the engine to measure the exhaust gas temperature. Smoke opacity was measured using AVL 437 smoke analyser and AVL digas 4000 gas analyser was used for measurement of unburnt HC and NOx emissions. The fuel being consumed was measured using burettes and stopwatch. The spill method was used to measure injection timing. The protractor of resolution 0.5^o was used to measure crank angle and was fixed with the front pulley connected to the engine. The desired injection timing was obtained by adjusting the shims under fuel pump flange. The load was varied by the switching the load cells according to the desired value. Before testing the biodiesels or their blends, the engine was always run initially on diesel and after some time the fuel valve of biodiesel tank was closed and the one for the biodiesel was opened. The readings were noted only after assuring the engine is operating under constant conditions. Prior to the acquisition of the actual test data, the engine was warmed up. The temperature of the lubricating oil and that of the exhaust pipe close to the exhaust manifold were monitored to confirm that the warm-up period has ended before capturing the test data. It was decided to conduct the experiments under nearly constant ambient conditions, so as to allow easy comparison. The readings were taken in triplicate for each fuel under every condition and their average reading was used for the calculations.

Table 1. The physico-chemical properties of biodiesel blends

Properties	**Test methods**	**Diesel**	**KB20**	**KB50**	**KB100**	**JB20**	**JB50**	**JB100**
Density (kg/m^3)	ASTM D 4052	844	856	868	891	852	863	878
Kinematic viscosity @40° C (cSt)	ASTM D 445	3.84	4.10	4.68	5.64	3.97	4.35	5.11
Gross calorific value (MJ/kg)	ASTM D 240	44.3	42.8	41.6	38.1	43.08	42.37	39.2
Net calorific value (MJ/kg)	-	41.42	39.5	38.7	34.8	40.2	39.1	36.3

Table 2. Technical specifications of the engine

Engine manufacturer	Kirloskar Oil Engines Limited, Rajkot (India)
Engine type	Single cylinder, vertical, 4-stroke diesel engine
Type of cooling	Air cooled
Bore and stroke (mm)	80x110
Maximum rated speed (RPM)	1500
Brake horse power (BHP)	6HP (4.41 KW) at 1500 RPM
Compression ratio	17.5 : 1
Type of injection	Direct injection
Injection timing	23° btdc
Lubrication oil	SAE 30/SAE 40
Governing class	“A2/B1”

3. Results and Discussion

Fuels used for the experiments were petroleum diesel, biodiesels (JB100 and KB100) and their various blends (JB20, JB50, KB20, KB50). The measurements were made for the exhaust gas temperatures; exhaust analysis was done for measurements of smoke opacity, unburnt hydrocarbons (HC) and NOx. BSFC and BTE were also evaluated.

The readings for all the parameters were taken at three different loads (40%, 70%, 100%) and for normal injection timing (23° BTDC), advanced injection timing (28° BTDC) and retarded injection (18° BTDC) for each load.

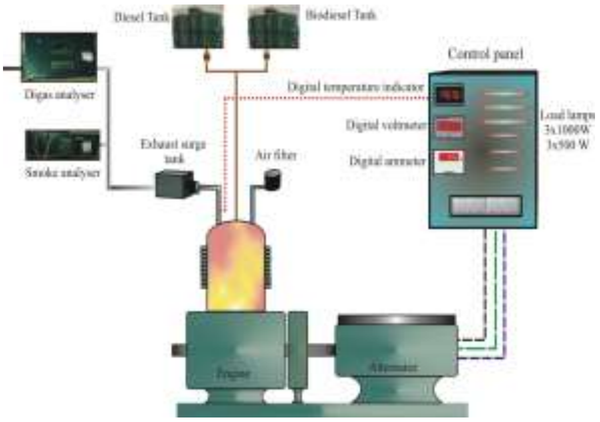
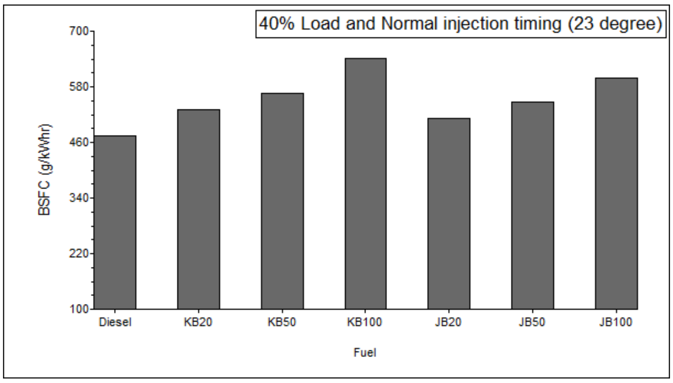


Fig. 1 Schematic of the engine setup

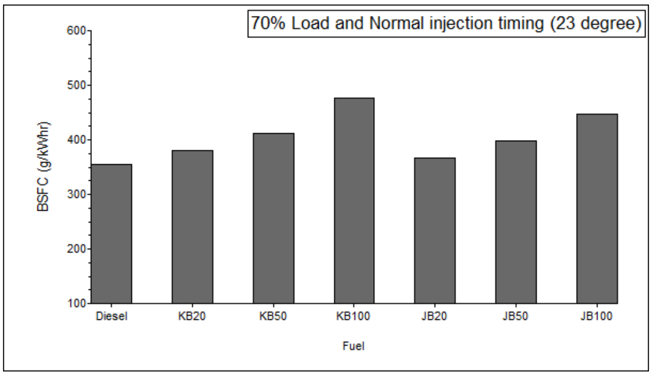
3.1 Performance analysis

3.1.1. Brake specific fuel consumption (BSFC) at normal injection

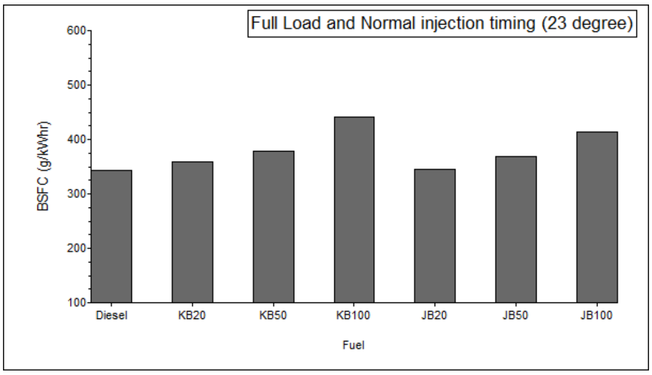
The BSFC means the fuel consumed divided by the brake power produced. BSFC may be affected by combustion characteristics, density, viscosity and calorific value and the oxygen present in the fuel [28, 31, 32]. Results for the BSFC for 40%, 70% and full load at normal injection timing (23°) are shown in figs 2a-c. Pure diesel has minimum BSFC at all loads. Also, increasing amount of biodiesel in the blend causes increase in the BSFC. This can be associated to the loss of calorific values and increase in viscosity and oxygen present in the fuel [31]. For KB20, there was 4.3% increase in BFSC consumption whereas for JB20, the increase was less than 1% at full load and normal injection. At 50% blends of Jatropha and Karanja, JB50 and KB50, the increase in BSFC when compared with diesel was 7.2% and 10.1% respectively. However, BSFC consumption for JB100 and KB100 was noticed to be about 20% and 28% higher than that of diesel at normal injection and full load.



(a) At 40% load



(b) At 70% load .



(c) At full load

Fig. 2a-c. BSFC for various fuels tested

Another observation is that at full load, JB20 blend has bsfc almost same as diesel. Jatropha biodiesel/blends have BSFC slightly lower than that of the Karanja biodiesel and their corresponding blends. Lower calorific value and higher viscosity of karanja methyl ester may be the reason behind it.

3.1.2 Variation of Brake specific fuel consumption (BSFC) with load and injection timing

The trends shown in fig.3 reflect the decrease in bsfc for all the blends with increase in the load. The decrease in bsfc is steeper for load variation from 40% to 70%. The BSFC decreases by 25% - 27% for various fuels tested. When there is increase in the engine load, the efficiency increases and ratio of friction to brake power goes down [33], which leads to decrease in BSFC.

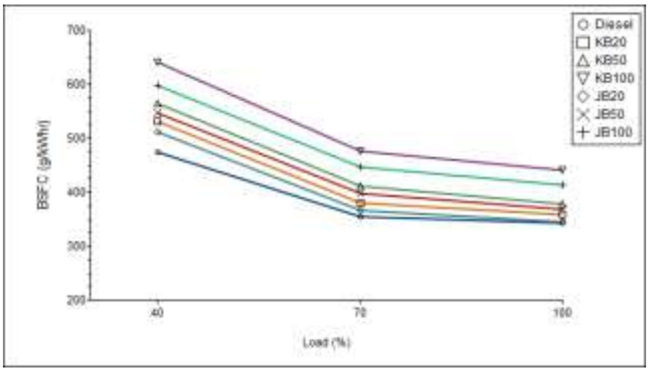
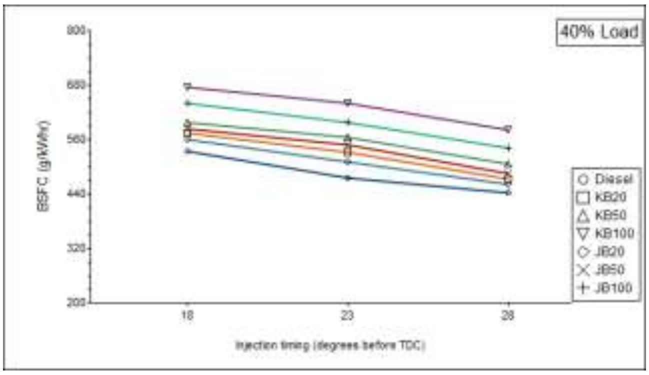
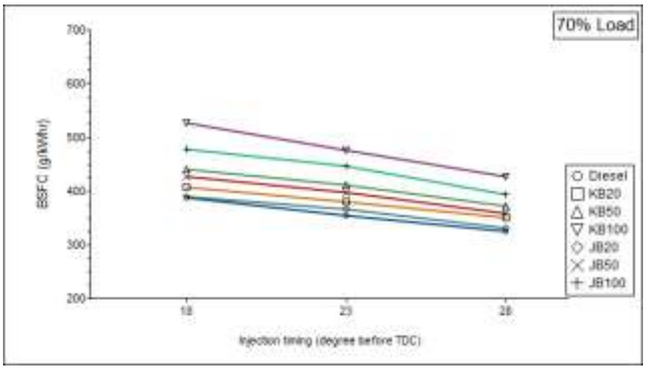


Fig. 3 Effect of load on BFSC

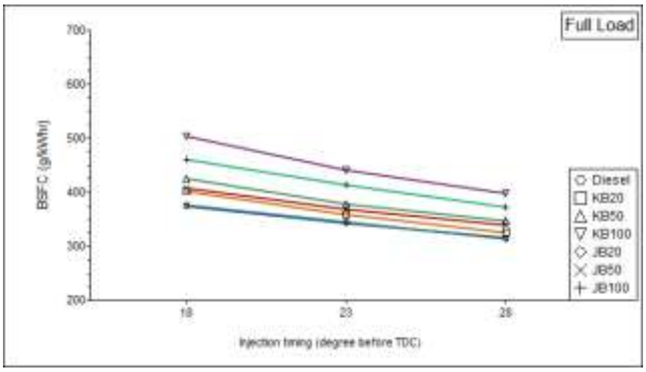
When the load is increased from 70% to 100%, the further decrease in bsfc is very less. The decrease is minimum for diesel (3%) and maximum for KB50 (7.8%). This may be due to decrease in fuel conversion efficiency at higher load, which may reduce the effect of increase in efficiency. Figs 4a-c show the consequence of deviation of injection timing on bsfc.



(a) At 40% load



(b) At 70% load



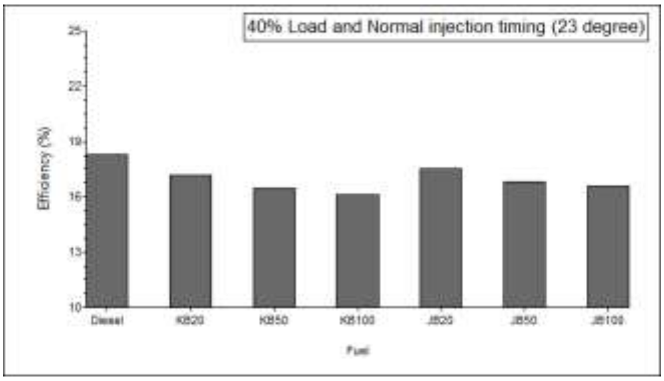
(c) At full load

Fig. 4a-c Variation of BSFC with start of injection at different loads

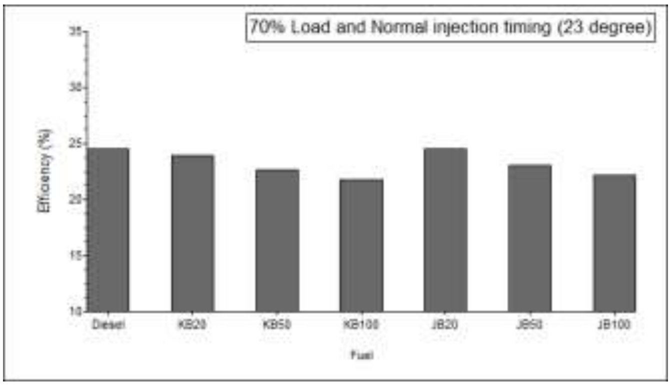
When the start of injection is advanced by 5° (23° to 28° btdc), there is reduction 7-12% in bsfc for the fuels tested where as retarding the start of injection by 5° (from 23° btdc to 18° btdc) causes the rise in bsfc by 7-14% for the fuels. Advancing the start of injection leads earlier start of combustion which further leads to more fuel burning before TDC due to which the combustion maximum pressure occurs closer to TDC and more power produced for the same fuel. On the contrary, retarding injection timing causes late combustion, and rise in pressure occurs during the expansion stroke resulting in a lower effective pressure for doing the work. [21, 34]

3.1.2. Brake thermal efficiency (BTE) at normal injection

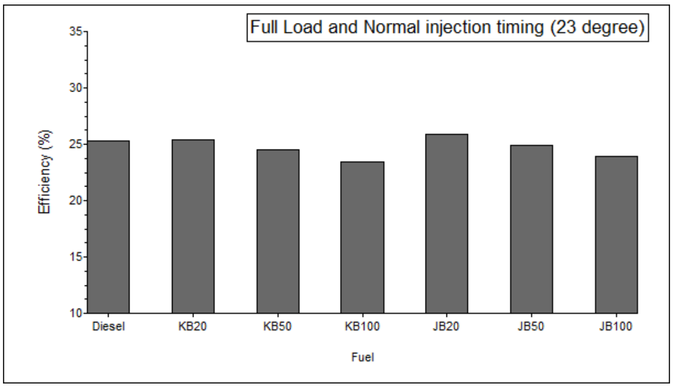
BTE is appropriate factor to judge the performance of tested fuels due to their different calorific values. From the analysis of BTE with blends, it was observed that blending of biodiesel in diesel causes the drop in efficiency with 20% blend of jatropha biodiesel as an exception, for which the efficiency is higher than diesel. The trends are shown in figs.5a-c. It can be observed that at lower loads diesel fuel is more efficient than the pure biodiesel or any of their blends. The efficiency of pure diesel at low loads and normal injection is 18.3% which is higher than pure jatropha biodiesel (16.6%) or pure karanja biodiesel (16.1%) and all the blends. The efficiency reduces with increase in biodiesel in the blend. Lesser heating value of the fuel and higher viscosity of the biodiesels may be the reason for this reduction. However at 70% load and full load, 20% jatropha blend (JB20) is slightly more efficient (25.8%) than pure diesel (25.2%). At full load KB20 has efficiency 25.4% which is also slightly more than diesel. The higher efficiency of 20% blends may be due with the oxygen present in the biodiesels and the better lubricating properties of the biodiesel [35] which leads to better combustion. The difference in efficiencies of the fuel samples at high loads is lesser than that at the mid loads. This can be due to higher fuel consumption and higher temperatures at high loads.



(a) At 40% load



(b) At 70% load



(c) At full load

Fig. 5a-c. BTE for various fuels

3.1.4 Variation of Brake thermal efficiency (BTE) with load and injection timing

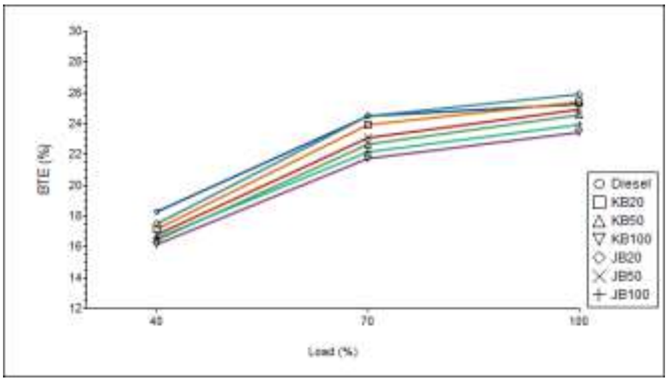
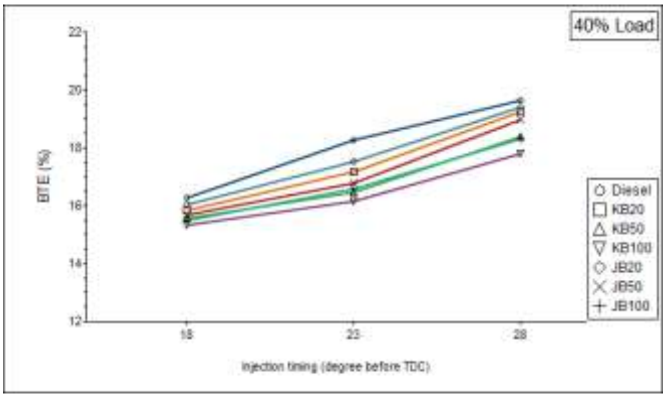


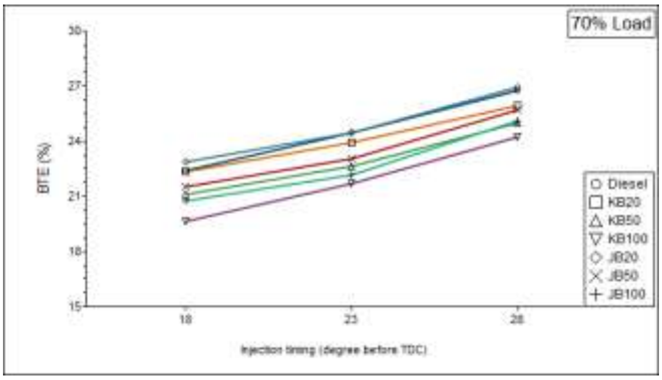
Fig. 6 Effect of load on BTE

Fig 6. Shows how BTE is affected when the load applied is varied. It is indicated in the fig. 6 that all fuels tested give maximum BTE at full loads. The reason for higher efficiency at maximum load is that there is lesser loss of power at that time and more fuel is being burnt to produce more power. For diesel fuel at normal injection timing, the efficiency at full load is 6.9 % more than that at 40% load. For JB100 and KB100 this difference is 7.2% and 8.4% respectively. Another point that can be observed from the results is that change in efficiency from 40% loads to full load is more in case of ignition advance. It is observed in this study that increase in efficiency from 40% to full load for diesel, KB100 and JB100 is 5.2% and 6.0% respectively for retarded timing and the corresponding values for advanced injection timing are 8.12 % and 8.4% respectively.

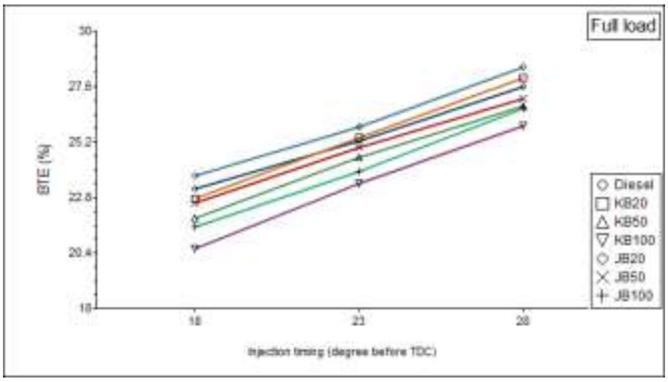
Figs.7a-c. show the trends for BTE of the diesel engine when injection timing is varied at 40%, 70% and full load respectively. It can be seen that for all loads, advancing the ignition improves the efficiency and retardation causes decrease in efficiency. The reason may be that advancing leads to better combustion properties, peak pressure near the TDC and lesser losses. Maximum efficiency for any fuel is observed while using advanced ignition timing and full load. The maximum efficiency of 28.6% was found with JB20 at full load and injection timing of 28^{o} btdc (advanced). This was followed by KB20 (27.9%) and diesel (27.5%). The maximum efficiency at full load and advanced injection timing for JB100 was 26.6% which was higher than 25.9% for KB100 under same conditions.



(a) At 40% load



(b) At 70% load



(c) At full load

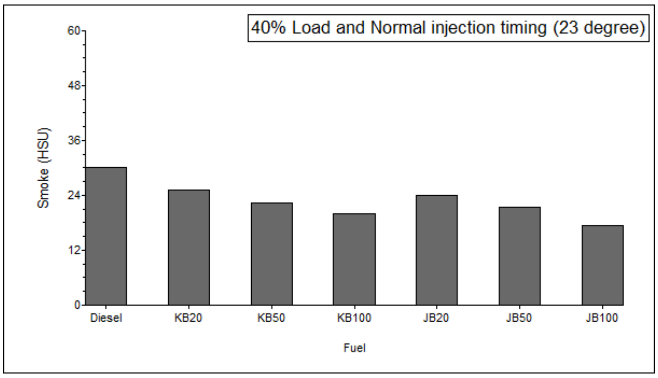
Fig.7.a-c Variation of BTE with start of injection at different loads

3.2 Emission analysis

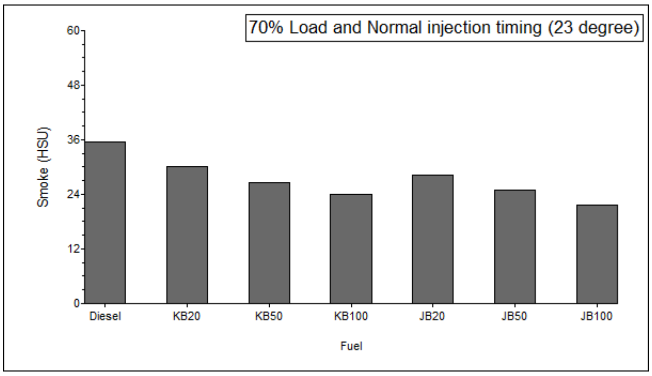
3.2.1 Smoke at normal injection

Figs. 8a-c show the smoke opacity of the fuels tested at 40%, 70% and 100% load at normal injection timing of 23^{o}. The trends indicate that pure biodiesel burns more cleanly than diesel at all loads. Also the blending diesel with biodiesel reduces smoke opacity. The free oxygen molecules present in the biodiesel leads to better combustion quality. Smoke at 40% load is 20 HSU for KB100 and 17 HSU for JB100 as compared to diesel which has smoke opacity of 30 HSU. At 70% load these values are 35, 30 and 26 HSU for

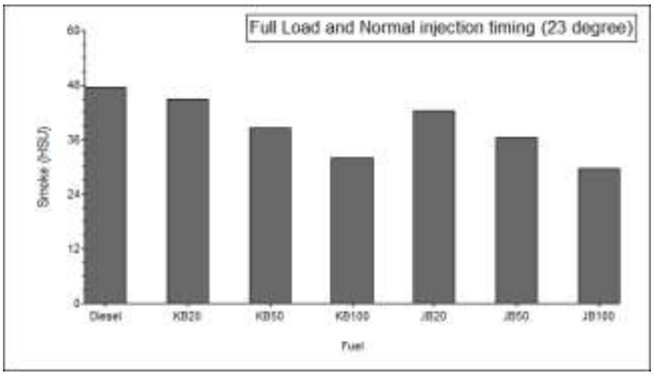
KB20, KB50 and KB100. The corresponding values for JB20, JB50 and JB100 are 28, 24 and 21 HSU respectively. As compared to JBD, KBD gives more smoke at all loads and blends. The reason may that due to more viscosity of KBD; the droplet size for the KBD is more than JBD droplet size which may lead to poor mixing with air as compared to JBD. The smoke opacity for JB100 is 8.1% lesser than that of KB100 at full load and normal injection.



(a) At 40% load



(b) At 70% load



(c) At full load

Fig. 8 a-c. Smoke opacity for various fuels tested

3.2.2 Smoke variation with load and injection timing

Fig. 9 shows the influence of load on the smoke opacity for the fuels under observation. It is observed that increase in load causes increase in smoke opacity for all the fuels. The increase in smoke level is more for mid load to high load. The reason may be that at higher loads more fuel enters the combustion chamber and due to the formation of fuel rich air fuel mixture, the exhaust smoke level increases. The reductions in smoke for JB100 at full load are 23.2%, 37.9% and 47% for retarded, normal and advanced injection respectively. The corresponding reductions for KB100 are 20.1%, 32.4% and 44% % for retarded, normal and advanced injection respectively.

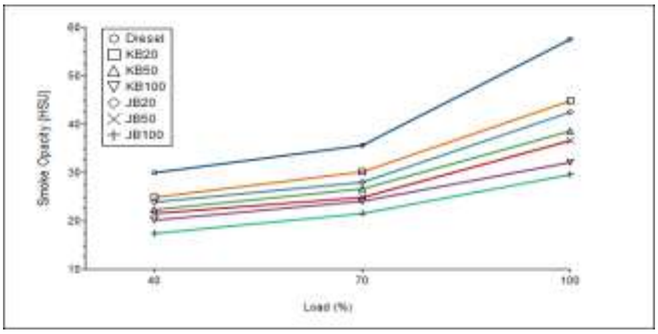
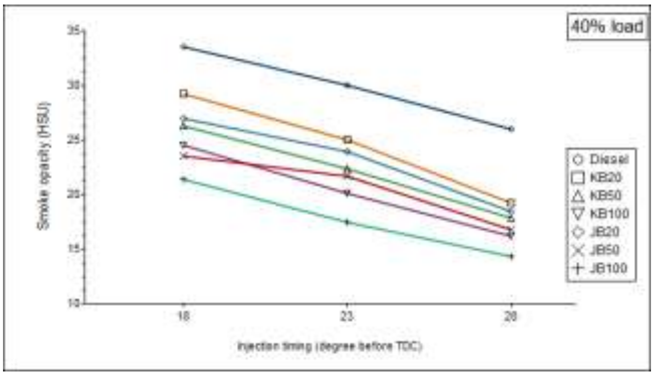
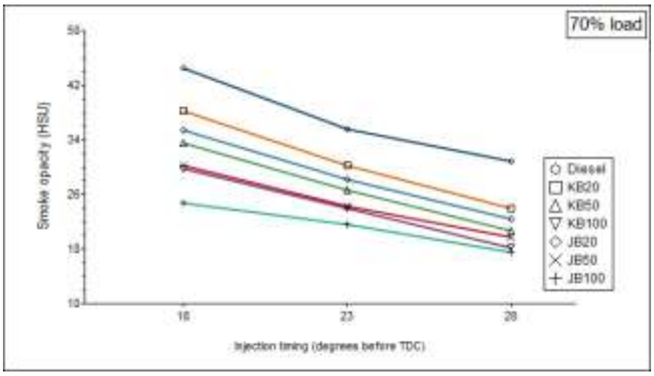


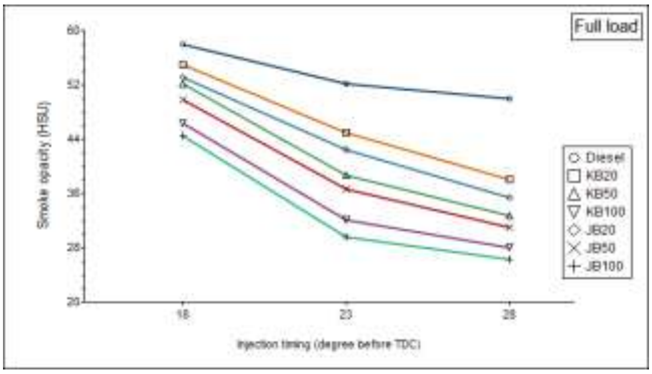
Fig. 9 Effect of load on Smoke emissions



(a) At 40% load



(b) At 70% load



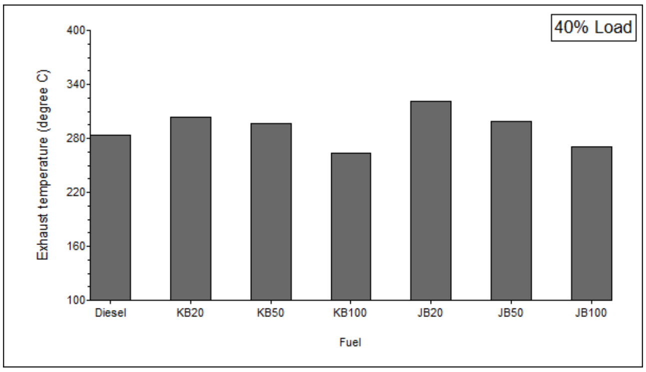
(c) At full load

Fig. 10.a-c Variation of Smoke opacity with start of injection at different loads

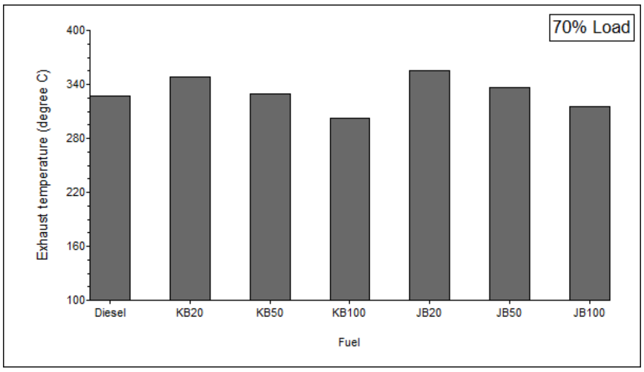
Figs. 10a-c show the change in smoke levels with the start of injection (18° before TDC, 23° before TDC and 28° before TDC) for all the fuels. The trends show that the smoke levels increase by 10-22 % for different fuels at full load and retarded timing (18° BTDC) and reduce by 6%-18% for different fuels when the start of injection is advanced by 5°(28° BTDC). The reason for reduction in smoke levels due to advancing the start of injection may be the improved fuel air mixing of as the fuel burns more in premixed combustion phase. Whereas, during the retarded injection timing, more fuel burns during the power stroke during which, after sometime, the temperatures become quite less to support the complete combustion.

3.2.3 Exhaust gas temperature at normal injection

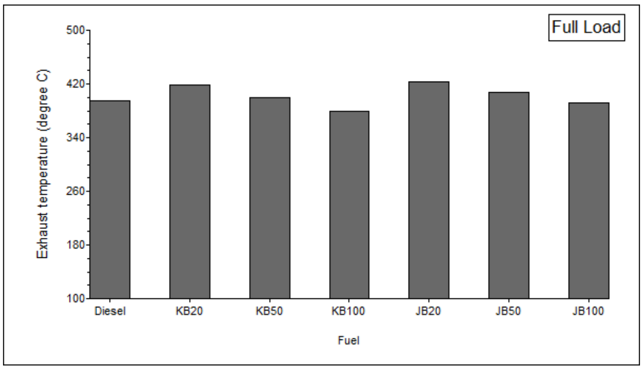
EGT is dependent on the ignition delay, availability of oxygen and calorific value of the fuel. Longer ignition delay leads to proper mixing and better combustion and hence more exhaust gas temperatures [26, 28]. Availability of oxygen improves the combustion quality and high calorific value leads to more release of energy during combustion which leads to higher exhaust temperatures. Figs. 11a-c clearly indicate that at any particular load, the blends (JB20, JB50, KB20 and KB50) have more exhaust temperatures as compared to diesel. The pure biodiesels somehow have a about 5-6 % lesser temperature of exhaust gases than the diesel at low loads, possibly due to the lower calorific value of biodiesel. At normal injection and full load, the difference in temperature of JB20 blend and diesel is about 28°C (7% higher) and that between KB20 blend and diesel is 23°C (6 % higher).



(a) At 40% load



(b) At 70% load



(c) At full load

Fig. 11 a-c. EGT for various fuels tested

3.2.4 Exhaust gas temperature variation with load and injection timing

Fig. 12 shows how exhaust temperatures vary with load at normal injection. Results reflect that at higher loads the exhaust gas temperatures increase for all the fuels. Maximum temperature (423°C) noted is at full load for JB20 which is 7% more than that of the exhaust from diesel.

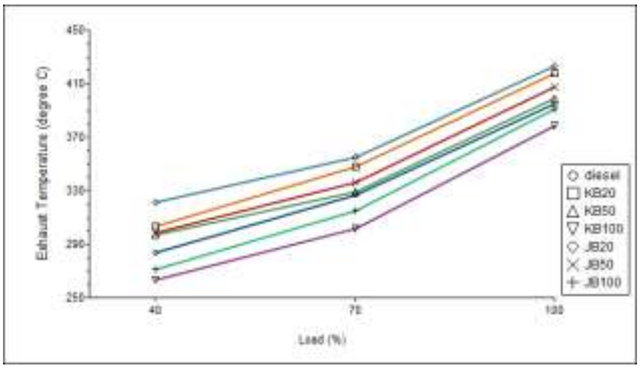
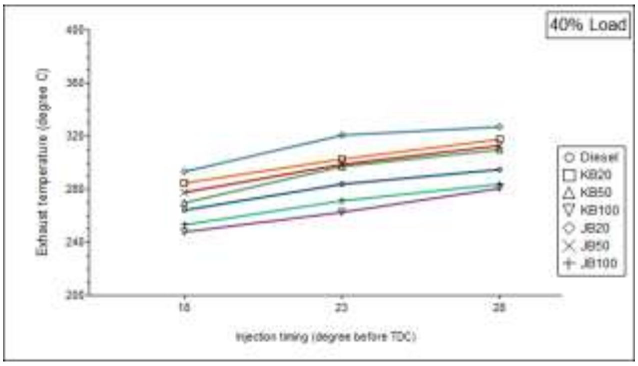


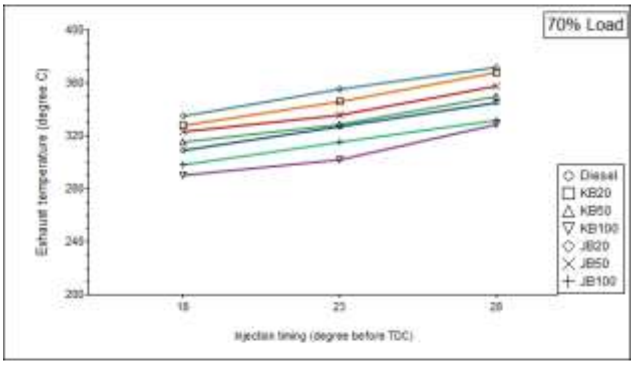
Fig. 12 Effect of load on EGT

Figs. 13a-c show the trends of variation of exhaust gas temperatures with start of injection timing. It is clear from the figures that upon advancing the injection by 5° (28° BTDC), exhaust gas temperatures increase by 4%-7% of the normal exhaust temperatures for different fuels tested and reduce by 4%-7% upon retarding the start of injection by 5°

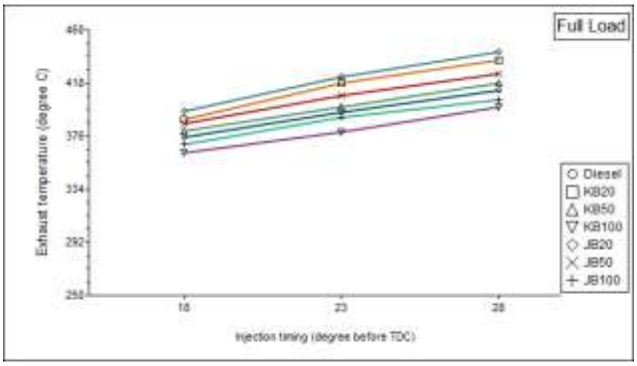
(18° BTDC). The reason may be improvement in combustion quality due to advancing the injection.



(a) At 40% load



(b) At 70% load

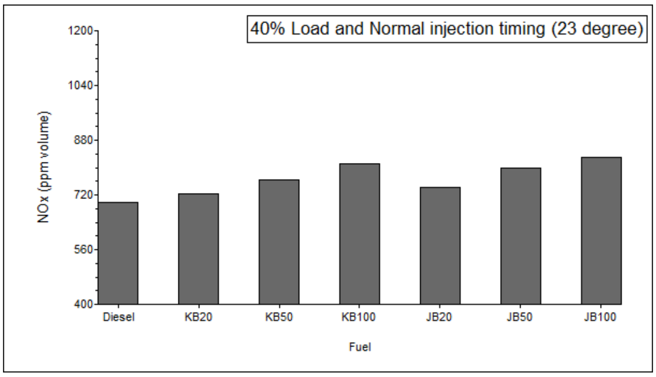


(c) At full load

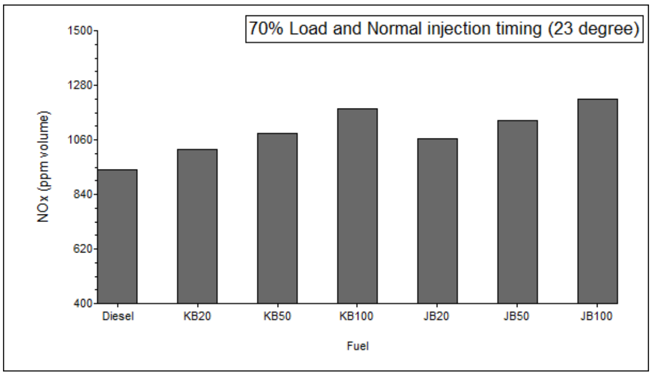
Fig. 13.a-c Variation of EGT with start of injection at different loads

3.2.5 NOx at normal injection

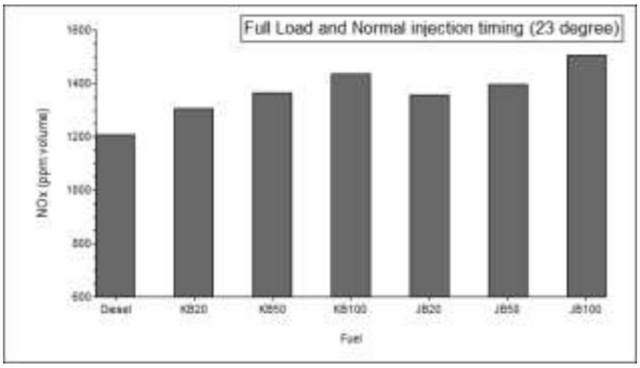
The oxides of nitrogen (NOx) emissions depend on the temperature of combustion and availability of oxygen. Where the use of biodiesel reduces most of the harmful emissions, NOx emissions are found to increase [25, 26, 27, 28]. Figs. 14a-c show the NOx emissions of the fuels investigated at different loads and normal injection. It appears that blending of biodiesel with diesel causes rise in the NOx at all loads. This can be associated to the fact that biodiesel has higher cetane number that leads to shorter ignition delay and early combustion and high peak temperatures [36]. Also the oxygen present in the biodiesel makes suitable conditions for NOx to increase than that of the diesel. From the figures, it is clear that the maximum NOx at any loads are found to be for the pure biodiesel. At 40% load, the NOx with JB100 are 18.9% higher than those from the diesel and for KB100 are 16% higher. NOx emissions are 24% and 19% higher than diesel at full loads for JB100 and KB100 respectively. Addition of 20% biodiesel causes 4-6% increase in NOx emissions at 40% load and 8-12% increase in NOx at full load. The NOx with Jatropha are more than that with Karanja biodiesel. The reason may be the higher combustion temperatures in case of jatropha due to its higher Calorific value.



(a) At 40% load



(b) At 70% load



(c) At Full load

Fig. 14a-c. NOx emissions for various fuels tested

3.2.6 *Variation of NOx emissions with load and injection timing*

Fig. 15 shows the that NOx emissions for all the tested fuels increase with load. On changing the load from 40% to 100% at normal injection, the NOx emissions increase from 698 ppm to 1207 ppm for diesel, 810-1435 ppm for KB100 and 830 ppm to 1504 ppm for JB100. Advancing the injection leads to better fuel-air mixing and thus improves combustion quality. The pressure peak is near TDC and peak temperature is also higher due to which the NOx emissions increase. Whereas retarding the injection reduces the time for proper air fuel mixing and most of the combustion takes place in the expansion stroke. Due to this the temperatures are also reduced and hence there is a drop in NOx emissions [21, 31, 37]. Figs. 16a-c show how NOx emissions vary with injection timing. Results show that at full loads there is increment of 14-17.8% of NOx when start of injection is advanced from 23° BTDC to 28° BTDC. The maximum change (17.8%) is for KB100 and minimum change (14%) is for diesel at full load. Retarding, on the contrary, causes 5-15% reduction in NOx emissions for various fuel samples. At full load there is at least 7-11% reduction in the NOx emissions for the fuel samples.

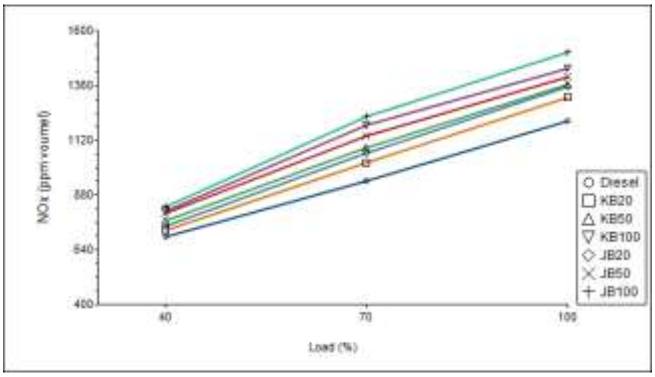
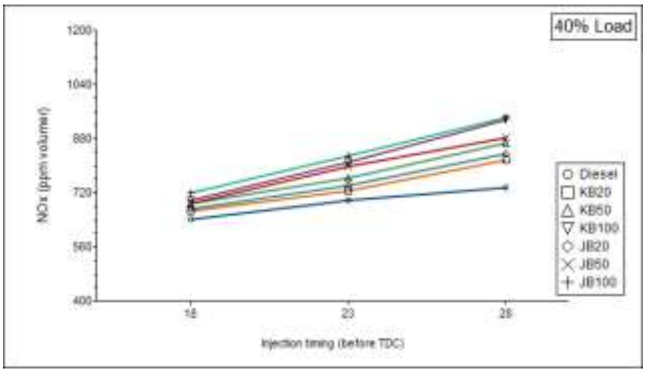
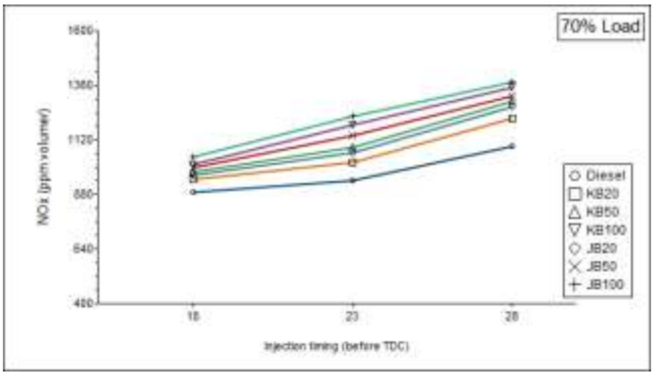


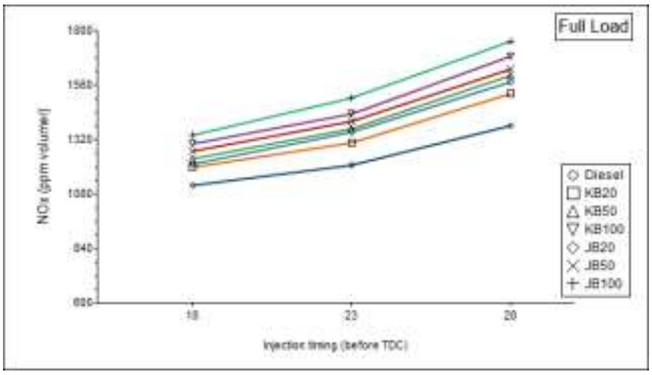
Fig. 15 Effect of load on NOx emissions



(a) At 40% load



(b) At 70% load



(c) At full load

Fig. 16.a-c Variation of NOx emissions with start of injection at different loads

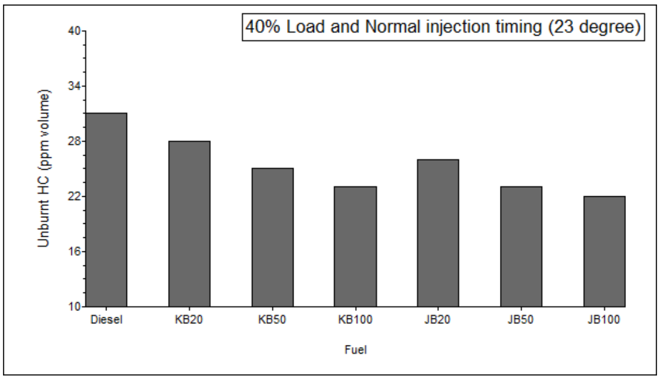
3.2.7 *Unburnt hydrocarbons at normal injection*

The major reasons for HC emissions in a diesel engine are

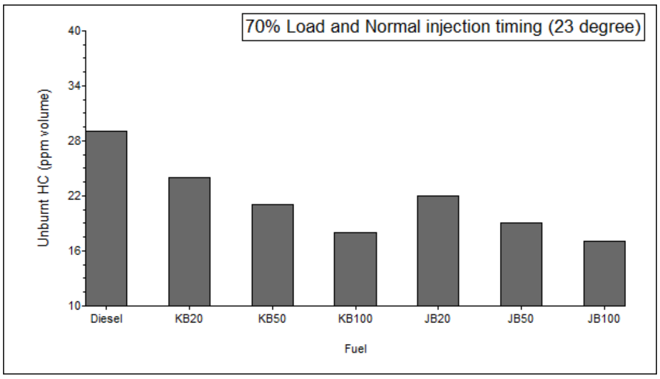
(i) Excess dilution (over-lean fuel air mixture)

(ii) Under-mixing of fuel due to injector sac volume or over-fuelling conditions [33, 38]

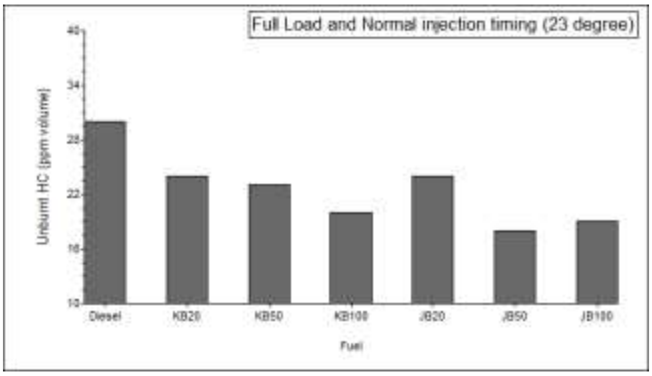
HC emissions at normal injection for the various fuels tested are represented in the figs. 17a-c. The results reflect that the HC emissions are maximum for diesel at all loads and minimum for pure biodiesels. The reason for this may be the oxygen present in the biodiesel [39] and the high cetane number of the biodiesel that causes reduced combustion delay [40, 41]. HC emissions for diesel, KB100 and JB100 at 40% load and normal injection are 31 ppm, 23 ppm and 22 ppm, respectively whereas for 70% load is 29 ppm, 18 ppm and 17 ppm, respectively. Also, HC emissions lowered as the concentration of biodiesel was increased in the blend. The values of HC emissions are higher for karanja biodiesel and its blends than those of jatropha biodiesel and its corresponding blends. This may be due to its high viscosity.



(a) At 40% load



(b) At 70% load



(c) At Full load

Fig. 17 a-c. Unburnt HC emissions for various fuels tested

3.2.8 *Variation of unburnt hydrocarbons with load and injection timing*

Fig. 18 shows the variation for Unburnt HC emissions with load at normal injection. No clear trends with load could be observed at different loads. When load was increased from 40% to 70%, HC emissions for all the fuels reduced. However the HC emissions increased slightly at 100% load, though JB50 showed decrease in HC emissions for load change from 70% to 100%.

Figs. 19a-c show the impact of start of injection on the unburnt HC emissions. It is evident that advancing the injection timing from 23° btdc to 28° btdc helps in curbing the HC emissions and retarding the start of injection from 23° btdc to 18° btdc causes rise in unburnt HC for all the fuels tested. The reason may be that the temperatures during combustion are higher in case of advanced injection and this causes the complete combustion and reduced HC emissions. Advancing of injection timing by 5° causes the decrease of upto 41% in HC emissions where as retarding of injection timing by 5° causes upto 23% rise in the HC emissions. Minimum HC emissions were found for advanced injection and 70% load for each of the tested fuel.

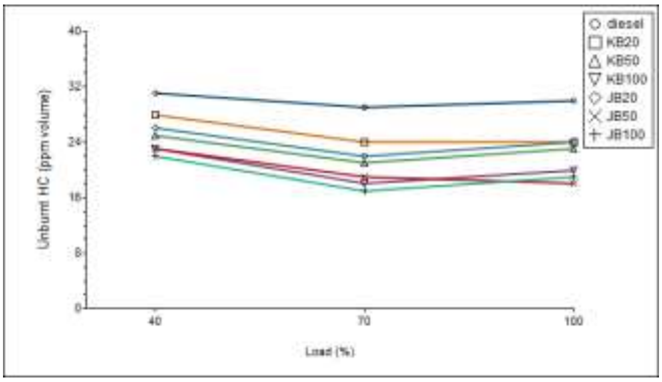
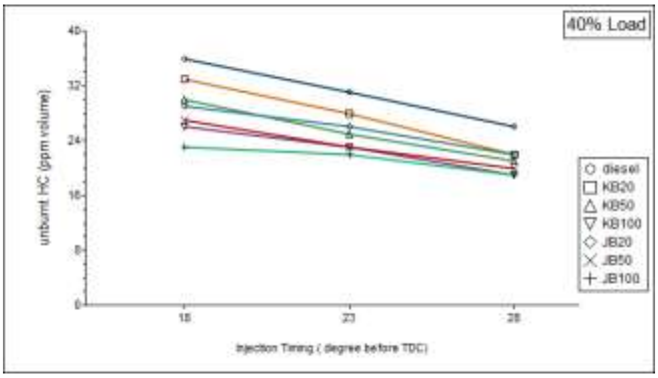
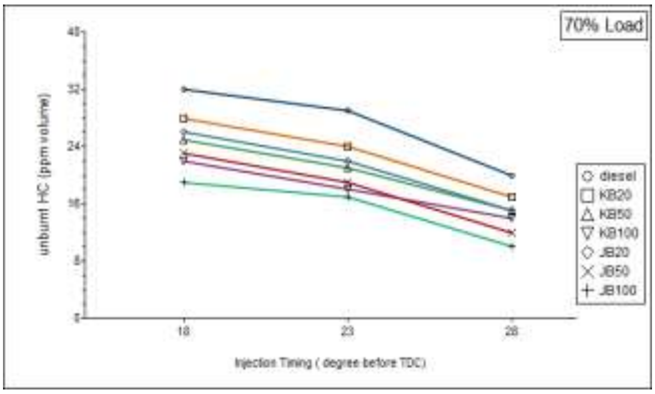


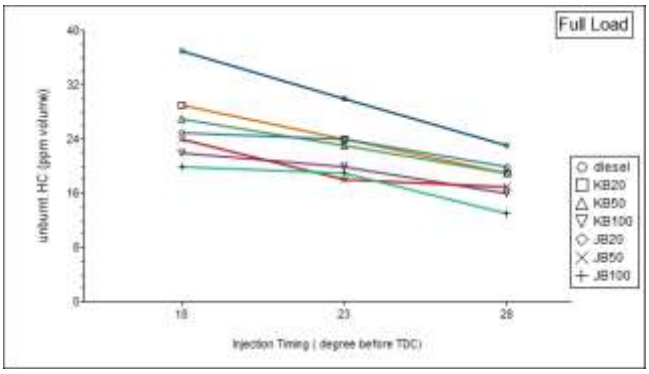
Fig. 18 Effect of load on Unburnt HC emissions



(a) At 40% load



(b) At 70% load



(c) At full load

Fig. 19.a-c. Variation of HC emissions with start of injection at different loads

4. Conclusion

In the present study, the performance and emission characteristics of 7 different fuels viz. petroleum diesel, Jatropha methyl ester (JB100), Karanja Methyl ester (KB100) and their various blends (JB20, JB50, KB20, KB50) with diesel were investigated. The objective of the study was to determine the effect of blending, variation of the load and the injection timing on the BTE, BSFC, smoke, exhaust gas temperature, NOx and unburnt HC emissions.

- The results of the study indicate that at low loads, diesel has better thermal efficiency than biodiesel and its blends. However at high loads, the efficiency of the 20% blend of jatropha J20 was slightly better. The efficiencies of JB20 at full loads and at retarded, normal and advanced injection timing were 23.7, 25.8 and 28.6% respectively which was higher than that for diesel which was 23.1%, 25.3% and 27.6% and the corresponding values for KB20 were 22.7%, 25.3 % and 27.9% respectively.

- BSFC of diesel fuel was found to be lowest under all conditions of load and injection timings. Increasing the biodiesel proportion in the blend causes increase in bsfc, because of the low calorific value of the biodiesel. Jatropha biodiesel has lesser bsfc than karanja biodiesel. The decrease in bsfc is steeper when load is increased from 40% to 70%. This is due to increase in efficiency and reduction of friction to brake power. For further increase in load, the reduction in bsfc is very less. This is due to reduction in fuel conversion efficiency which reduces the efficiency effect. BSFC reduces by 7-12% for different fuels with injection advance due to early combustion. BSFC increases by 7-14% upon retarding the injection due to lower effective pressure during working stroke.

- Smoke emissions are also reduced by adding biodiesel to the diesel as there is oxygen present in it. Jatropha biodiesel was better than Karanja biodiesel in terms of smoke emissions due to its lower viscosity and smaller droplet size. Increase in load causes increase in smoke opacity due to formation of rich fuel air mixture at high loads. Advancing the start of injection by 5° lowers smoke by 6-18% and retarding by 5° causes increase in smoke opacity by 10-22%.

- 20% and 50% blends of biodiesels were found to have higher EGT than those of diesel. However pure biodiesels have about 5-6% lesser EGT. Jatropha biodiesel and its blends have comparatively higher EGT than the corresponding karanja biodiesel and its blends. The EGT also increase with advancing the injection by 4-7% due to improvement in combustion quality and decreases by the 4-7% on retarding the start of injection by 5°.

- Rise in NOx emissions is associated with use of biodiesel as the diesel engine fuel due to high cetane number and free oxygen content in it. JB100 and KB100 had 24% and 19% higher NOx emissions respectively than diesel at full loads. Addition of 20% biodiesel causes 4-6% increase in NOx emissions at 40% load and 8-12% increase in NOx at full load. The NOx with Jatropha biodiesel are more than that with Karanja biodiesel due to higher combustion temperatures in case of jatropha biodiesel. NOx increase for all the fuels when load is changed from 40% to 100%. Advancing the injection from 23° btdc to 28° btdc causes 14%-17.8% increment in the NOx due to higher combustion temperatures and retarding causes 5-15% reduction in NOx emissions

- Biodiesel use also cuts the unburnt HC emissions. The values of HC emissions decrease as the concentration of biodiesel in a blend is increased. Out of Jatropha and karanja biodiesel and corresponding blends, latter had higher HC emissions due to higher viscosity of Karanja. HC emissions for all the fuels reduced when load was increased from 40% to 70%. However increase in HC emissions was observed with further increase of load to 100%, though JB50 showed decrease and KB100 showed no change for the increase in HC emissions for load change from 70% to 100%. Advancing of injection timing by 5° causes the decrease of upto 41% in HC emissions where as retarding of injection timing by 5° causes upto 23% rise in the HC emissions.

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