Comparative Analysis of Performance and Combustion of Koroch Seed Oil and Jatropha Methyl Ester blends in a Diesel Engine

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Abstract: The present study analyzes the performance and combustion characteristics of 10%, 20%, 30% and 40% blending of Koroch Seed Oil Methyl Ester (KSOME) and Jatropha Methyl Ester (JME) with diesel as fuels in a d iesel engine. The brake specific fuel consumption (BSFC) was more for the methyl ester blends and particularly for the JME blends. The brake thermal efficiency (BTE) was slightly lower for the biodiesel blends and for the JME blends it was less compared to that of the KSOME blends. The indicated power was more in case of the blends; however it reduced significantly for the 40% blend of KSOME. Both the KSOME and JME blends exhibited similar combustion trend with that of diesel, however, the blends showed an earlier start of combustion with shorter ignition delay. The ignition delay was less and the combustion duration was more for the JME blends as compared to t he KSOME blends. The overall observation was that the KSOME blending up to 30% showed an acceptable performance and combustion trend whereas the JME blends showed favorable combustion trend but due its comparatively higher fuel consumption characteristics, finally the engine BTE was less with the JME fuel blends.

Keywords: *Biodiesel, diesel engine, Koroch seed oil, Jatropha*

1. Introduction

Biodiesel obtained from non e dible plant species such as Jatropha *curcas (Ratanjot), Pongamia pinnata (karanj)*, *Calophyllum inophyllum (Nagchampa)*, *Madhuca indica* (*Mahua*), *Hevea brasiliensis* (*Rubber seed)* are gaining importance as possible renewable alternate fuels in India. Biodiesel is non toxic, biodegradable, and environmentally friendly as it c ontains minimum sulfur and aromatics. However, its higher viscosity leads to poor atomization of the fuel spray and incomplete combustion, coking of the injector tips, oil ring sticking and thickening and gelling of the engine lubricant oil. Its lower calorific value and lower volatility are regarded as its disadvantages. Therefore, the 5-20% (by volume) blending with standard diesel has been considered as suitable at present for using in existing diesel engines without any modifications. Many researchers have evaluated the performance of conventional diesel engines fuelled by bio-diesel and its blends. Raheman and Ghadge [1] while evaluating the performance of a single cylinder, four stroke Ricardo E6 engine with various biodiesel blends and pure biodiesel from Mahua seed oil found higher BSFC and lower BTE in case of the blends. Ramadhas et al. [2] used Rubber seed oil and its blend in a single cylinder diesel engine and observed that the blends containing 20–40% of rubber seed oil in the blend yielded an engine performance closely matching that of diesel oil. Raheman and Phadatare [3] used karanja methyl ester and its blends in a single cylinder, four-stroke, direct injection (DI) diesel engine and observed slightly higher torque in case of 20% blending (B20) and 40% blending (B40) while lower torque was observed with 60% blending (B60) to pure biodiesel (B100) when compared to diesel. BSFC was lower for B20 and B40 and found to be higher for blends ranging from B60–B100. The BTEs were also higher for B20 and B40. Sahoo and Das [4] made a combustion analysis using neat biodiesel from Jatropha, Karanja and Polanga; and their blends (B20 and B40) at various loads. Saravana et al. [5] observed lower delay period, lower maximum rate of pressure rise and heat release with 20% blending of crude rice bran oil methyl ester (CRBME) in a stationary small duty DI diesel engine. The BSFC of CRBME blend was found to be only marginally different from that of the diesel. Qi et al. [6] evaluated combustion and performance of a single cylinder four stroke diesel engine (rated power 11.03 kW, rated speed 2000 rpm) with biodiesel produced from crude soybean oil. However, the performance and combustion trend vary depending upon the type of biodiesel used, engine configurations, test conditions, and the method of analysis. Also, the appropriate blend that would give optimum engine performance and best combustion characteristics may vary from biodiesel feedstock to feedstock, its production processes and the type of engine in which it is used. For the present investigation, biodiesel was prepared from Koroch seed and Jatropha curcus oil using a two step acid base catalyzed trans-esterification process in a laboratory scale. The properties of the various blends prepared by mixing biodiesel in various volumetric proportions with diesel obtained from Numaligarh refinery limited (NRL) are summarized in Table 1. The properties were determined at the Quality and Control Laboratory of NRL. Koroch is a tree found in abundance in the forests of north east India and oil obtained from Koroch seed has its own unique characteristics as a potential source of biodiesel. The author of this paper has not come across any study on diesel engine performance and combustion involving KSOME and its diesel blends. Although related literatures are available for JME, still blends of JME have been chosen as fuels for a comparative analysis.

Table 1. Properties of NRL diesel and various biodiesel blends

Fuel	NRL diesel	KB10	JB10	KB20	JB20	KB30	JB30	KB40	JB40
Density at 15°C (gm/cc)	0.8460	0.8500	0.8474	0.8548	0.8512	0.8594	0.8552	0.8661	0.8574
Kinematic Viscosity at 40°C (cSt.)	2.34	2.64	2.58	2.84	2.62	3.07	2.74	3.28	2.85
HHV (kJ/kg)	45553.0	45489.9	45682.4	45418.1	45471.9	45348.9	45379.0	45247.4	45161.2
Cetane index	46.60	46.34	47.48	46.50	48.01	46.34	48.54	45.39	48.61
Flash point (°C)	46	47	47	49	52	53	54	55	53
Pour point (°C)	3	-3	3	0	-3	3	-6	6	-6
Sulpher content (ppm)	489	440	452	390	370	302	308	274	292

2. Methodology

Tests were performed in a single-cylinder; four-stroke, naturally aspirated, DI diesel engine and its specifications are given in Table 2. T he test engine is provided with necessary instruments for combustion pressure, fuel pressure and crank-angle measurements. The in-cylinder and the fuel pressure are sensed by two piezo sensors. Signals from these pressure transducers are fed to a charge amplifier. A high precision CA encoder is used to give signals for top dead centre (TDC) and the CA. The signals from the charge amplifier and the CA encoder are supplied to a data acquisition system which is interfaced to a computer through engine indicator for obtaining pressure CA diagram. There are provisions in set up a lso for interfacing airflow, fuel flow and load measurement. The engine is coupled with an eddy current dynamometer for controlling the engine torque through computer. A Lab view based engine performance analysis software package evaluates the on line engine performance. The tests were conducted at steady state and 100% load at average engine speed of 1,535 rpm where the average engine torque was 21.85 Nm. This yielded an average brake power (BP) of 3.5 kW in each fuel test. Three test runs were performed under identical conditions to check for the repeatability of all the results. The repeatability of the results was found to be within an acceptable limit. The test results were then averaged and the average test results have been reported.

Table 2. Engine Specifications

Make and Model	Kirloskar –TV1
Rated power and speed	3.5 kW and 1500 rpm
Type of Engine	1 cylinder, DI type, 4Stroke
Compression ratio (CR)	12-18:1
IV Opening	4.5° before TDC
IV Closing	35.5° after BDC
EV Opening	35.5° before BDC
EV Closing	4.5° after TDC
Bore & Stroke	87.5mm and 110mm
Nozzle opening pressure	220 bar
Cooling Medium	Water cooled

3. Results and Discussion

3.1. Performance Characteristics

3.1.1. Brake thermal efficiency

Fig. 1 shows the BTE of the test engine for the tested fuels. It was observed that the BTE with the methyl ester fuel blends were comparatively less. The BTE decreased with increasing proportion of methyl ester in the blends. Further, the BTE for the JME blends were less compared to that for the KSOME blends. The BTE values with NRL diesel, KB10, JB10, KB20, JB20, KB30, JB30, KB40 and JB40 are 25.63%, 24.86%, 23.89%, 24.34%, 23.24%, 24.13%, 22.41%, 22.35% and 22.18% respectively. K and J here refer to KSOME and JME respectively. Compared to KSOME blends, slightly lower BTEs for the JME blends was mainly due to their increased fuel consumption rates for maintaining a constant BP output. Since the density and viscosity values of the JME blends were lower and the HHVs were higher compared to their corresponding KSOME blends, fuel consumption for the JME blends should have been lower than those of KSOME blends. Similarly the BTEs of the JME blends should also be more due to better combustion resulting from lower viscosities of JME blends compared to their KSOME counterparts. But the opposite trend in fuel consumption and BTE could not be understood. An energy balance study determining the various energy losses could be an appropriate future work for confirming this opposing trend.

3.1.2. Brake specific fuel consumption

The BSFC for the blends of JME and KSOME are compared with NRL diesel and is shown in Fig. 2. It was seen that the BSFC for the biodiesel blends was more. BSFC was marginally higher in case of the JME blends. This is due to higher fuel consumption rate in case of the JME blends. The fuel consumption rate for NRL diesel, KB10, JB10, KB20, JB20, KB30, JB30, KB40 and JB40 are 1.15 kg/h, 1.187 kg/h, 1.23 kg/h, 1.214 kg/h, 1.27 kg/h, 1.228 kg/h, 1.32 kg/h, 1.328 kg/h and 1.34 kg/h respectively.

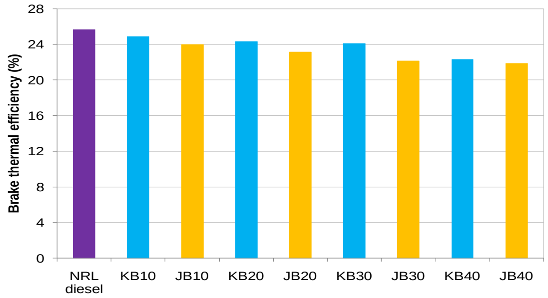


Fig. 1. BTE for the tested fuels

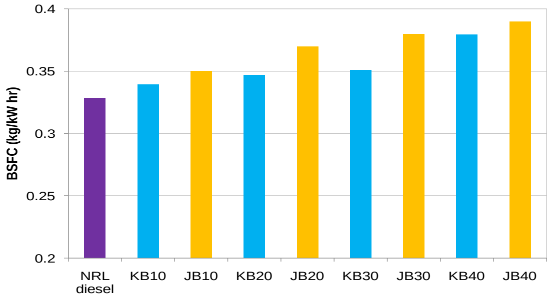


Fig. 2: BSFC for the tested fuels

3.1.3. Indicated power

From Fig. 3 it is observed that the engine IP operated with the blends is slightly more except for the blend KB40. The engine IP produced with NRL diesel, KB10, JB10, KB20, JB20, KB30, JB30, KB40 and JB40 are 5.6 kW, 5.76 kW, 5.7kW, 5.80 kW, 5.83kW, 5.92 kW, 6.02kW, 5.42 kW and 6.09kW respectively. It was observed that the loop work i.e. the work done during the gas exchange process and the compression work were less while the combustion and expansion work were more in case of the blends. Hence the net work done during the cycle was more and this resulted in higher IP. Slightly higher IP with the methyl ester blends may also be due to combustion of relatively more amount of fuel in case of the blends. Although the calorific values of blended fuels were lower than that of NRL diesel, the fuel energy was more for the blends and particularly for the JME blends due to relatively higher fuel consumption rate. Lower IP with KB40 was due to increase in the compression and loop works and decrease in the expansion work. The viscosity of KB40 was higher and may be due to poor combustion of this fuel blend it resulted in cylinder pressure variation leading to lower IP. Again, the IP with the JME blends was comparatively more than that with the KSOME fuel blends. It was due to higher energy input in respect of these blends and also due to higher net works done during the cycle as can be seen from the Table 3 shown below.

Table 3. Various works done during the cycle

Fuel	NRL diesel	KB10	JB10	KB20	JB20	KB30	JB30	KB40	JB40
Combustion and Expansion work (kJ)	724.13	728.18	721.84	719.64	734.99	743.05	748.1	692.86	749.90
Comprssion work (kJ)	309.80	300.51	285.98	286.15	288.43	294.92	288.63	311.35	280.55
Loop work (kJ)	24.16	20.12	10.42	18.32	8.48	14.64	13.84	42.97	8.55
Net work (kJ)	390.17	407.55	425.44	415.17	438.08	433.49	445.63	338.54	460.80

4. Combustion characteristics

4.1. Pressure crank angle diagram, peak pressure and rate of pressure rise

The pressure CA variation at full load is shown in Fig. 4 for the tested fuels. It was observed that pressure rise takes place early in case of the biodiesel blends. As compared to the KSOME blends, the pressure rise was earlier in case of the JME blends. Early pressure rise for the JME and KSOME blends may be due to their lower ignition delay which can be found out and will be discussed separately in section 3.2.4. Early pressure rise with JME blends in comparison to that with the KSOME blends implies relatively lesser ignition delay for the JME blends. It was also seen that more the amount of biodiesel in the blend, early is the pressure rise that occurs. Fig. 5 shows the peak cylinder pressure for the tested fuels. The peak pressure depends on the amount of fuel taking part during premixed combustion which in turn depends upon the delay period and the spray envelope of the injected fuel. Larger the ignition delay more will be the fuel accumulation, which finally results in a higher peak pressure. It was seen that the peak pressure for NRL diesel as well as the KSOME blends was almost the same at full load, the peak pressure values for KB10, KB20, KB30 and KB40 being 57.35, 57.62, 57.31 and 57.16 bar respectively, as against a peak pressure value of 57.43 bar for NRL diesel. However, the peak pressure for the JME blends were slightly less and these being 57.02, 56.98, 56.04 and 55.93 bar for JB10, JB20, JB30 and JB40 respectively. This is again due to combustion of relatively less amount of fuel during premixed phase of combustion as a result of lesser ignition delay period associated with the JME blends. The CAs at which these peak pressures occurred were 370, 370, 370, 370, 370, 369, 370, 369 and 369 degree CA for NRL diesel, KB10, JB10, KB20, JB20, KB30, JB30, KB40 and JB40 respectively. Even though the pressure rise was occurring earlier in case of the JME and KSOME blends, but the peak values occurred almost at the same CA for these blends at full load. This may be due to lower rate of pressure rise in case of the biodiesel blends which is shown in Fig. 6. Rate of pressure rise was slightly more in case of the biodiesel blends towards the end of compression and it was more in case of the JME blends as compared to the KSOME blends. The pressure rise rate first decreased during the delay period for all the fuels and then it increased before the start of combustion (SOC) with a sharp rate of rise after SOC. However the peak of the rate of pressure rise was less and it also advanced in case of the biodiesel blends. Compared to the KSOME blends, the peak of the rate of pressure rise was less in case of the JME blends with early occurrence of the same.

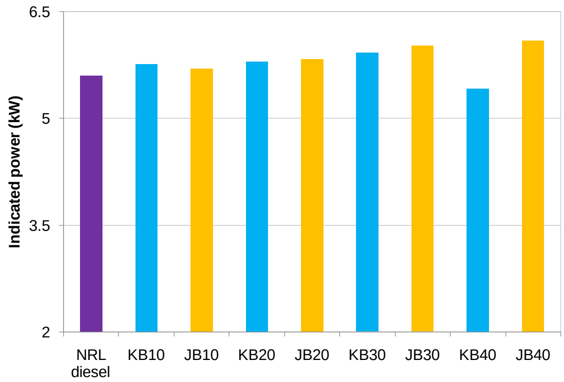


Fig. 3. Indicated power for the tested fuels

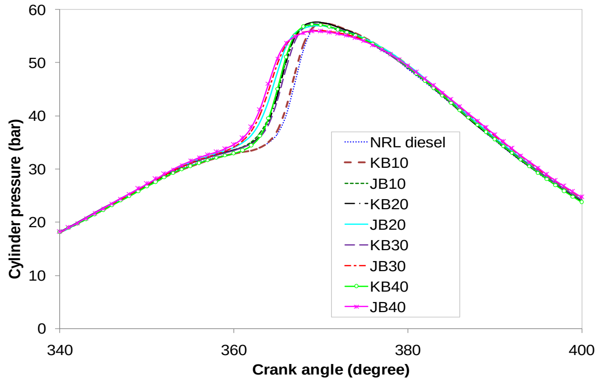


Fig. 4. Pressure crank angle variation for the fuels

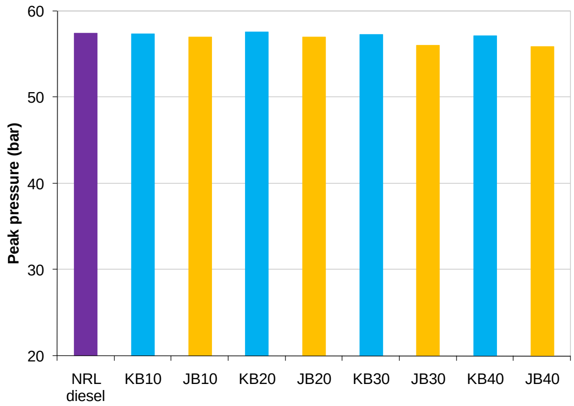


Fig. 5. Peak pressure for the tested fuels

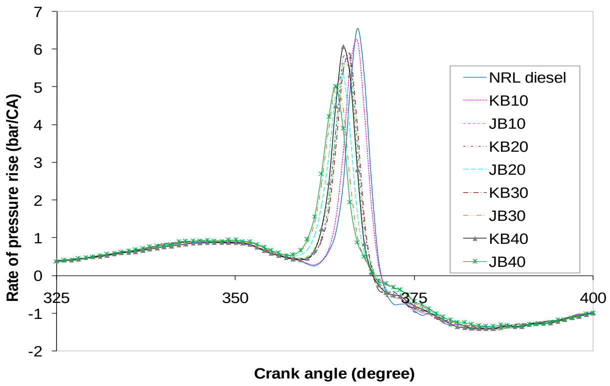


Fig. 6. Rate of pressure rise for the tested fuels

4.2. Net heat release rate

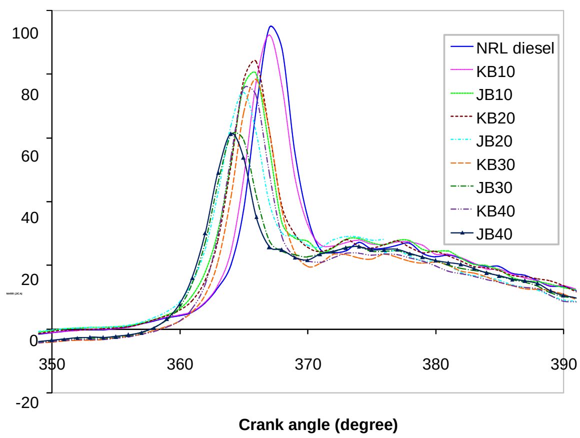
The heat release rate was calculated by first law analysis of the pressure CA data. The apparent net heat release rate which is the difference between the apparent gross heat release rate and the heat transfer rate to the walls is given by Equation (1) as given below.

$$\frac{dQ_n}{d\theta} = \frac{\gamma}{\gamma - 1} p \frac{dV}{d\theta} + \frac{1}{\gamma - 1} V \frac{dp}{d\theta} \qquad (1)$$

An approximate range for γ (specific heat ratio) for diesel engine heat release analysis is 1.3 to 1.35. However the values of γ which will give more accurate heat release information are not well defined [7]. In the present analysis value of γ for all the fuels were taken as 1.35. Lower heat release rate was observed in case of methyl ester blends at full load as can be seen from Fig. 7. In the equation (1), it is the second term in the right hand side which mainly influences it over a w ide range of TDC and therefore the rate of heat release is directly proportional to the rate of pressure rise. Since the pressure rise was earlier in case of the biodiesel blends and also due to the early occurrence of the peak of the rate of pressure rise which was also lower for the blends it is seen in Fig. 7 that the net heat release rate also followed the same trend. As obviously the rate of net heat release raised early in case of the JME blends as compared to that of the KSOME blends. Similarly the peak of net heat release rate was also less for the JME blends. It was also seen that the net heat release rate was higher particularly for the JME blends during the reaction controlled diffusion and late combustion phases.

4.3. Cumulative heat release

Cumulative heat release is shown in fig. 8 for the tested fuels. It was observed that cumulative heat release was more for most of the biodiesel blends towards the later part of the combustion process which means that greater amount of heat was released in case of the blends for producing a given output. This was due to greater heat release as a result of diffusion combustion in case of the blends. As the amount of fuel taking part in combustion was more in the case of the KSOME and JME blends therefore it resulted in higher amount of heat release with the biodiesel blends. This is also the reason of higher IP associated with these blends. Although the calorific value of the KSOME and JME blends was less compared to that of NRL diesel but the lower calorific value of these fuel blends were compensated by their higher fuel flow rate and hence cumulative heat release increased in case of the blends. In case of the JME blends both the fuel consumption rates and the calorific values were more compared to their KSOME counterpart. Therefore the cumulative heat release was also more for the JME blends. Slightly lower cumulative heat release in case of JB10 was due to lower heat release during later part of its diffusion combustion. Exceptionally the cumulative heat release for the blend KB40 was significantly lower towards the later part of combustion. Although the fuel consumption rate was higher but may be due to incomplete burning of this particular fuel blend together with its lower calorific value it resulted in low cylinder pressure and low rate of pressure rise during the later part of combustion. This ultimately affected the cumulative heat release. The reason for incomplete burning can be its higher viscosity due to which it led to poor atomization and ultimately resulted in lower heat release. The same can also be the reason of lower engine IP produced with this particular fuel blend.



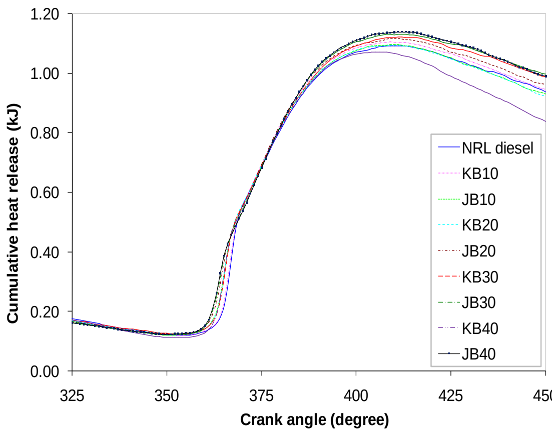


Fig.7. Net heat release rate for the tested fuels *Fig.8. Cumulative heat release for the tested fuels*

4.4. Igniton delay

Ignition delay is the time period between start of injection (SOI) and SOC. The point of SOI was determined from measurement of the fuel injection pressure profile. SOI is usually taken as the time when the injector needle lifts off its seat. As no needle lift sensor was fitted to the injector, therefore the CA at which the fuel pressure in the fuel line reached its maximum value followed by a sudden drop in pressure, was considered as the SOI. Criterion based on max $\left(d^2p / d\theta^2 \right)$ is widely used to predict SOC [7] and was also used in the present study to determine SOC. Fig. 9 shows the ignition delay for NRL diesel and various biodiesel blends at full load. It was found that the ignition delay period for the KSOME and JME blends was less. Further, the delay period was found to be less for the JME blends compared to the KSOME blends and the prediction made in pressure CA and heat release analyses was found to be correct. Cetane index of the KSOME and JME blends were higher and therefore the ignition delays were less for the biodiesel blends. Cetane index of the JME blends were comparatively higher and hence delay periods were lower for the JME blends compared to KSOME blends. Moreover, biodiesel typically contains unsaturated fatty acids and these get oxidized when exposed to oxygen environment. May be due to presence of higher oxygen content, biodiesel blends get ignited earlier than that of diesel. Another reason could be the rapid preflame chemical reaction of the biodiesel mixed fuel with high temperature air during injection and also the thermal cracking due to which the high molecular weight ester (biodiesel) breaks down to lighter compounds and ignites earlier resulting in shorter ignition delay.

4.5. Combustion duration

Determination of combustion duration of a diesel engine is a difficult task because the total combustion process consists of phases such as rapid premixed combustion, mixing controlled combustion and the late combustion of fuel present in the fuel rich combustion products. It can be defined as the time interval from the start of heat release to the end of heat release [4]. Banapurmath et al. [8] evaluated the combustion duration considering the CA interval between the SOC and 90% cumulative heat release. They observed higher combustion duration with Honge, Jatropha and Sesame oil methyl esters which they attributed to the longer diffusion combustion phase of the esters. Rao et al. [9] however observed lower combustion duration with JME blends and it was stated to be due to early start and faster rate of combustion. In the present study the CA at which the cumulative heat release is the maximum has been considered as the end of combustion. Fig. 10 shows the combustion duration for NRL diesel and the various methyl ester blends at full engine load. It was seen that, the combustion durations of KB30 and NRL diesel were the same (47° CA duration) and it was slightly less for the other KSOME blends. Even though the amount of injected fuel was more for the KSOME blends but slightly lesser combustion duration may be due to fact that biodiesel is oxygenated in nature which helps in early completion of combustion of the blends as it was the case for KB10. But with the increase in the amount of biodiesel in the blend, combustion duration increased for KB20 and KB30 which may be due to increase in the amount of fuel injected. But again the combustion duration decreased in case of KB40, which may be due to higher viscosity of this particular blend. However for the JME blends, the combustion durations were slightly more compared to the KSOME blends and these were 46, 47, 50 and 50° CA for JB10, JB20, JB30 and JB40 respectively. Slightly higher duration of combustion particularly with respect to JB30 and JB40 could be due to earlier start of combustion and relatively longer diffusion combustion for these blends.

5. Summary and Conclusion

Compared to NRL diesel operation, the KSOME and JME blends resulted in slightly poor performance in terms of BTE and BSFC. However the IP produced with the methyl ester blends was more except for the blend KB40. Although the fuel consumption with KB40 was higher, but may be due to higher viscosity it resulted in poor fuel atomization leading to incomplete combustion, lower heat release and hence lower IP. All the blends revealed almost similar pressure CA characteristics, however early pressure rise and lower ignition delay was observed in case of the blends. Compared to the KSOME blends, the ignition delay period and the pressure rise were early in case of the JME blends. The JME blends also showed better combustion trend with improved rate of pressure rise and heat release due its lower viscosity, increased fuel consumption and slightly higher calorific value. However, BTE values were slightly lower for the JME blends.

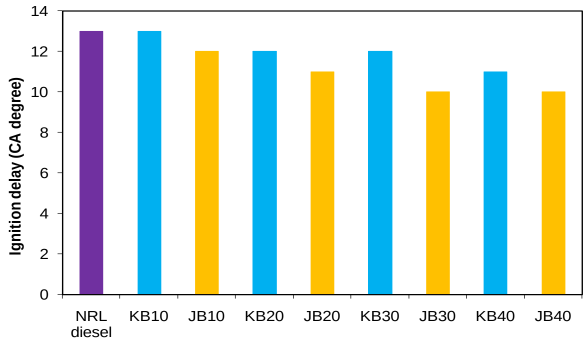


Fig.9. Ignition delay of the various fuels

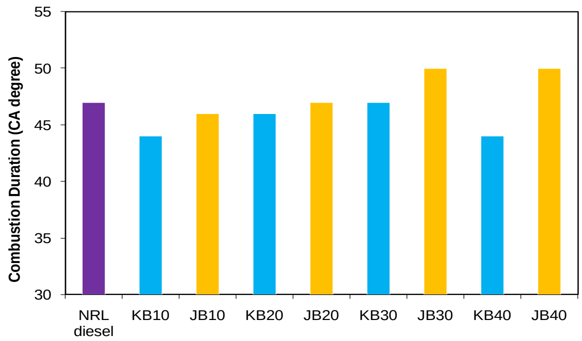


Fig. 10. Combustion duration of the fuels

References

[1] H. Raheman, S.V. Ghadge, Performance of compression ignition engine with mahua (Madhuca indica) biodiesel. Fuel 86 (2007) pp. 2568–2573

[2] A.S. Ramadhas, C. Muraleedharan, S. Jayaraj, Characterization and effect of using rubber seed oil as fuel in the compression ignition engines, Renewable Energy 30 (2005) pp. 795–803

[3] H. Raheman, A.G. Phadatare, Diesel engine emissions and performance from blends of karanja methyl ester and diesel, Biomass and Bioenergy 27 (2004) pp. 393 – 397

[4] P.K. Sahoo, L.M. Das, Combustion analysis of Jatropha, Karanja and Polanga based biodiesel as fuel in a diesel engine, Fuel 88 (2009) pp. 994–999

[5] S. Saravanan, G. Nagarajan, G. L. N. Rao, S. Sampath, Combustion characteristics of a stationary diesel engine fuelled with a blend of crude rice bran oil methyl ester and diesel, Energy 35 (2010) pp. 94–100

[6] D.H. Qi, L.M. Geng, H. Chen, Y.ZH. Bian, J. Liu, X.CH. Ren, Combustion and performance evaluation of a diesel engine fueled with biodiesel produced from soybean crude oil

[7] J.B. Heywood, Internal combustion engine fundamentals. New York: McGraw-Hill;1988.

[8] N.R. Banapurmath, P.G. Tewari, R.S. Hosmath, Performance and emission characteristics of a DI compression ignition engine operated on H onge, Jatropha and Sesame oil methyl esters. Renewable Energy 2008; 33:1982-8

[9] G.L.N. Rao, B.D. Prasad, S. Sampath, K. Rajagopal, Combustion Analysis of Diesel Engine Fueled with Jatropha Oil Methyl Ester - Diesel Blends. Int J of Green energy 2007; 4:645–58