Effect of B20 and B30 jatropha biodiesel blends on combustion characteristics of mullite coated LHR DI diesel engine

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Abstract: For conform suitability of biodiesel in an internal combustion engine, the improved performance and reduced emission characteristics are required. These characteristics belong to combustion characteristics of fuel. In the present experimental analysis, various combustion characteristics of conventional and modified engines are analysed for the use of biodiesel blend fuels. For modification, Oerlikon Metco-6150 ($Al_2O_3 + SiO_2$) mullite powder material was coated on the crown of the piston, cylinder head and both valves of single cylinder DI diesel engine. Coating was carried out by using atmospheric plasma spray process. Characteristics from both engine operations by using two jatropha biodiesel blends (B20 and B30) were compared with the diesel fuelled CE operation. Ignition delay with biodiesel blends B20 and B30 at CE operation was decreased by 0.49°CA and 0.54°CA respectively. It was further reduced during LHRE operation. Similarly, the MRPR with biodiesel blends B20 and B30 at CE operation was decreased by 0.42 bar/°CA and 0.54 bar/°CA respectively. Although the MRPR is slightly higher in LHRE, it was less in CE operation with diesel fuel. By this way, the variations in pressure, temperature, premixed, diffused, after burning, combustion duration, etc. and their effects were discussed.

Keywords: diesel engine; biodiesel; METCO 6150 mullite material; LHR engine.

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1 Introduction

The quality of Earth's future environment almost depends on the rapid and effective mobilisation of a renewable energy economy of every country. The present rapid rate of fossil fuel consumption caused its future insecurity and also raised its cost continuously, since from last decades. The Kyoto protocol agreement was into force in which every nation requires to reduce greenhouse gas (GHG) emissions. Hence, many countries have been realised that, in future, biofuels would have been an effective and alternative fuel for sustainability (Siddiqui et al., 2011). Liquid transport fuels like ethanol and biodiesel have been heavily promoted in recent years. It is a step to increase energy security. It is supporting agricultural producers to generate some sort of money income to them. This has intangible benefit in reducing GHG emissions. European Council has decided to grow the application of percentage of renewable energies out of total primary energy consumption to 20% by 2020 (Oberweis and Al-Shemmeri, 2011). Indian Government has recently announced through India's National Policy on Biofuels (NPB) – 2018 (NPB, 2018) the reduction in energy emissions intensity targeted up to 33%–35% by 2030 and the stake of non-fossil fuel based capacity in the electricity mix is marked at above 40% by 2030. The suggestive target of 20% blending of ethanol in petrol and 5% blending of biodiesel in diesel is projected by 2030. The GHG emission intensity reduction is proportional to biodiesel blending in diesel (Jagtap et al., 2020). Hence, in this experimentation, B20 and B30 biodiesel blends were taken into consideration for attaining the emissions intensity target by biodiesel as a non-fossil fuel only. Conventional or fossil fuel resources are limited, polluting, non-renewable and hence, need to be used cautiously. On the other hand, biofuels are renewable non-polluting, indigenous and vitally inexhaustible energy resources. Biofuel technologies were further divided into the production of biogas, bioethanol, torrefaction (Cahyanti et al., 2020), and biodiesel. Biodiesels (Dabi and Saha, 2019) obtained from various vegetables namely cashew nuts (Vedharaj et al., 2014), corn oil (Işcan and Aydin, 2012), neem and kernel (Shrigiri et al., 2016), linseed oil (Agarwal et al., 2008), Pongamia oil (Siddiqui et al., 2011), Karanja oil (Lahane and Subramanian, 2015) and so on had been used for experimentation. Jatropha oil obtained from the plant jatropha carcass which is better alternative to internal combustion engine fuels. Jatropha plants can cultivate in desert or waste lands and wants very little care for carcass collection. Oil generated from jatropha carcass is non-edible and even cattle's are not able to graze plants. By simple jatropha seed crushing producess about 25% oil. By double crushing, oil production can increases up to 28.5% and from solvent extraction method, it extended to 30% (Murali Krishna et al., 2014). The transesterification process was used to esterifies the crude oil from vegetables and thus it was converted into biodiesel. The esterified oil called biodiesel could reduce viscosity and increased cetane number (CN) (Subba Rao et al., 2013). Many countries like India have adopted the NPB under the commitment in United Nations Framework Convention on Climate Change (UNFCCC). The policy proposed 20% biofuel (ethanol and biodiesel) mandatory up to 2030–2031 (Purohit and Subash, 2015).

Fossil diesel fuel and biodiesel have different thermophysical properties; hence by their use in internal combustion engines, the combustion characteristics are different. Biodiesel contained lower carbon (10%) and higher oxygen (11%) than diesel fuel (Dwivedi et al., 2013). This caused the net heat release rate (HRR) was enhanced during the biodiesel combustion and could reduce CO, HC, and smoke emissions (except NOx) (Parlak et al., 2013; Dhinesh et al., 2016; Parida and Rout, 2017). During biodiesel blend fuel injection in the combustion chamber of CI engine, the start of injection was advanced. It was due to the higher bulk modulus property of biodiesel fuel. After injection of biodiesel in combustion chamber the earlier start of combustion was observed than fossil diesel fuel. It was due to excess oxygen content (Lahane and Subramanian, 2015). Therefore this variation in timing from injection as well as start of combustion with biodiesel application caused the reduce ignition delay (ID). It further reduces the MRPR. The reduced MRPR confirms the reduction in noise and knocking tendency of engine operation. The higher cetane number with biodiesel blends also helpful for reduction in ID. Hence combustion characteristics analysis of any fuel application in engine was highly helpful to evaluate its further applicability. It is also helpful to determine the suitable measures for further improvements in performance and reduction in emissions.

The brake thermal efficiency (BTE) of CI engine at biodiesel blend fuel operation was decreased. The decreased BTE was due to the lower heating value of the biodiesel blend. Hence for enhancing the performance, these biodiesel blends were used in low heat rejection engine (LHRE). The conventional diesel engine (CE) rejects about two-thirds of the heat energy of the fuel [one-third to the coolant and one third to the exhaust] and leaves only about one-third energy to convert it to useful power. Theoretically, if the heat rejected could be reduced, then the BTE may be improved. BTE improvement may reach at least up to the limit set by the second law of thermodynamics

(Vedharaj et al., 2014) Hence in this experimentation biodiesel blends are used in LHRE for doing the combustion analysis which helps to predict expected performance and reduced emission.

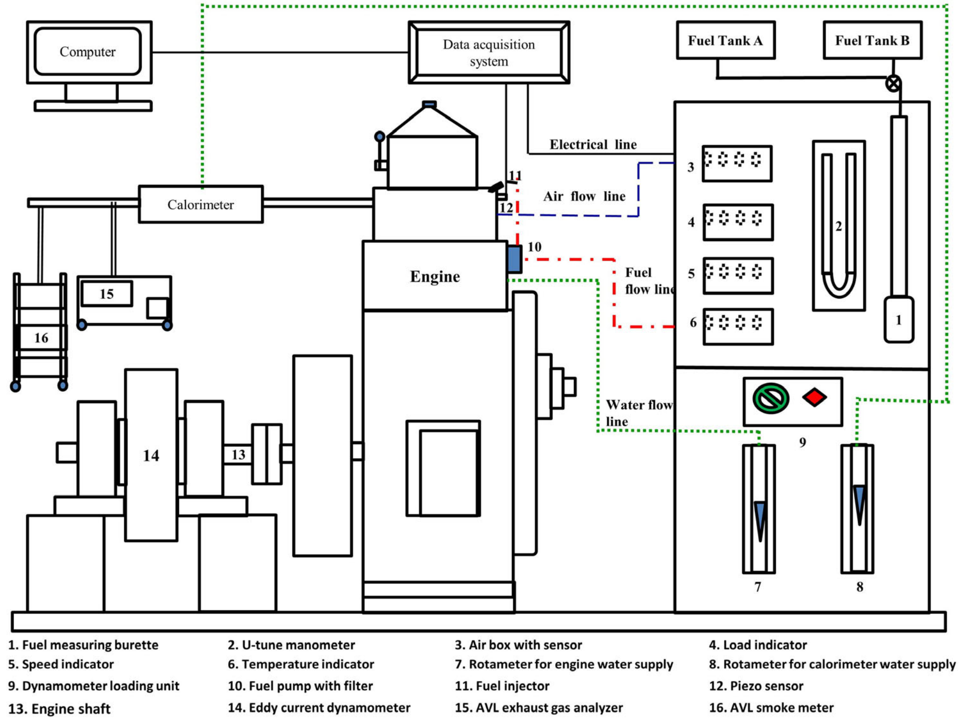
The diesel engine with its combustion chamber walls (crown of combustion chamber components) were insulated by ceramics is referred as a LHR engine (Işcan and Aydin, 2012). Thermal barrier coatings (TBC) were used to improve reliability and durability of hot section metal components and also to enhance engine performance of diesel engines. Due to lower heat rejection increases the temperature of the combustion chamber. Higher combustion chamber temperature changes the combustion characteristics in LHRE operation. Mohamedmusthafa (2011) used Al_2O_3 as a coating material for combustion chamber elements. The thickness of the coating was 200 µm by using plasma spray-coating method. The experimentation was carried out with Pongamia methyl ester (PME) blends of 20% and 40% by volume with diesel. They observed that engine power was increased and specific fuel consumption decreased. Also, the significant improvements in CO, HC and smoke density (except NOx) were observed. Masera and Hossain (2018) reviewed the various research papers and reported that LHRE operation could attain around 11% higher IGT compared to CE operation. They were also noticed that increased IGT was responsible for the reduction in the ID, increase in-cylinder gas pressure (IGP), increase multi-fuel operational ability, improved mixability of fuel with air, quicker vaporisation of the fuels, easy start-up of the engine and less noise and knocking during combustion. From the review report, LHRE operation shows the reduced CO, HC and smoke (opacity) emissions around 20%, 50% and 25% respectively compare to CE. But NOx emission was increased nearly 30%. Karthickeyan et al. (2019) was used total 500 µm coating (including NiCrAl and PSZ) on combustion chamber components to form LHRE. Performance and emission characteristics were improved with lemon oil biodiesel application. This was due to adding of cetane enhancer in lemon oil (as lemon oil had lower cetane number but better calorific value). In present experimental investigation of combustion characteristics, the mullite material (Al_2O_3 + SiO_2) was applied to insulate the engine components (crown of Piston, cylinder head and both valves). The mullite material has excellent properties such as toughness, high expansion coefficient and low thermal conductivity. It also has lower density, better thermal stability, poor thermal conductivity and favourable strength (Shrirao and Pawar, 2011). The sustainability of mullite coating on engine components is significantly better than other zirconia material (Kokini et al., 1996). Engine performance and its various pollutants level in the atmosphere mostly depends on engine operation and its design for a particular fuel application (diesel/petrol). By using the baseline fuel (fossil diesel fuel) in diesel engine operation, there are some combustion characteristics which govern the output and emission parameters. While the use of biodiesel blend without modification or with modification (LHR) in the engine, the combustion characteristics must be vary from baseline diesel fuel of CE operation. In present experimental study for predicting the expected performance and emission characteristics from conventional as well as LHR engine with biodiesel application, the various combustion characteristics are determined. These characteristics are compared with characteristics from normal diesel fuel in CE operation.

2 Setup for experimentation and material

2.1 Setup for experimentation

The experimentation was executed with biodiesel application in four strokes, single combustion cylinder diesel engine. The engine body temperature was maintained by jacket water cooling. A dynamometer (type-eddy current) was attached for measuring its power. The schematic representation for the arrangement to measure various characteristics is shown in Figure 1.

Figure 1 Test rig for single cylinder DI diesel engine (see online version for colours)



The specifications of engine are as per mentioned in Table 1. The experimental setup comprises different instruments for measurements of fuel flow rate, temperatures at required position, engine load, combustion chamber gas pressure and crank angle. Two sets of rotameter attached to water pump line that maintains cooling water circulation in engine jacket cooling and in calorimeter for exhaust heat loss estimation. A burette was attached to measure fuel flow rate. U-tube manometer was attached to measure airflow for fuel combustion in the engine cylinder.

K-type thermocouples were attached to the digital temperature indicators for measuring room temperature, engine cylinder temperature and temperature across the calorimeter were measured by using connected to digital indicator. A piezo sensor was connected to the head of engine cylinder for measurement of pressure during fuel combustion. A rotary encoder was mounted near the main shaft of engine which records crank angle position signals. Collectively the pressure and crank angle signals were recorded at the same time and interface with a computer. The setup had separate arrangement for attaching exhaust gas analyser to measure all emission parameters.

Table 1 Specifications of single cylinder diesel engine

Rated output	5 HP (3.67 kW)
Make	Kirloskar India Pvt. Ltd.
Model	TV1 (water cooled)
Speed	1,500 RPM
Compression ratio	18:01
Injection pressure	210 bar
Dynamometer	Eddy current, water cooled with loading unit

2.2 *Material*

Experimentation from CE as well as LHRE is carried out with transesterified jatropha oil. LHRE was created by doing TBC (mullite material) on the crown of the piston, cylinder head and both valves. Jatropha crude oil has a higher viscosity, lower volatility and poor heating value. These characteristics causes' problems like injector blocking, gummy piston rings, thickening lubrication oil from long term use and filter gumming. These problems were controlled by doing transesterification of crude biodiesel to procedure monoesters (or biodiesel). Hence many researchers (Vedharaj et al., 2014) had discussed the transesterification process to generate biodiesel from crude vegetable oil. Esterified biodiesel with improved properties was suitable for engine operation. The thermophysical character ties of transesterified jatropha oil and fossil diesel are shown in Table 2.

Table 2 Properties of fuels

Thermal characteristics	*Fossil diesel*	*Transsterified jatropha oil (EJO)*
Density (kg/m^3)	846	870
Kinematic viscosity. (cSt)	2.51	12.408
Calorific value (kJ/kg)	42,600	35,500
Flash point (°C)	64	180
Cetane number	46	51.3

In present combustion analysis, 20% and 30% EJO combined with pure diesel to form B20 and B30 blend fuels which were used for experimentations.

CE was converted to LHRE by doing TBC on combustion crown of combustion chamber components. METCO 6150 (Make-Oerlikon Metco) mullite material was used to as a topcoat material and NiCrAlY was considered as a bond material between coating components and mullite top coat material. The coating was carried out by using atmospheric plasma spray process. It involves a gun through which TBC (mullite) powder and bond coat (NiCrAlY) dust material at higher plasma temperature stage and with a high velocity sprayed over the crown of engine components. The mixture of argon and hydrogen, were allowed in plasma gun between the anode (copper) and the cathode (tungsten). Water as a coolant was circulated to spray machine for maintaining normal temperature to machine drives. Micromachining operation on coating surfaces of the engine components was carried out before the coating operation. Micromachining helps to adhere to coating material on substrates. It also helped to maintain the same compression ratio after the coating process. Initially, bond coat with 75 µm thick was provided to develop the adhesive property between mullitecoating and engine components. Finally, mullite powder with 250 µm thick layer was sprayed. The combustion characteristics with B20 and B30 fuels from the operations of coated (LHRE) and uncoated conventional engine (CE) were compared to the characteristics from normal diesel operated CE.

3 Results and discussion

3.1 In-cylinder gas pressure

The IGP variation with crank angle position ($p - \varphi$) during the power cycle operation for both conventional as well as the LHR engine was represented, as shown in Figure 2. The combustion characteristics with B20 and B30 fuels from the operations of coated (LHRE) and uncoated CE were compared to the characteristics from fossil diesel operated CE. The combustion characteristics were estimated at rated load and constant speed (1,500 rpm) condition. The pick IGP was increased with an increase in biodiesel quantity from B20 to B30 fuel. While injecting fuel through fuel pump, the pressure waves are formed in fuel supply line. In case of biodiesel application, these pressure waves transmitted more rapidly just before the injector nozzle hence fuel injection was advanced (Lahane and Subramanian, 2015). The growth in pressure (waves) of injecting fuels in the injector is straight proportional to bulk modulus of the fuel. Higher bulk modulus in biodiesels (about 150 MPa high) than fossil diesel fuel was noticed (Lahane and Subramanian, 2015). It is the ratio of variation in pressure (dp) of fuel fluid with its volumetric strain (dv/v). As the injecting fuel is liquid and hence incompressible, the volumetric strain (dv/v) was considered constant. Increase in share of biodiesel in blend fuel for its injection results in higher fuel line pressure. Hence biodiesel blend injection was earlier than expected crank angle injection point called injection advance. The injection advance and higher dissolved oxygen in biodiesel caused the earlier ignition. This injection and ignition change on crank angle position caused reduces ID (discussed latter in Figure 8). Better combustion with higher peak pressure was noticed in premixed combustion phase during biodiesel operation. The peak pressure of fossil diesel, B20 and B30 fuels are 60.16, 62.29 and 63.79 bar in CE operation as shown in Figure 3.

In case of LHR engine, the higher in-cylinder gas temperature (IGT) was noticed. It was due to lower heat rejection from combustion chamber walls which was accelerated ignition timing. Thus could further reduce the ID and complete combustion of biodiesel blend. Finally increased peak pressure in LHRE operation was noticed than CE. The peak pressure of B20 and B30 fuels are 65.47 and 65.70 bar in LHRE operation respectively as shown in Figure 3.

3.2 In-cylinder gas temperature

The IGT was increased with biodiesel blend B20 and B30 fuel relates to fossil diesel application as shown in Figure 4. Similar to in-cylinder pressure, the pick temperature in combustion chamber also increased from B20 to B30 biodiesel fuel. This increased IGT was found due to reduced ID period and better combustion because of supplementary oxygen molecule present in biodiesel. These properties were helped to maintain better improvements in complete combustion. The IGT with diesel, B20 and B30 is 1,093°C, 1,144°C and 1,149°C respectively in CE operation. The IGT of same B20 and B30 blend fuel was further increased to 1,171°C and 1,175°C respectively with LHRE operation.

Figure 2 The variations in combustion chamber pressure with crank angle (see online version for colours)

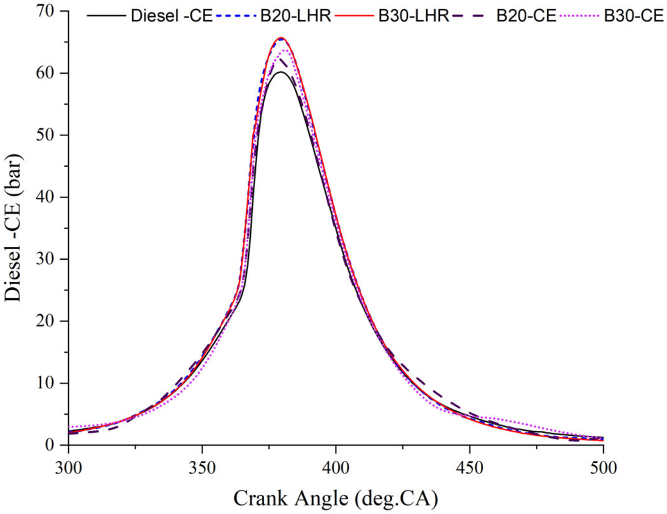


Figure 3 The variations in peak in-cylinder pressure for various fuels

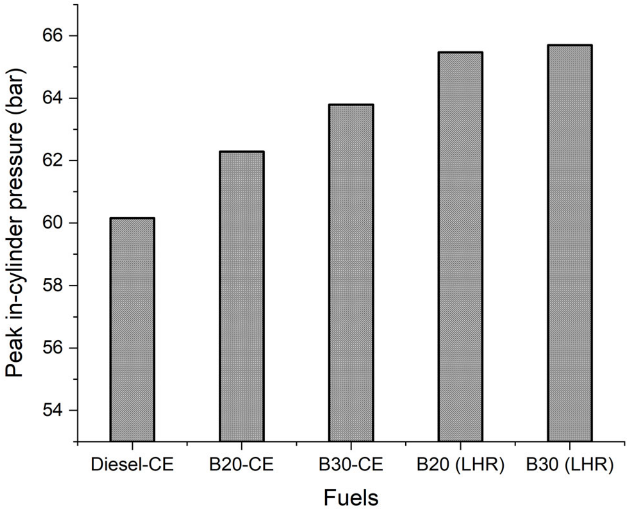
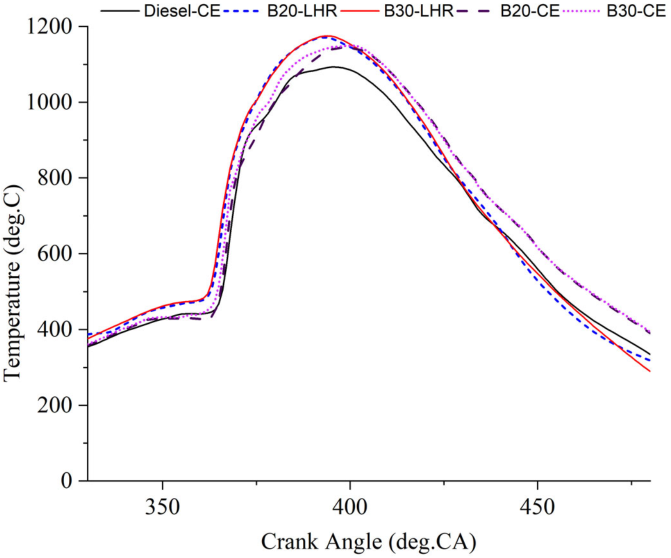


Figure 4 The variations in combustion chamber temperature with crank angle (see online version for colours)



3.3 *Maximum rate of pressure rise (MRPR)*

For any change in engine operation (by fuel change or modification by coating), smoother engine operation is expected. The change in pressure per degree crank angle (or MRPR) is a useful indicator for knowing the engine operation. The smoother engine operation by using fossil diesel in CE operation (through its MRPR indicator) was compared with the operation (MRPR indicators) of B20 and B30 fuel blends at both the engine operations. The variations in rapid growth and reduction of pressure per crank angle position was analysed and shown in Figure 5. The maximum values of sudden rise and fall in pressure per crank angle position (by Figure 5) called MRPR is shown in Figure 6. The MRPR for fossil diesel, B20 and B30 fuels at CE operation was 6.33 bar/°CA, 5.91 bar/°CA and 5.79 bar/°CA respectively. The reduction in MRPR during biodiesel blends with CE operation provides further improvements in smoother engine operation.

MRPR results with biodiesel blends B20 and B30 from LHRE operation were slightly increased and up to 5.98 bar/°CA and 5.89 bar/°CA respectively. The slight increase in MRPR with LHRE operation was observed. It was due TBC on combustion chamber components which causes increase in-cylinder temperature. It also advances the start of combustion in LHRE operation. Though MRPR results lower than 9 bar/°CA for both the CE as well as LHRE which reflects smoother engine operation (Shelke et al., 2016). Hence, smoother engine operation during conventional (without coated engine components) as well as modified (coated by thermal barrier mullite material coating) operation with biodiesel was noticed.

3.4 Net HRR

The variations in net HRR with engine crank angle position for pure diesel, B20 and B30 at rated load is shown in Figure 7. The NHRR plot is useful tool to evaluate ID and various combustion phases (premixed, diffusion and afterburning) for every fuel samples. The net HRR at particular crank position is estimated by using first law of thermodynamic.

Figure 5 The variations in rate of pressure rise with crank angle (see online version for colours)

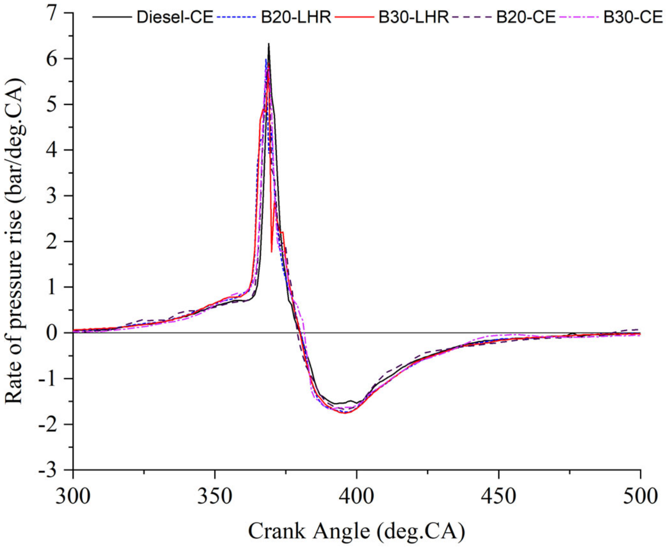


Figure 6 The variations in MRPR for various fuels

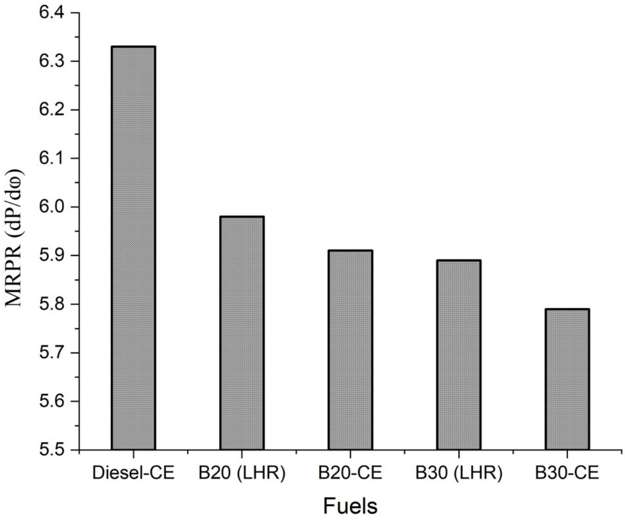


Figure 7 The variations in net HRR with crank angle (see online version for colours)

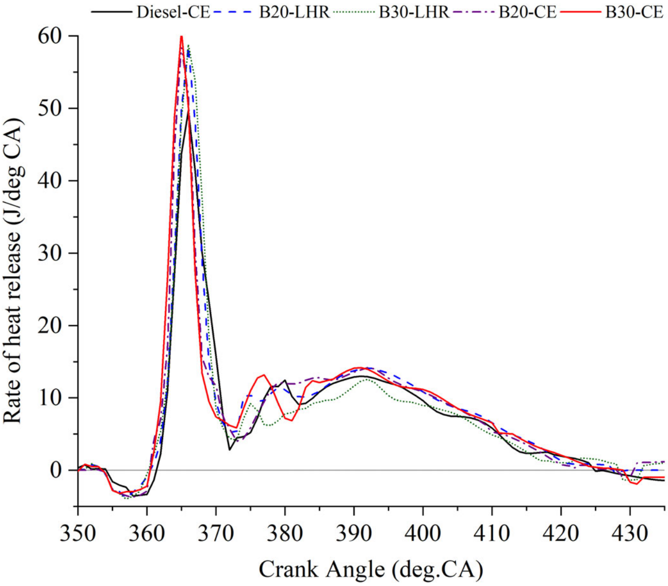
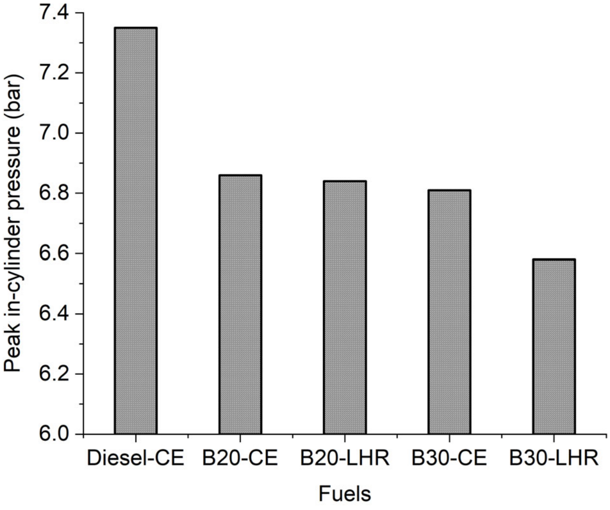


Figure 8 The variations in ID for various fuels



3.5 Ignition delay

Ignition of injected fuel does not initiate as soon as it injected in combustion chamber. It takes certain delay (physical and chemical delay). The ID was actually calculated from the crank position of negative net HRR loop which can be observed straight earlier to the initiate fuel combustion as shown in Figure 8. The negative loop was formed due to the endothermic reaction of the combustible air-fuel mixture (Subramanian and Lahane, 2012). It is reduced from pure diesel to biodiesel blends in CE. With an increase in biodiesel share its ID decreases. This decrease in ID with biodiesel operation was due to higher cetane number and higher bulk modulus as discussed earlier. Biodiesel blend (B20 and B30) had advanced injection timing as compared to pure diesel operation. The reduction in ID was responsible for improvement in complete fuel combustion during premixed phase. The ID period of pure diesel, B20 and B30 was observed as 7.35°CA, 6.86°CA and 6.81°CA respectively. In LHRE operation, it was further reduced. This further reduction in ID period in LHRE operation was due higher internal energy available in the combustion chamber. TBC on combustion chamber components was responsible for lowering heat rejection through jacket cooling. Higher internal energy available in combustion chamber provides retardation in start of ignition time and it ignited the fuel earlier. For biodiesel blends B20 and B30, the ID was further reduced to 6.84°CA and 6.58°CA respectively in LHRE operation. It was responsible for further improvement in combustion.

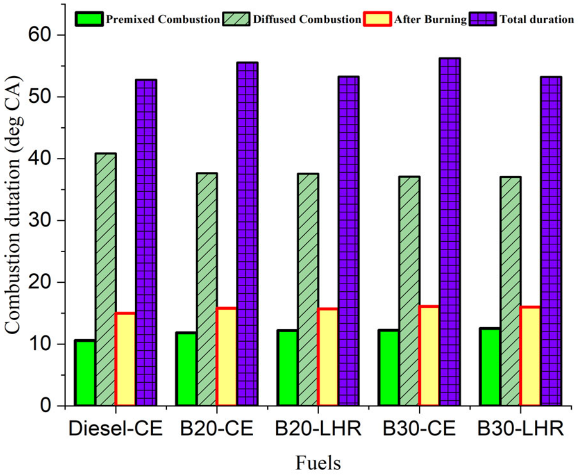
3.6 Premixed, diffused and afterburning combustion phase

The changes various combustion phases (premixed, diffused and afterburning) for fossil diesel, B20 and B30 fuel are shown in Figure 9. Premixed or rapid combustion phase was controlled by altering the ID period. NOx emission increases with increase in premixed combustion duration (Jagtap et al., 2020). Hence this phase is responsible for high NOx formation and knocking in engine operation. During premixed combustion, certain quantity of injected fuel provides rapid rise in HRR and forms high peak loop in the NHRR plot (refer to Figure 7). The peak HRR as well as peak IGP was responsible for the generation of higher temperature as discussed earlier. Oxidation of nitrogen happens at a higher temperature. Hence for higher temperature higher NOx would have been formed. For biodiesel operation, the premixed combustion duration was increased. Hence NOx formation tendency is higher (Subramanian and Lahane, 2012) but it also tends to complete the combustion. The premixed combustion (high peak loop) duration for pure diesel, B20 and B30 fuels was 10.59°CA, 11.84°CA and 12.54°CA respectively during CE operation. This premixed combustion duration was raised to 12.2°CA and 12.54°CA for B20 and B30 fuels respectively during LHRE. This was due to early start of combustion and reduced ID period.

A certain quantity of fuel (which was mixed in air and vaporised during delay period) was consumed in premixed phase. The further fuel burning rate is controlled by a mixture available in the combustion chamber during an injection span called controlled or diffused combustion phase. From the HRR plot, the second lower peak loop is recognised as diffused combustion phase. The diffused phase is liable for smoke formation. It reduced somewhat from B20 to B30 fuel compare to pure diesel operation as shown in Figure 9. The decreased in the controlled combustion phase is responsible for the reduction in smoke and CO formation (Jagtap et al., 2020). The diffused combustion duration of diesel, B20 and B30 fuel was 40.84°CA, 37.62°CA and 37.07°CA respectively with CE operation. Further, the diffused combustion phase for B20 and B30 blends was reduced to 37.58°CA and 37.04°CA, respectively.

After controlled combustion duration heat release continued at a lower rate during expansion stroke. Combustible charge in the cylinder was non-uniform and hence this phase promotes complete combustion. Finally burnout process becomes slower and cylinder gas temperature falls during expansion stroke. As the afterburning phase increases the total combustion duration also increases. It was increased from B20 to B30 blend during CE operation. The afterburning phases of fossil diesel, B20 and B30 were 14.98°CA, 15.81°CA and 16.1°CA, respectively. The same biodiesel blends responded for the reduction of afterburning phase during LHRE operation. The reduced afterburning phase was 15.7°CA and 15.98°CA for B20 and B30 fuels, respectively. This reduction in afterburning phase duration was due to advance burning of all fuel molecules during LHRE operation. Overall the complete burning time per cycle was reduced during LHRE compares to CE operation as shown in Figure 9. Hence, the improved combustion of biodiesel during LHRE operation was observed.

Figure 9 The variations of premixed, diffused and afterburning phases (see online version for colours)



4 Conclusions

As many countries have adopted the NPB under the commitment in UNFCCC, India's NPB-2018 targeted the reduction in energy emissions intensity up to 33%–35% by 2030. Hence in this experimentation, B20 and B30 biodiesel blends were taken into consideration for attaining the emissions intensity targeted by the policy. For sustainable development, transesterified jatropha oil was selected for the application of biofuel. Biodiesel blended diesel fuels (B20 and B30) were used for experimentation to evaluate combustion characteristics of a single cylinder, direct injection, diesel engine. Also for further improvement in characteristics, the biodiesel blends were considered for experimentation in LHRE. The Oerlikon Metco made mullite material (Metco-6150) was considered as TBC material for forming LHRE. Mullite coating was made on the crown of piston, cylinder head and both valves. The combustion characteristics from both conventional as well as low heat rejected engine with esterified biodiesel blend (B20 and B30) were drawn. Also, the combustion characteristics at conventional (without mullite material coated) engine for the use of fossil diesel were evaluated for baseline reference. Hence the combustion characteristics at biodiesel blends operation during coated and uncoated engines were compared with baseline operation which are helpful to predict the performance and emission effect:

- While using biodiesel blend (B20 and B30) application higher IGT and pressure in coated and uncoated engines was observed. The highest IGT was observed for B30 fuel in LHRE operation. Hence this higher temperature can enhance the NOx emission.
- ID of biodiesel blends (B20 and B30 fuels) was reduced with CE operation. It was also further reduced in LHRE operation.
- Premixed combustion stage was increased in both B20 and B30 fuel operation which is the good sign of better combustion.
- Decreased diffused combustion phase with B20 as well as the B30 fuel was noticed. It was due to that more fraction of mass burned in earlier work generating premixed combustion phase. The decreased in diffused combustion phase can reduce smoke and CO formation.
- The MRPR was decreased with biodiesel at CE operation, which has provided the smoother engine operation. MRPR with biodiesel blends was slightly increased in LHRE but it was lower than baseline operation. Thus it did not affect the smoother engine operation while biodiesel application in LHRE also.

The above combustion results were observed for stationary diesel engine operation at a constant speed and variable load condition. Hence biodiesels application is more suitable in power generating units (DG set). The combustion results were useful for predicting the expected performance and emission quality of a diesel engine with biodiesel fuels. Biodiesel blending in conventional diesel fuel improves fuel combustion, but it may increase NOx formation. In further analysis of the existing study, a suitable method for NOx reduction is to be considered and compare the combustion characteristics with baseline operation for confirming the importance of combustion characteristics. In future biodiesel may be one of the easy and low-priced alternative fuels for various needs.

References

Agarwal, D., Kumar, L. and Kumar, A. (2008) ‘Performance evaluation of a vegetable oil fuelled compression ignition engine’, *Renewable Energy*, Vol. 33, No. 6, pp.1147–1156.

Cahyanti, M.N., Doddapaneni, T.R.K.C. and Timo, K. (2020) ‘Biomass torrefaction: an overview on process parameters, economic and environmental aspects and recent advancements’, *Bioresource Technology*, April, Vol. 301.

Dabi, M. and Saha, U.K. (2019) ‘Application potential of vegetable oils as alternative to diesel fuels in compression ignition engines: a review’, *Journal of the Energy Institute*, Vol. 92, No. 6, pp.1710–1726.

Dhinesh, B., Lalvani, J.I.J.R., Parthasarathy, M. and Annamalai, K. (2016) ‘An assessment on performance, emission and combustion characteristics of single cylinder diesel engine powered by Cymbopogon flexuosus biofuel’, *Energy Conversion and Management*, 1 June, Vol. 117, pp.466–474, https://doi.org/10.1016/j.enconman.2016.03.049.

Dwivedi, G., Jain, S. and Sharma, M.P. (2013) ‘Diesel engine performance and emission analysis using biodiesel from various oil sources – review’, *Journal of Materials and Environmental Science*, Vol. 4, No. 4, pp.434–447.

Işcan, B. and Aydin, H. (2012) ‘Improving the usability of vegetable oils as a fuel in a low heat rejection diesel engine’, *Fuel Processing Technology*, June, Vol. 98, pp.59–64.

Jagtap, S.P., Pawar, A.N. and Lahane, S. (2020) 'Improving the usability of biodiesel blend in low heat rejection diesel engine through combustion, performance and emission analysis', *Renewable Energy*, August, Vol. 155, pp.628–644.

Karthickeyan, V., Thiyagarajan, S., Geo, V.E., Ashok, B., Nanthagopal, K., Chyuan, O.H. and Vignesh, R. (2019) 'Simultaneous reduction of NOx and smoke emissions with low viscous biofuel in low heat rejection engine using selective catalytic reduction technique', *Fuel*, et al. November, Vol. 255.

Kokini, K., Takeuchi, Y.R. and Choules, B.D. (1996) 'Surface thermal cracking of thermal barrier coatings owing to stress relaxation: zirconia vs. mullite', *Surface and Coatings Technology*, Vol. 82, Nos. 1–2, pp.77–82.

Lahane, S. and Subramanian, K.A. (2015) 'Effect of different percentages of biodiesel-diesel blends on injection, spray, combustion, performance, and emission characteristics of a diesel engine', *Fuel*, 1 January, Vol. 139, pp.537–545.

Masera, K. and Hossain, A.K. (2018) 'Biofuels and thermal barrier: a review on compression ignition engine performance, combustion and exhaust gas emission', *Journal of the Energy Institute*, Vol. 92, No. 3, pp.1–19.

Mohamedmusthafa, M. (2011) 'Effects of Al2O3 coating on diesel engine performance, combustion, and emission characteristics fueled by pongamia methyl ester and its blends with diesel', *Environmental Progress and Sustainable Energy*, Vol. 31, No. 1, pp.147–156.

Murali Krishna, M.V.S., Seshagiri Rao, V.V.R., Kishen Kumar Reddy, T. and Murthy, P.V.K. (2014) 'Comparative studies on performance evaluation of DI diesel engine with high grade low heat rejection combustion chamber with carbureted alcohols and crude jatropha oil', *Renewable and Sustainable Energy Reviews*, August, Vol. 36, pp.1–19.

National Policy on Biofuels (NPB) (2018) *Ministry of Petroleum and Natural Gas Notification*, The Gazette of India, pp.13–23.

Oberweis, S. and Al-Shemmeri, T.T. (2011) 'Emissions and performance of a stationary diesel engine run on biodiesel blends', *Int. J. Oil, Gas and Coal Technology*, Vol. 4, No. 4, pp.375–386.

Parida, M.K. and Rout, A.K. (2017) 'Investigation of performance and emission analysis of argemone Mexicana biodiesel blends as a fuel in a DICI engine at part load conditions', *Energy Sources, Part A: Recovery, Utilization and Environmental Effects*, Vol. 39, No. 6, pp.623–629.

Parlak, A., Karabas, H., Ozsert, I., Ayhan, V. and Cesur, I. (2013) 'Effects of tobacco seed oil methyl ester on performance and exhaust emissions of diesel engine', *Journal of the Energy Institute*, Vol. 86, No. 3, pp.147–152.

Purohit, P. and Dhar, S. (2015) *Biofuel Roadmap for India*, UNEP DTU Partnership, Technical University of Denmark, Denmark.

Shelke, P.S., Sakhare, N.M. and Lahane, S. (2016) 'Investigation of combustion characteristics of a cottonseed biodiesel fuelled diesel engine', *Procedia Technology*, Vol. 25, pp.1049–1055.

Shrigiri, B.M., Hebbal, O.D. and Reddy, K.H. (2016) 'Performance, emission and combustion characteristics of a semi-adiabatic diesel engine using cotton seed and neem kernel oil methyl esters', *Alexandria Engineering Journal*, Vol. 55, No. 1, pp.699–706.

Shrirao, P.N. and Pawar, A.N. (2011) 'Performance evaluation of single cylinder diesel engine with mullite as thermal barrier coating and its validation using MATLAB', *Int. Journal of Emerging Trends in Engineering and Development*, November, Vol. 3, pp.–50.

Siddiqui, M.H., Kumar, A., Farooqui, A., Kesari, K.K. and Arif, J.M. (2011) 'Biodiesel production from crude oil of Jatropha curcas and Pongamia pinnata by transesterification process', *Int. J. Oil, Gas and Coal Technology*, Vol. 4, No. 2, pp.192–206.

Subba Rao, B., Murthy, P.V.K., Ramjee, E. and Murali Krishna, M.V.S. (2013) 'Studies on exhaust emissions and combustion characteristics of tobacco seed oil in crude form and biodiesel from a high grade low heat rejection diesel engine', *International Journal of Industrial Engineering and Technology (IJIET)*, Vol. 3, No. 1, pp.27–36.

Subramanian, K.A. and Lahane, S. (2012) 'Comparative assessment of injection, combustion, performance and emission characteristics of a diesel engine for biodiesel-diesel blends', *International Journal of Renewable Energy Technology*, Vol. 3, No. 4, p.410.

Vedharaj, S., Vallinayagam, R., Yang, W.M., Chou, S.K., Chua, K.J.E. and Lee, P.S. (2014) 'Experimental and finite element analysis of a coated diesel engine fueled by cashew nut shell liquid biodiesel', *Experimental Thermal and Fluid Science*, February, Vol. 53, pp.259–268.

Abbreviations and nomenclature

Abbreviations	
CE	Conventional engine
CI	Compression ignition
LHRE	Low heat rejection engine
BTE	Brake thermal efficiency
HC	Hydrocarbon
CO	Carbon monoxide
NOx	Oxides of nitrogen
CN	Cetane number
MRPR	Maximum rate of pressure rise
TBC	Thermal barrier coating
ID	Ignition delay
B20	20% biodiesel + 80 diesel
B30	30% biodiesel + 70 diesel
EJO	Esterified jatropha oil
Nomenclature	
P	In-cylinder gas pressure
φ, CA	Crank angle
ppm	Part per million
T	Temperature
$r = \frac{C_p}{C_v}$	Specific heat ratio (1.3 to 1.35)
$\frac{dQ_{ht}}{d\theta}$	Heat transfer through cylinder wall (J/°CA)
P	Instantaneous pressure (N/m^2)
V	Instantaneous volume (m^3)
h_c	Heat transfer coefficient (W/m^{2}K)
P_c	Instantaneous cylinder pressure (bar)
V_p	Mean piston velocity (m/s)
V	Instantaneous cylinder volume (m^3)
T_g	Cylinder charge temperature (k)
N	Engine rpm
T_w	Wall temperature (k)
A_c	Surface area of heat transfer (m^2)