Available online at www.sciencedirect.com

ScienceDirect

Procedia Technology 25 (2016) 1049 – 1055

Procedia Technology

Global Colloquium in Recent Advancement and Effectual Researches in Engineering, Science and Technology (RAEREST 2016)

Investigation of Combustion Characteristics of a Cottonseed Biodiesel Fuelled Diesel Engine

Pankaj S. Shelke[a], Nitin M. Sakhare[a], Subhash Lahane[a]*

Department of Mechanical Engineering, MIT Aurangabad, 431010, Maharashtra, India

Abstract

Diesel engines are very well known for their high torque and high thermal efficiency. But, the increase in demand of energy, rapid depletion of fossil fuels and meeting the stringent emission regulations, the researchers take interest to derive the alternative fuels from renewable resources. Among from all the different alternative fuels, vegetable oil has potential to substitute the traditional diesel fuels. The well-established transesterification process is generally used for the production of biodiesel from vegetable oil. In transesterification process the tri-glycerides are converted into mono glycerides with the help of alcohol and catalyst under certain temperature. In the present research work cottonseed vegetable oil is used to produce biodiesel by transesterification process using methanol and KOH as catalyst. As diesel engine combustion is heterogeneous spray combustion, it is very complex phenomenon. The physico-chemical properties of biodiesel are slightly different from diesel fuel. It is very interesting to study the combustion characteristics of a cottonseed based biodiesel fuelled diesel engine. This was the main motivation to take up this study to understand and analyze the combustion characteristics of a cottonseed biodiesel fuelled diesel engine. The experiment was carried out on a single cylinder diesel engine for base diesel and cottonseed biodiesel blends (B5, B10, B15, and B20) as a fuel. The combustion characteristics such as ignition delay, start of combustion, premixed, diffusion and after burning combustion phases, end of combustion and combustion duration were analyzed and compared with base diesel. It was observed that ignition delay and maximum rate of pressure rise decreased with biodiesel as compared to base diesel due to higher cetane number of biodiesel blends which confirms the smooth running of the engine. Ignition delay decreased from 11 ºCA with base diesel to 6.5 ºCA with B20 biodiesel. The start of combustion was advanced with all biodiesel blends due to higher bulk modulus results in automatic advance in dynamic injection timing and lesser ignition delay. The combustion duration was longer with all biodiesel blends as compared to base diesel due to longer injection duration results in poor performance of the engine with biodiesel blends.

* Corresponding author. Tel.: +91-240-2375199; Fax: +912402375275
E-mail address: subhashlahane@gmail.com

doi:10.1016/j.protcy.2016.08.205

Keywords: Cotton seed biodiesel, diesel engine, combustion characteristics, combustion phases, heat release rate

1. Introduction

Due to the petroleum shortage the researchers take interest in finding the alternative fuels for internal combustion engine. There are various types of alternative fuels available for internal combustion engine but biodiesel is most important alternative to diesel engine. Biodiesel is popular due to its renewability, lower exhaust emissions, and biodegradability [1]. Most of the researchers have defined transesterification is one of the process for production of biodiesel. Transesterification process is most suitable method used for the production of biodiesel [2]. Biodiesel is a nontoxic, biodegradable and renewable alternative as compared with diesel fuel. The properties of biodiesel are somewhat similar with the diesel fuel. Therefore with few or no any engine modifications are required to use biodiesel in diesel engine. Biodiesel has higher cetane number than petroleum diesel fuel and it does not contain aromatics. The availability of oxygen contains is around 10% to 11% by weight. Due to these characteristics of biodiesel, the emissions reduced in the exhaust gas as compared to base diesel fuel [3]. The cottonseed crop is a fast growing plant and that grows even on drought and poor soils. Biodiesel also sustains at high temperature up to 44°C and at low temperature of up to 4°C. Cotton was the third biggest crops grown worldwide as measured by acreage: soybean which is 47%, occupying 75.4 million hectares; biotech maize (51 million hectares at 32%), biotech cotton (around 24.7 million hectares at 15%) and biotech canola (8.2 million hectares at 5%) [4, 5]. The use of biodiesel in diesel engine increased brake thermal efficiency and reduces emissions [6]. It was also found that additives improved the fuel blend properties like density and viscosity which in turn of improved in the atomization of fuel and showed better combustion characteristics. It results in to higher brake power (BP), lower brake specific fuel consumption (BSFC) and higher brake thermal efficiency (BTE) than diesel [7]. Capered et al. [8] revealed that by using B5, B20 and B100 produced a peak power of 13.6 kW, 13.4 kW and 13.1 kW. Brake-specific fuel consumption increases by using B5, B20 and B100 were 1276, 1155 and 1238 g/kW-h. Carbon monoxide emissions increased by an average 15% and 19% by using B5 and B100. Hydrocarbon emissions decreased by 14% and 26% by using B5 and B100. Oxides of nitrogen (NOx) emission decreased by 4%, 5% and 14 % with B5, B20 and B100 biodiesel blends respectively. However, most of literatures revealed that CO, HC and smoke emissions decreased with biodiesel whereas oxides of nitrogen, carbon dioxide and BSFC increased with biodiesel [9-11]. Sulphur dioxide emissions decreased by an average of 86% and 94% by using B100 and B50 biodiesel blended with ultra-low sulphur diesel. The higher oxygen content of biodiesel improved premixed combustion phase to progress in a better way which leads to better combustion. It is also mentioned that premixed combustion phase is responsible for higher NOx emission [9-10]. B15 blend shows 2.67%, 3.81%, 4.22% and 5.31% higher peak pressure than diesel at 20%, 40%, 60% and 80% load respectively. Gopal and Karupparaj [12] revealed that combustion starts earlier for base biodiesel and its blends with diesel. The peak heat release rate of biodiesel fuels is lower than conventional diesel fuel because of shorter ignition delay period and lower calorific value (CV) of biodiesel that contributes to lower heat release rate. Combustion for biodiesel starts earlier which results in to shorter ignition delay period and advanced injection timing at all engine loads. The biodiesel gives similar power output as that for diesel. The BSFC for biodiesel increases due to lower heating value of biodiesel. The rate of heat release for diesel fuel is slightly lower than that for biodiesel at lower engine loads. But, as the engine load increases, the heat release rate for diesel is increased and it is higher than that of diesel because of the longer ignition delay period, all through which more fuel is accumulate in the combustion chamber which releases higher heat during the premixed combustion phase. At higher engine loads, the peak cylinder pressures for both fuels are almost same, but the rate of pressure rise and rate of heat release are lower for biodiesel. Mattarelli et al. [13] reported that BSFC of rapeseed biodiesel increased by 18% than diesel, soot formation reduced by 37.5%. The in-cylinder pressure at low rpm for diesel is higher, revealing a smother combustion start for biodiesel blends. The in-cylinder pressure analysis shows slight differences in the premixed combustion phase, depending on engine speed, at low speed the presence of biodiesel seems to speed up combustion whereas, at high speed, the situation is reversed; after the completion of first combustion phase, the difference among the fuels become smaller. It is also observed that ignition delay period decreases with biodiesel than diesel due to the complex and rapid preflame chemical reaction which generally takes place at high temperatures. As a result of the high cylinder temperature and existing fuel injection condition, biodiesel may go through thermal cracking and results in formation of lighter compounds. This earlier ignition result in a shorter ignition delay [14-15]. Kuti et al. [16] For all fuels, the peak heat release rate increases as the load increased which tends to high temperature, high cylinder pressure, better fuel–air mixing, and higher flame velocity at higher loads.

Nomenclature

CA	crank angle
CV	calorific value
SOC	start of combustion

2. Experimental details

The experimental setup consists of single cylinder four stroke diesel engines. The engine test setup specifications are given in Table 1. The pressure sensor is mounted on cylinder head which is exposed to combustion chamber for measurement of in-cylinder combustion pressure with respect to crank angle. The crank angle encoder was mounted on crank shaft to measure the crank angle. The eddy current dynamometer was used for loading the engine. The data acquisition system was used for acquiring the pressure-crank angle data and for further analysis. The engine speed (1500 rpm) and static injection timing were maintained as constant throughout tests. The experimental test setup is shown in Fig. 1.

Table 1. Engine specifications

Parameters	Specifications
No. of Cylinder	1
No of Strokes	4
Fuel	H.S. Diesel
Rated Power	3.5 kW @ 1500 rpm
Cylinder Diameter	87.5 mm
Stroke Length	110 mm
Connecting Rod Length	234 mm
Compression Ratio	12:1 To 18:1
Orifice Diameter	20 mm
Dynamometer Arm Length	185 mm

The cotton seed methyl ester was prepared in laboratory scale and it was blended with commercially available diesel such as B5, B10, B15 and B20. The physico-chemical properties such as viscosity, density and calorific value were measured using Setavis Kinematic Viscometer, density bottle and bomb calorimeter respectively as shown in Table 2.

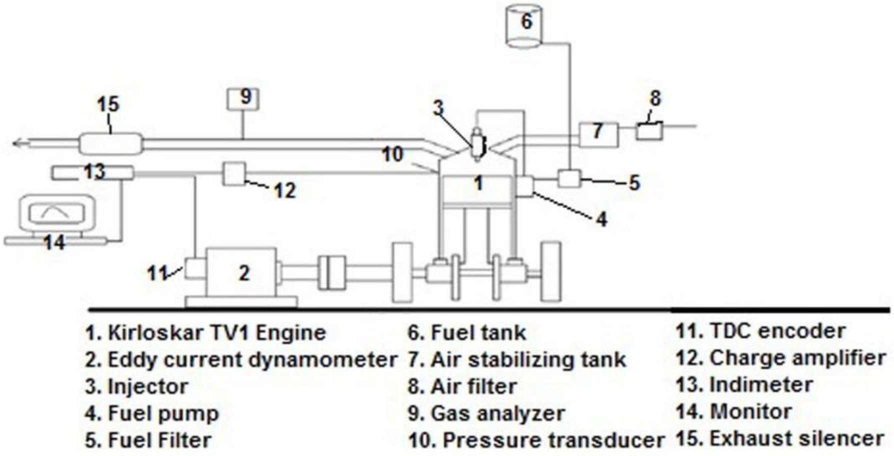

Fig. 1 Experimental Setup

Table 2. Physico-chemical properties of biodiesel blends and diesel

Property	Cottonseed biodiesel blends				
	DIESEL	B5	B10	B15	B20
Density	0.825	0.836	0.838	0.842	0.844
Calorific value	42.5	42.36	42.16	41.9	41.55
Cetane number	49.5	-	-	49.87	-
Viscosity	2.7	-	-	3.2	-
Moisture	-	NA	NA	NA	NA
Flash point	64	-	-	122	-
Fire point	71	-	-	122	-

3. Results and discussion

The combustion analysis has been carried out by analyzing the pressure traces acquired in the combustion chamber with respect to crank angles. The pressure transducer and the crank angle encoder are used to measure the in-cylinder pressure with respect to the crank angle. The important combustion phases in diesel engine are ignition delay period, start of combustion, end of combustion, rapid pressure rise, premixed combustion phase, diffusion phase and afterburning phase. The comparison of ignition delay for cottonseed biodiesel blends and base diesel is shown in Fig.2 (a). The ignition delay is the time lapse between the start of injection into the cylinder and start of combustion. As high ignition delay leads to high rate of pressure rise, some extend to knocking, premixed combustion phase, noise and NOx emission; it needs to optimize to improve the engine performance. The ignition delay period for cottonseed biodiesel blends decreased as compared to base diesel. It decreased from 11 ºCA with diesel to 9.5 ºCA, 8.5 ºCA, 7.5 ºCA and 6.5 ºCA with B5, B10, B15 and B20 biodiesel blends respectively. Ignition delay decreased mainly due to higher cetane number of biodiesel. Another reason could be due to higher bulk modulus of biodiesel results in automatic advance in start of injection. The comparison of start of combustion of biodiesel blends and base diesel is shown in Fig.2 (b). The start of combustion advanced from 349 ºCA with base diesel to 347.5 ºCA, 346.3 ºCA, 345.5 ºCA and 344.5 ºCA with B5, B10, B15 and B20 biodiesel blends respectively. As already discussed that the biodiesel has higher bulk modulus results in early start of injection and higher cetane number reduces the ignition delay, this finally results in early start of combustion with biodiesel blends as compared base diesel [15].

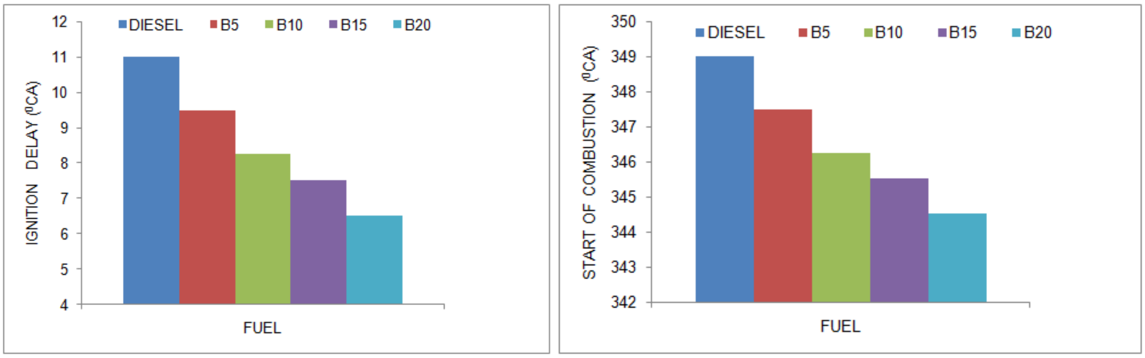

Fig. 2. (a) Comparison of ignition delay for diesel and biodiesel blends (b) Comparison of start of combustion for diesel and biodiesel blends

The in-cylinder pressure versus crank angle (P-θ) data for base diesel and biodiesel blends is shown in Fig.3 (a). The peak in-cylinder pressure increased from 52.28 bar with base diesel to 55.61 with B20 biodiesel blends. This is due to higher cetane number of biodiesel tends to lower ignition delay period of biodiesel blends than base diesel. The in-cylinder pressure versus crank angle data plays very important role in engine design and smooth engine running operation. If engine gives sudden rise and drop in in-cylinder pressure with respect to crank angle that is (dp/dθ rate of pressure rise), which indicates the knocking in diesel engine. The dp/dθ should be less than 9 bar/ ºCA for stationary engine. The rate of pressure rise for base diesel and biodiesel blends is shown in Fig. 3 (b). It is observed that rate of pressure rise is decreased with all biodiesel blends as compared to base diesel. It is mainly due to higher cetane number of biodiesel tends to lower ignition delay. The heat release rate for base diesel and biodiesel blends is shown in Fig.4 (a). Figure shows that the heat release rate initially goes in negative due to endothermic reaction. The heat release rate gets positive when combustion starts. The heat release rate lowers in case of biodiesel than diesel due to the lower calorific value of biodiesel results in lower brake thermal efficiency of biodiesel fuelled diesel engine.

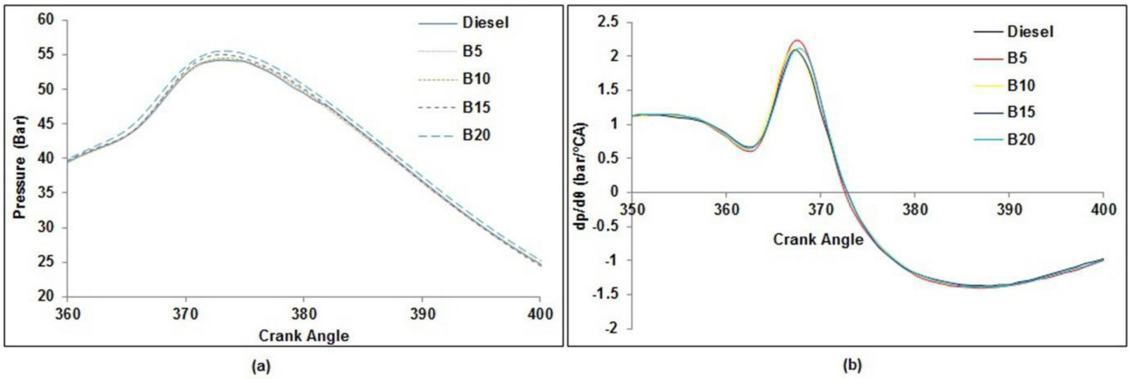

Fig.3 (a) Variation of In-cylinder pressure for diesel and biodiesel blends (b) Variation of rate of pressure rise for diesel and biodiesel blends

The premixed, diffusion and afterburning combustion phase for biodiesel and base diesel is shown in Fig.4 (b). The heat release rate diagram is used to calculate the premixed combustion phase, diffusion combustion phase and afterburning combustion phase. The premixed combustion duration increased from 22 ºCA with base diesel to 31 ºCA with B20 biodiesel. The increase in premixed combustion phase is responsible for higher NOx emission with biodiesel blends. There is no significant change in diffusion combustion phase for base diesel and biodiesel blends. The afterburning combustion phase increases in case of biodiesel blends than base diesel result in longer combustion duration.

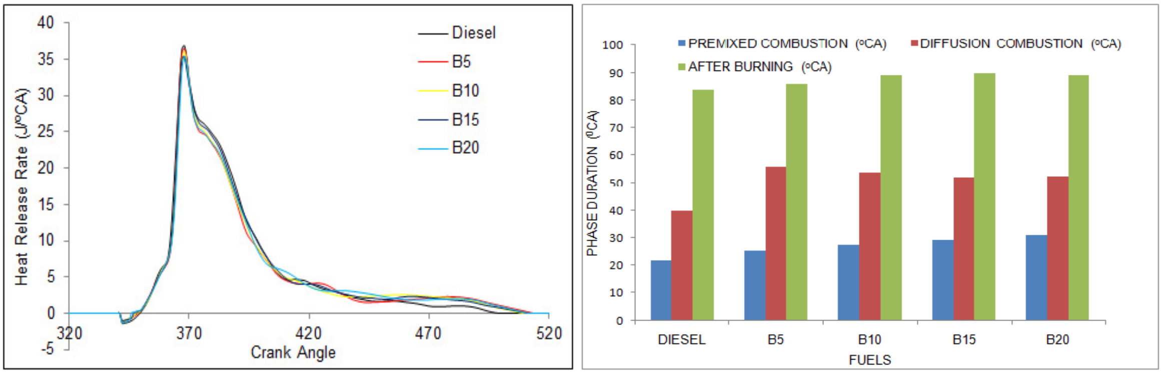

Fig.4 (a) Variation of heat release rate for diesel and biodiesel blends (b) Comparison of phase duration for diesel and biodiesel blends

4. Conclusions

The following conclusions are drawn based on the experimental results of the diesel engine with cottonseed biodiesel blends as compared to base diesel. Cottonseed biodiesel can be used in blended form as an alternative fuel in any diesel engine without any modification.

- Ignition delay decreased from 11 ºCA with diesel to 9.5 ºCA, 8.5 ºCA, 7.5 ºCA and 6.5 ºCA with B5, B10, B15 and B20 biodiesel blends respectively.
- The start of combustion advanced from 349 ºCA with base diesel to 347.5 ºCA, 346.3 ºCA, 345.5 ºCA and 344.5 ºCA with B5, B10, B15 and B20 biodiesel blends respectively.
- The peak in-cylinder pressure increased from 52.28 bar with base diesel to 55.61 with B20 biodiesel blends.
- The rate of pressure rise is decreased with all biodiesel blends as compared to base diesel. It is mainly due to higher cetane number of biodiesel tends to lower ignition delay.
- The premixed combustion phase increases in case of biodiesel which is mainly responsible for higher NOx emission. Combustion duration increases as the percentages of biodiesel increases.

References

[1] Hsing PL, Shannon S, Mike W, Robert H, Jude O. Combustion emissions modeling and testing of neat biodiesel fuels. Proceedings of the ASME 2010 4th International Conference on Energy Sustainability 2010, Phoenix, AZ USA.
[2] Bhuiya MMK , Rasul MG, Khan MMK, Ashwath N, Azad AK, Hazrat MA. Second generation biodiesel: potential alternative to- edible oil-derived biodiesel. The 6th International Conference on Applied Energy 2014; 61; 1969 – 1972.
[3] Mohamed F Al, Bhatti S.K. Experimental and computational investigations for combustion, performance and emission parameters of a diesel engine fueled with soybean biodiesel-diesel blends. Energy Procedia 2014; 52; 421 – 430.
[4] Yogendra PU, Sharma RB, Amit P. Production of biodiesel from non edible cottonseed oil by mechanical stirrer technique. IOSR Journal of Mechanical and Civil Engineering 2013; 8 (1); 22-26.
[5] Sergio CC, Jacob P. Calvin P. Engine performance and exhaust emissions of cottonseed oil biodiesel. Beltwide Cotton Conferences, Nashville, Tennessee, 2008.
[6] Verma P, Sharma MP. Performance and emission characteristics of biodiesel fuelled diesel engines. International Journal of Renewable Energy Research 2015; 5 (1).
[7] Imtenan S, Masjuki HH, Varman M, Arbab MI, Sajjad H, Rizwanul IMF, Abedin MJ, Abu SH. Emission and performance improvement analysis of biodiesel-diesel blends with additives. Procedia Engineering 2014; 90; 472 – 477.
[8] Capareda S, Powell J, Parnell C., Engine performance and exhaust emissions of cottonseed oil biodiesel. Beltwide Cotton Conferences, Nashville, Tennessee, 2008.
[9] Lahane S. and Subramanian K. A., Effect of different percentages of biodiesel-diesel blends on injection, spray, combustion, performance, and emission characteristics of a diesel engine. Fuel 2015; 139; 537-545.

[10] Lahane S. and Subramanian K. A., Impact of nozzle holes configuration on fuel spray, wall impingement and NOx emission of a diesel engine for biodiesel-diesel blend (B20). Applied Thermal Engineering 2014; 64 (1-2); 307-314.
[11] Subramanian, K. A. and Lahane S., Comparative evaluations of injection and spray characteristics of a diesel engine using Karanja biodiesel-diesel blends. International Journal of Energy Research 2013; 37 (6); 582-597.
[12] Nantha GK, Thundil KR. Effect of pongamia biodiesel on emission and combustion characteristics of DI compression ignition engine. Ain Shams Engineering Journal 2015; 6; 297–305.
[13] Mattarelli E, Rinaldini CA, Savioli T. Combustion analysis of a diesel engine running on different biodiesel blends. Energies 2015; 8; 3047-3057.
[14] Kasaby M, Nemit-allah MA. Experimental investigations of ignition delay period and performance of a diesel engine operated with Jatropha oil biodiesel. Alexandria University. Production and hosting by Elsevier 2013.
[15] Ahire YH, Lahane S, Patil NG, Lata DB. Investigation of combustion, performance and Emission characteristics of a castor biodiesel fulled compression ignition engine. 24th National conference on IC engine and combustion 2015.
[16] Maina P. Engine emissions and combustion analysis of biodiesel from East African countries. South African Journal of Science 2014; 110.