Experimental Investigations on Combustion and Emission Characteristics of Biodiesel Blends in CI Engine

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Abstract - *Experiments were conducted to evaluate the combustion and emission of DI diesel engine using Java plum seed oil and custard apple seed oil blends of 25% and 50%, and standard diesel fuel separately. The experimental results indicate that the use of custard apple seed and Java plum seed biodiesel blends produces lower brake thermal efficiency (BTE) compared to diesel fuel. The carbon monoxide (CO) and Hydrocarbon emissions of B100 fuels were found to be 6-9% and 25-32% lower than that of the diesel fuel, respectively. The NO_x emission found slightly higher for both the biodiesel fuels. From the combustion data, it was found that ignition delay was shorter for Java plum seed methyl ester blends compared to that of standard diesel and custard apple methyl ester blends. The combustion characteristics of methyl ester blends intimately followed those of standard diesel fuel.*

***KeyWords*: Transesterification, Methyl ester, Performance, Emission, Combustion.**

1. INTRODUCTION

Diesel fuels have an essential function in the industrial economy of a country with applications in heavy trucks, city transport buses, locomotives, electric generators, farm equipment, earthmoving and underground mining equipments [1]. Biodiesel, an alternative diesel fuel, is made from renewable biological sources such as vegetable oils and animal fats [2]. Biodiesel production is a very modern and technological area for researchers due to the relevance that it is winning everyday because of the increase in the petroleum price and the environmental advantages [3]. A wider flammability limit, significant fuel oxygen content, lower viscosity, higher specific heat and higher latent heat of vaporization of methanol remains an advantage in terms of faster combustion, lower smoke and nitric oxide emissions as reported in literature [4-9]. Potassium hydroxide (KOH) and sodium hydroxide (NaOH) were the most commonly used alkali catalysts but higher yield was reported with KOH [10]. Methanol and ethanol are the alcohols employed frequently in the transesterification process; but methanol is preferred owing to its low cost and higher reactivity when compared to ethanol [11]. High purity methyl ester can be achieved by transesterification of fresh vegetable oils with methanol in the presence of an alkaline catalyst [12]. Biodiesel fuel can effectively reduce engine-out emissions of particulate matter, carbon monoxide (CO), and unburned hydrocarbons in modern four-stroke compression–ignition engines. However, a slight increase in emissions of nitrogen oxides (NO_x) has been observed in the use of oxygenated fuels in general [8,11,14]. In the present study, neat rapeseed oil was considered as a potential alternative fuel for an unmodified diesel engine because it has high oil content (around 40%) for biodiesel production. Main aim of this study is to investigate the engine performance, emission and combustion characteristics of a diesel engine fuelled with Java plum seed and custard apple seed biodiesels and its diesel blends compared to those of standard diesel. It is also hoped that the new data presented here will assist in developing new prognostic methods or procedures for this actual problem.

2. BIODIESEL PRODUCTION AND PROPERTY ANALYSIS

2.1 Transesterification

The reaction mechanism for alkali catalyzed transesterification was formulated as three steps. Transesterification is the process of conversion of the triglyceride with an alcohol in the presence of a catalyst to form esters and glycerol. Vegetable oil is subjected to chemical reactions with alcohol like methanol or ethanol in the presence of a catalyst. Since the reaction is reversible, excess methanol is required to reduce the activation energy, thereby shifting the equilibrium to the product side. The triglyceride present in the vegetable oil is converted into biodiesel. Among the alcohols used for the transesterification reaction are methanol and ethanol. However, when methanol is processed, methyl esters are formed, whereas ethanol produces ethyl esters. Both these compounds are biodiesel fuels in different chemical combinations. The mechanism of transesterification reaction scheme is illustrated by Fig-1. Transesterification of rapeseed oil produces ester whose properties are comparable with those of diesel fuels. Schematic diagram of biodiesel plant is shown in Fig-2. The properties of the diesel fuel and the grape seed biodiesel are summarized in Table 1.

CH_2OOCR						CH_2OH
|						|
$CHOOCR$	+	$3CH_3OH$ --------->	$3CH_3OOCR$	+		$CHOH$
|		*(Catalyst NaOH)*				|
CH_2OOCR						CH_2OH
Triglyceride		*Methanol*	*Methyl Esters*			*Glycerol*

Fig-1: Mechanism of transesterification process

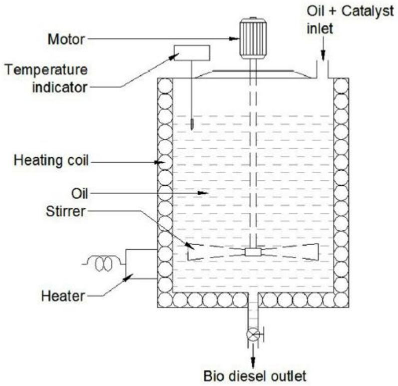

Fig-2 Schematic diagram of Biodiesel Plant

Table 1 Properties of diesel and biodiesel blends

Properties	Diesel	Java plum seed biodiesel	Custard apple seed biodiesel
Specific gravity@ 15/15°C (gm/cc)	0.835	0.8512	0.8532
Kinematic Viscosity @ 40°C (cst)	2.56	3.8	4.2
Flash Point (°C)	44	102	112
Fire Point (°C)	48	110	1115
Pour Point (°C)	-14	-4	-6
Gross calorific value (Kcals/kg)	10,660	10,325	10,115
Density @ 15°C (gm/cc)	0.8340	0.8490	0.8588

2.2 FTIR Analysis

The FTIR spectrum of diesel, custard apple and java plum methyl esters are shown in Fig-3, 4 and 5. From the Figures, there are two bands that correspond to the methyl and methylene groups in the area between 2920 and 2856 cm^{-1}; the first peak is recognized to the stretching vibrations of the terminal CH_2 group in the olefins. The second peak corresponds to stretching vibration and contraction of the C-H and CH_2 bonds of the methylene and methyl groups. These bands show similarity between diesel fuel and methyl esters. The most pertinent folding vibrations of the methyl groups are consistent to the phase folding deformation (between 1350 - 1400 cm^{-1} bands) and the beyond degenerate phase folding deformation (between 1450 - 1470 cm^{-1} bands). The folding ascends from twisting and matching that seem at low frequencies. The methylene group offerings scissors vibrations at 1457 cm^{-1}. Based on the above discussion, it is clear that both diesel and grape seed methyl ester are saturated hydrocarbons and the presence of hydrocarbon group C-H indicates that it has a potential as a fuel for diesel engine.

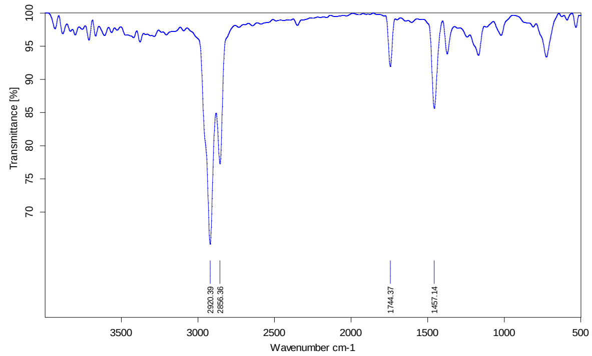

Fig-3 FTIR spectrum of diesel fuel

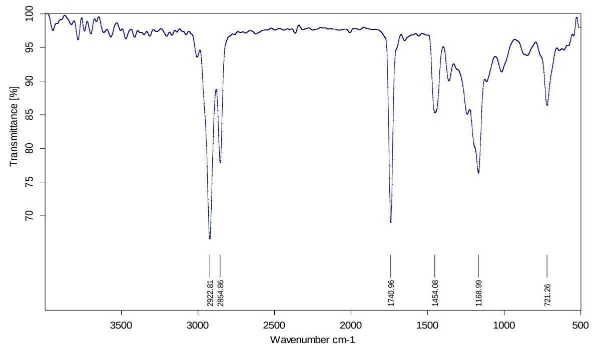

Fig-4 FTIR spectrum of custard apple seed methyl ester

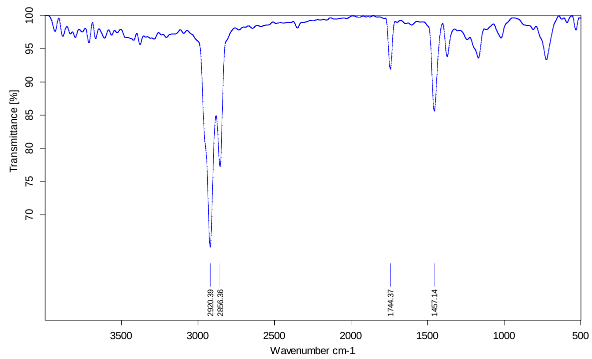

Fig-5 FTIR spectrum of java plum seed methyl ester

2.2 TGA Analysis

Schematic view of TGA analysis of diesel, JPSME and CASME was shown in Fig-6, 7 and 8. From the figure, it was clear that the biodiesel combustion reaction takes place between 76-272˚C with a mass loss of 99.21%, peak temperature is around 227˚C under the heating rate of 6˚C/min. It is well known that as the sensitivity of the reactions decrease peak temperatures of the reaction increases. JPSME and CASME biodiesels combustion reactions also exhibit that, as the sensitivity of reactions decrease, i.e. the heating rate of the reaction increase, reaction intervals and the peak temperatures shift upper temperatures. Reaction intervals of 10˚C/min and 15˚C/min of biodiesel samples are 103-328˚C and 110-301˚C respectively, whereas peak temperatures are 264˚C and 270˚C. Biodiesel samples lose their stability as the heating rate of the experiments increase.

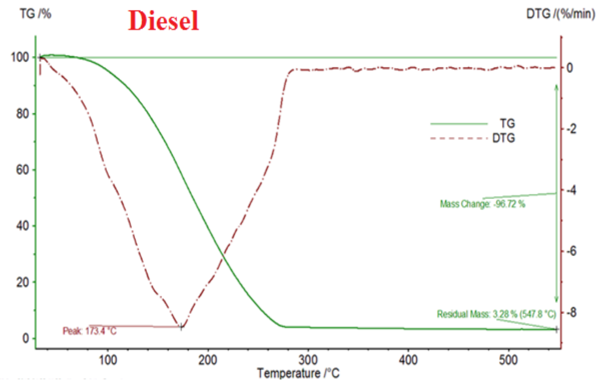

Fig-6 TGA analysis of neat diesel

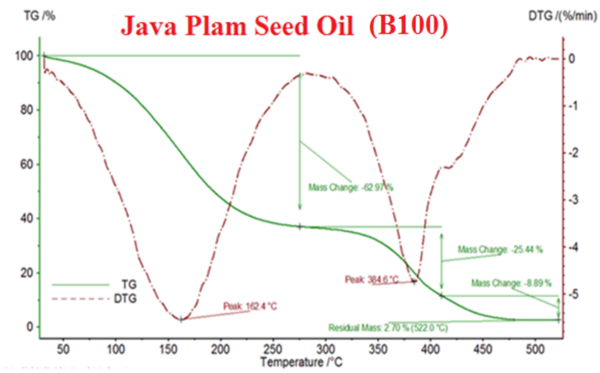

Fig-7 TGA analysis of java plum seed oil 100%

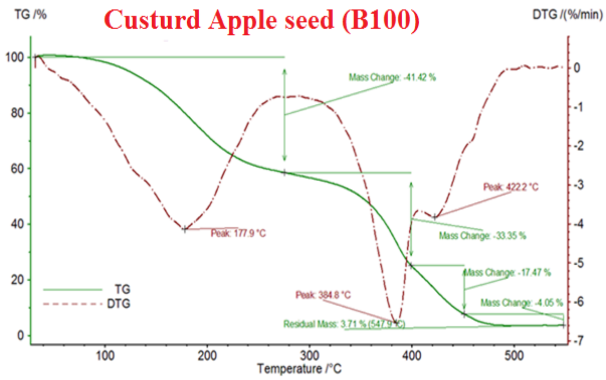

Fig-8 TGA analysis of custard apple seed oil 100%

3. EXPERIMENTAL SETUP

The diesel engine used for experimentation is Kirloskar TV1, single cylinder, water cooled engine coupled to eddy current dynamometer with computer interface. The detailed specification of the engine is shown in Table 2. A data acquisition system is used to collect and analyze the combustion data like in-cylinder pressure and heat release rate during the experiment by using AVL transducer. The tests are conducted at the rated speed of 1500 rpm. In every test, exhaust emission such as nitrogen oxides (NO_x), hydrocarbon (HC), carbon monoxide (CO) and smoke are measured. From the initial measurement, brake thermal efficiency (BTE) and specific fuel consumption (SFC) with respect to brake power (BP) for different blends are calculated. The blends of biodiesel and diesel used were B25 and B50. B25 means 25 % biodiesel fuel and 75% of diesel fuel by volume. In order to study the effect of biodiesel blends on the engine combustion and emission characteristics, the injection timing was kept constant at 23° bTDC. The effect of biodiesel blends was studied and results were compared with neat diesel.

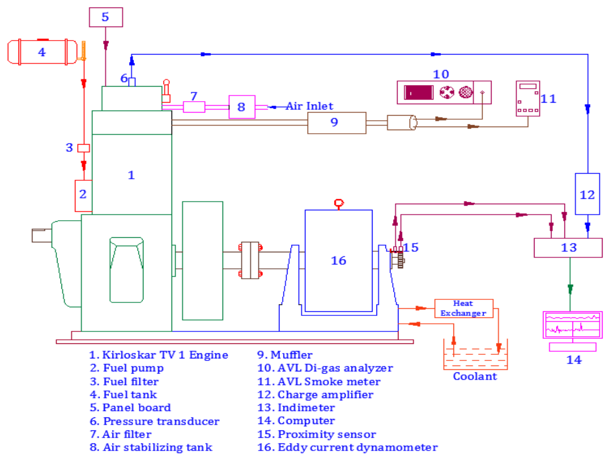

Fig-9 Schematic diagram of the experimental setup

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Table -2: Engine specification

Make	:	Kirloskar TV – I
Type	:	Vertical cylinder, DI diesel engine
Number of cylinder	:	1
Bore × Stroke	:	87.5 mm × 110 mm
Compression ratio	:	17.5:1
Speed	:	1500 rpm
Rated brake power	:	5.2 kW
Cooling system	:	Water
Fuel	:	Diesel
Injection Pressure	:	220 bar
Ignition timing	:	23° before TDC
Ignition system	:	Compression Ignition

4. RESULTS AND DISCUSSION

The operation of the DI diesel engine was found to be very smooth through the maximum load, without any operational problems for the custard apple seed and java plum seed biodiesels blended diesel fuel. In the present section, CO, HC and smoke emissions are plotted against brake power and based on the combustion data, cylinder pressure and heat release rate are plotted against crank angle.

4.1 Performance Characteristics

The variation in brake thermal efficiency (BTE) with brake power is shown in Fig-10. The influence of the biodiesel blends on the engine performance depends on the relationship between the fuel properties, oxygenation nature of the biodiesel, the higher viscosity and the lower calorific value as well, and these effects have a major influence on the spray formation and combustion [7, 15]. Therefore, the BTE results can be more precisely explained by the lower energy content of the biodiesel blends, which is 1-3%, lower than conventional diesel fuel.

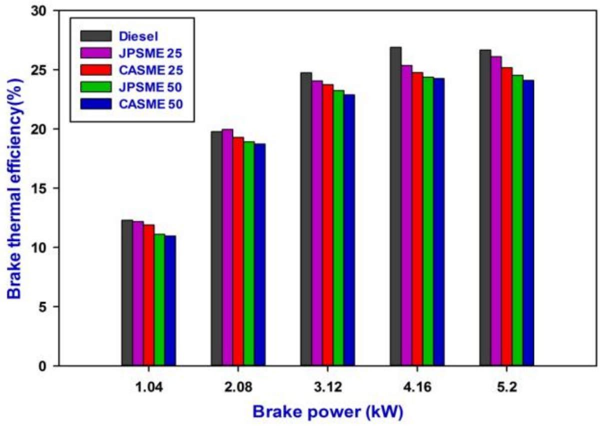

Fig-10 Brake thermal efficiency against brake power

4.2 Emission Characteristics

Fig-11 shows the variation in NOx emission with brake power for diesel, CASME25, CASME50, JPSME25 and JPSME50. From the literature it is revealed that NO_x is directly proportional to power output of the engine because NO_x emission increases with increase in combustion and exhaust temperature [10]. The present test results show that NOx emission decreases almost linearly with increase in brake power. It is found lowest for biodiesel blends compared with diesel fuel because of high viscosity which results in incomplete combustion causing lower combustion temperature. At maximum load condition NOx emission for diesel, CASME25, CASME50, JPSME25 and JPSME50 are found to be 1112ppm, 1097ppm, 1076ppm, 1045ppm and 1016ppm, respectively.

Variation in HC emission at different brake power conditions for diesel, custard apple seed and java plum biodiesel blends are shown in Fig-12. It is seen that unburnt hydrocarbon emission increases with that of brake power for all prepared test fuels. From the figure it is understood that biodiesel produces higher HC emission in comparison to that of diesel because of poor combustion of the test fuel and its blend [10, 15]. However, with increase in percentage of biodiesel HC emission increases with respect to brake power because of low cylinder pressure and temperature causing a comparatively lower burning rate. HC emission for diesel, CASME25, CASME50, JPSME25 and JPSME50 at full load condition are obtained as 120.67 ppm, 122.32 ppm, 123.54 ppm, 124.53 ppm and 125.63 ppm respectively.

Fig-13 shows the variation in CO emission with brake power. CO is formed during the combustion process whenever charge is burned with an insufficient air supply with low in-cylinder temperature. From the figure, it can see that the CO emission increased with the increase of biodiesel percentage, especially at higher brake power. Diesel fuel resulted in the lowest CO emission among all the tested blends. At maximum load condition CO emission for diesel, CASME25, CASME50, JPSME25 and JPSME50are found to be 0.34%, 0.35%, 0.36%, 0.36% and 0.37% by volume, respectively.

The results of smoke emission were given in Fig-14 for different brake powers. The formation of smoke emission is mainly due to the incomplete burning of the hydrocarbon fuel and the partially reacted carbon content. From the Fig-10, the smoke emission increased with the increase biodiesel percentage with diesel fuel. It can be attributed to the higher viscosity and poor atomization of biodiesel blends [10]. The smoke emission found increased 14.53%, 20.12%, 28.2% and 32.14% for the CASME25, CASME50, JPSME25 and JPSME50 blends, respectively, compared with fuelling with the conventional diesel fuel.

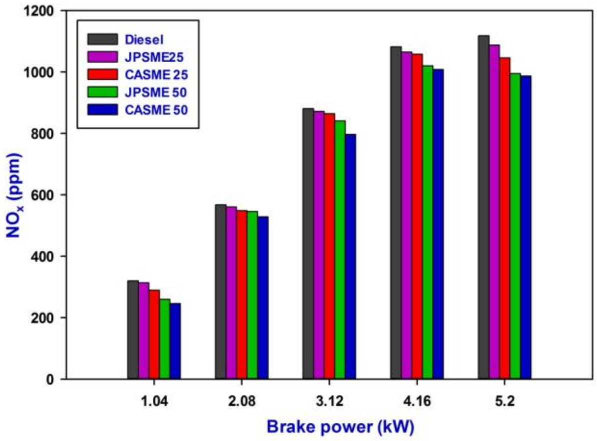

Fig-11 Oxides of nitrogen emission against brake power

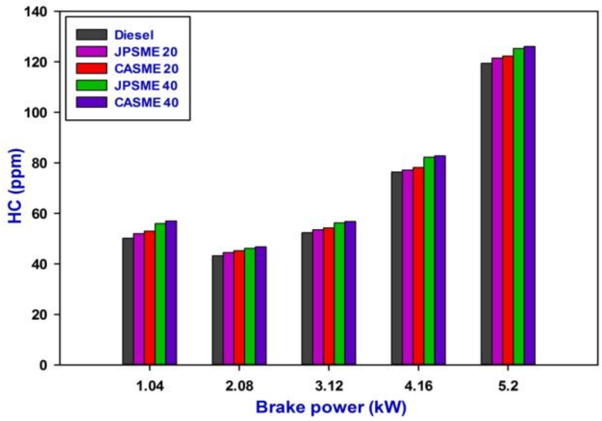

Fig-12 Hydrocarbon emission against brake power

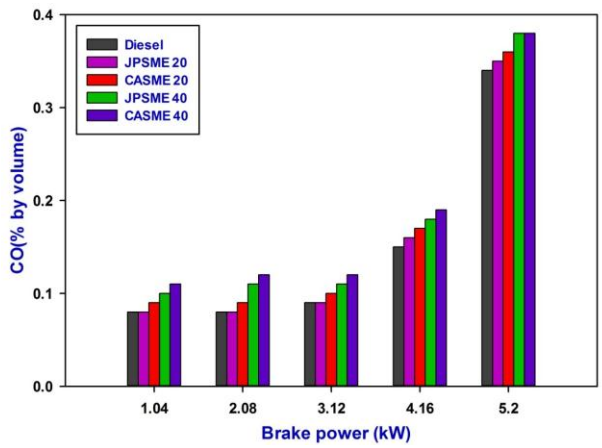

Fig-13 Carbon-monoxide emission against brake power

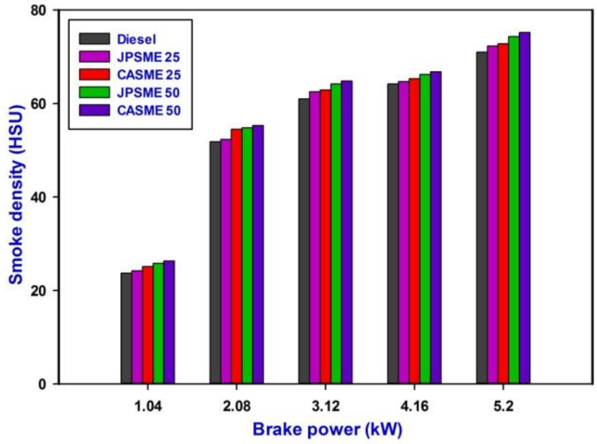

Fig-14 Smoke density against brake power

4.3 Combustion Characteristics

The increase in fuel viscosity, particularly for the biodiesel fuels, results in poor atomization, slower mixing and reduced cone angle. These phenomena results in a longer ignition delay. However, diesel has seen the opposite trend in the case of diesel and their blends [8]. The ignition quality of a fuel is usually characterized by its cetane number, and a higher cetane number generally results in a shorter ignition delay. The variation in cylinder pressure against crank angle is shown in Fig-15. From the figure it was clear that the in-cylinder pressure reduced with the increase in the percentage of biodiesel with diesel fuel. JPSME25 having the nearest value with diesel fuel compared with other biodiesel blends. The maximum in cylinder pressure was found in the case of diesel fuel as 52.3bar and it was 51.9bar for JPSME25 fuel blend. Fig-16 shows the heat release rate during the combustion for different fuel blends. From the figure, it was found that the peak heat release rate for all biodiesel blends were minimum when compared to diesel fuel. A longer ignition delay for the biodiesel blends fuel allowed for more air/fuel preparation, which is ready to auto ignite and results a lower premixed peak.

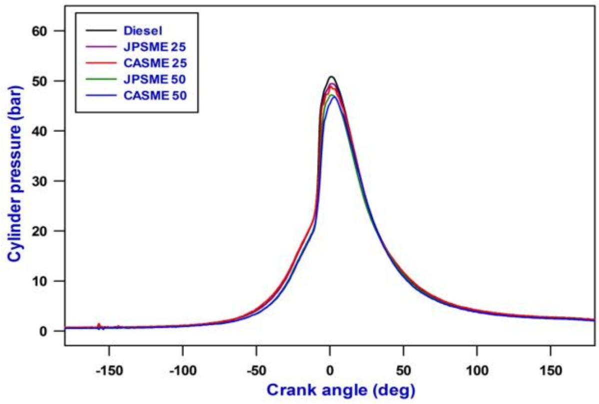

Fig-15 In-cylinder pressure against crank angle

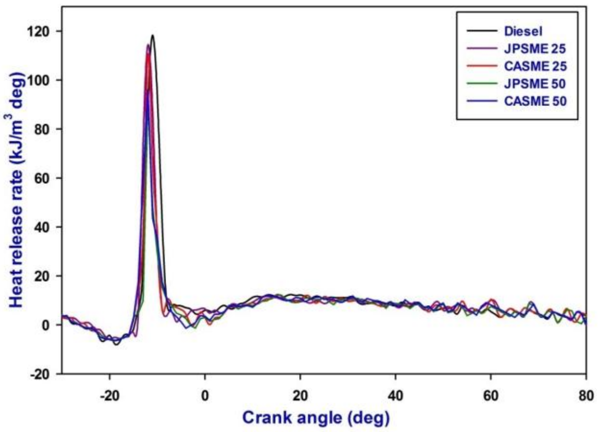

Fig-16 Heat release rate against crank angle

5. CONCLUSIONS

In the present investigation, CI engine performance, emission and combustion characteristics by using biodiesel blended diesel are studied and compared the values with neat diesel. The following results can be concluded from the experimental study

- Some fuel properties such as flash point, calorific values and cetane number are decreased by the addition of biodiesel with diesel fuel.
- The biodiesel blends also lead to shorter ignition delay periods and lower heat release rates during portions of the expansion stroke.
- A slight reduction in brake thermal efficiency was observed with the use of both biodiesel blends.
- The increase in HC and CO emission by using java plum seed and custard apple seed biodiesels blended with diesel. JPSME25 showing a same trend with neat diesel fuel in HC emission.
- NO_x Emission decreases by both biodiesel blended diesel fuel compared to neat diesel fuel.

Hence, java plum seed and custard apple seed biodiesels are efficient in utilizing and reducing the exhaust harmful emission like NOx from the DI diesel engine. Compared with other biodiesel blends JPSME25 was better in performance as well as emission characteristics.

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