Combustion Studies of a DI Diesel Engine Using Jatropha Methyl Ester-Tyre Pyrolysis Oil Blends

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Abstract

In the present study, an investigation was carriedout to explore the possibility of using biodiesel- pyrolysis oil blends as fuels in a single cylinder, four stroke, direct injection (DI) diesel engine with a rated power of 4.4kW running at 1500rpm. The combustion studies with Jatropha methyl ester-Tyre pyrolysis oil (JMETPO) blends as fuels are reported in this paper. Four different blends of varying TPO, from 5 to 20% in step of 5% on a volume basis, were considered for the investigation. The combustion parameters of the engine were evaluated, analysed, compared with diesel data of the same engine and presented in this paper. Combustion analysis indicated that ignition delay was shorter for the JMETPO blends compared to that of diesel. Peak pressure, maximum rate of pressure rise and heat release rate were lower for all the blends in comparison with diesel.

Keywords: Diesel engine; Jatropha methyl ester; Tyre pyrolysis oil; Combustion; Performance; Emission.

1. Introduction

In the alternative fuels era, two categories of fuels are mainly used: (i) first generation biofuels and (ii) second generation biofuels. In the last two decades, some of the countries have started utilizing the first generation biofuels (ethanol and biodiesel) for transportation applications. Ethanol is produced from starch based biomass and cellulosic and ***lignocellulosic*** materials by the fermentation process. 10% ethanol is blended with 90% gasoline (E10) in some countries, but it can also be blended at higher concentrations to get E85 and E95. Biodiesel is produced from vegetable oils, animal fats and algae by the tranesterification process. Biodiesel of up to 20% blended with diesel, can be used as fuel in all diesel engines.

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Even neat biodiesel can be used as fuel with little or no modification, in diesel engines that have been manufactured since 1994. The diesel engine can generate lower HC (burned hydrocarbons), CO (carbon monoxide) and particulate emissions with biodiesel [1]. The feedstock used for biodiesel production varies from country to country. In India, major research works carried out on the production and utilization of biodiesel focused on the non-edible seeds like Jatropha, Karanja, Mahua, Cotton seed, Rubber seed and Polanga. Several studies have been documented on the utilization of biodiesel from these oils for compression ignition (CI) engines.

Various researchers have studied the performance and the emission and combustion characteristics of a diesel engine, run on blends of methyl/ethyl esters of Jatropha, Karanja, and Mahua, Cotton seed oil, Rubber seed oil and Linseed oil with diesel. Some of them have investigated the utilization of these esters in diesel engines with engine modification, while others have studied their effects on varied engine components [2-6].

Among the non-edible seeds produced in India, Jatropha is the most preferred because of its high oil content and biodiesel yield. The research works related to the use of methyl/ethyl esters obtained from Jatropha oil in direct injection (DI) engines established different results. However, the biodiesel production from Jatropha has a limited scope, due to its lesser availability and collection of oil seeds, as of today. The government of India has already launched a biodiesel programme in the year 2003, to increase biodiesel production. As the availability of Jatropha oil and oil seeds is found to be less at this point of time, a certain percentage of biodiesel can be replaced by some other second generation biofuels [7-9].

The second generation biofuels are derived from different organic substances, using thermochemical or biochemical processes. Important thermochemical conversion processes include pyrolysis and gasification, while biochemical conversion includes anaerobic digestion. One distinct advantage with second generation biofuel is that, any organic substance other than the feed stocks used for the production of first generation biofuels, can be converted in to useful energy and value added products. This perhaps ensures that the waste is converted into energy thus reducing the disposal of wastes that are available in large quantity. Pyrolysis is one of the thermochemical methods to convert waste into useful energy. Several researchers have demonstrated the pyrolysis process for converting carbonaceous such as automobile tyres, rubber, agro waste, plastic etc. The pyrolysis of waste automobile tyres yields three value added products; tyre pyrolysis oil, pyrogas and carbon black. The production of pyrolysis oil from waste automobile tyres has gained momentum in the last five years across the world. In recent years, a significant number of pilot plants have been installed with the production capacity in the range of 5-20 tons in the countries, such as China, India, Canada, France, Italy and Spain. TPO consist of C, H, O, N and S containing organic compound and water. The organic compound range from C_5 to C_{20}. Pyrolysis oil thus contains fractions of volatility consistent with gasoline, kerosene and diesel fuel. [10]. Therefore, researchers have investigated the use of TPO as an alternative fuel in both spark ignition (SI) engines and compression ignition (CI) engines and only a few documents are available for reference. Preliminary research revealed that TPO exhibits longer ignition delay in a diesel engine due to high viscosity and poor volatility of the fuel [11]. In another work, the experimental investigation was carried out in a single cylinder, four stroke, direct injection diesel engine, with a dual fuel mode to study the effect of an ignition improver. Di ethyl ester (DEE) was used as an ignition improver, which was admitted at three different flow rates (65,130 and 170 g/h) [12]. This can be reduced by blending TPO with fuels having cetane number higher than that of conventional diesel.

The present study is aimed to evaluate the effect of TPO blended with JME in four different percentages as fuels, on the combustion characteristics of a direct injection (DI) diesel engine. The TPO at low percentages (5-20% at regular intervals of 5% on a volume basis), was blended with JME at 95 to 80% respectively, to get the fuel blends for the investigation.

2. MATERIALS AND METHODS

2.1 Jatropha Methyl Ester

The esters of vegetable oils are produced by transesterification. It is the process of reacting triglyceride with alcohol in the presence of a catalyst, to produce glycerol and fatty acid esters. For the present investigation, JME was collected from a commercial biodiesel plant in Raipur, India. The fatty acid compounds present in Jatropha oil are given in Table 1.

Table 1 Composition of Jatropha Oil

Fatty acid	Composition (%)
Palmitic acid	13.4–15.3
Stearic acid	6.4–6.6
Oleic acid	36.5–41
Linoleic acid	35.3–42.1
Other acids	0.8

The schematic diagram of the tranesterification process for the production of JME is given in Figure 1. The optimal inputs for the transesterification of Jatropha oil are identified to be 40% methanol and 1.0% NaOH. The maximum ester yield is achieved after 90min reaction time at 60°C. The physical properties of Jatropha oil and JME are given in Table 2.

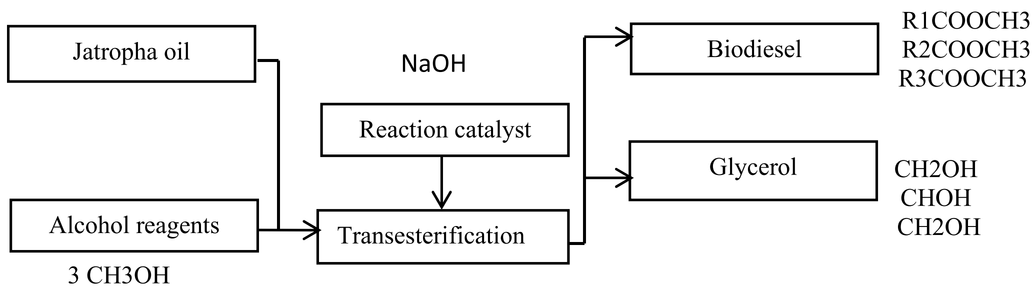

Fig. 1 Schematic diagram of the transesterification process

Table 2 Physical Properties of Jatropha Oil and Jatropha Methyl Ester (JME)

Property	Jatropha Oil	Jatropha Methyl Ester
Calorific value, kJ/kg	39774	38450
Density, kg/m^3	918	880
Kinematic viscosity, cSt	49.93	5.65
Flash point, °C	240	**170**
Cetane number	40-45	50-55
Carbon residue, %	.64	.5

2.2 Pyrolysis Process

For the study, TPO was collected from a commercial tyre pyrolysis plant. The feedstock used in the plant was truck tyres. The composition of the feedstock used in the pyrolysis process is given in Table 3. The chemical composition of the truck tyre used in the pyrolysis plant is given in Table 4.

Table 3 Composition of Truck Tyre

Composition of Tyre (%)	Value
Natural Rubber%	45
Synthetic Polymer %	4
Carbon Black %	22
Oil %	25 - 33
Chemicals %	4
Fabric %	5.5
Steel wire %	16.5
Others %	5

The capacity of the plant is 10T per batch. The reactor used in the pyrolysis unit is a horizontal and rotating type. The heating of the reactor is externally done with the help of coal/waste wood. The temperature rise of the reactor was found to be 30-40°C/h. During the pyrolysis process, the evolving vapour from the reactor enters the water cooled condenser, where it is condensed and converted into pyrolysis oil. Some of the vapour was not condensable and was used as secondary fuel for heating the reactor.

Table 4 Chemical Composition of Truck Tyre

Proximate analysis (wt %)		**Ultimate analysis (wt %)**	
Volatile matter:	66.64	Carbon:	83.87
Fixed carbon:	27.96	Hydrogen:	7.09
Moisture content:	0.62	Oxygen:	2.17
Ash content:	4.78	Nitrogen :	0.24
		Sulphur:	1.23
		Moisture:	0.62
		Ash:	4.78
Total:	100		100

The properties of Diesel, TPO, JMETPO5, JMETPO10, JMETPO15 and JMETPO20 are given in Table 5.

Table 5 Properties of Diesel, TPO, JMETPO5, JMETPO10, JMETPO15, and JMETPO20

Properties	**Diesel**	**TPO**	**JMETO5**	**JMETPO10**	**JMETPO15**	**JMETPO20**
Density, kg/m^3**@20 ^{o}C**	830	935	883.9	882.8	881.8	880.8
Kinematic viscosity, cSt **@40 ^{o}C**	2-4	3.77	6.22	5.96	5.85	5.6
Calorific Value, (MJ/kg)	43.8	39.2	39.96	39.24	38.42	37.74
Flash Point by Abel Method, ^{o}C	50	43	68	64	62	60
Fire Point, ^{o}C	56	50	82	78	75	73
Cetane number	45-50	25-30	NA	NA	NA	NA

3. EXPERIMENTAL

3.1 Engine Setup and Methodology

Experiments have been conducted in a single cylinder, four stroke, air cooled, direct injection, diesel engine with a developing power of 4.4kW at 1500 rpm. The technical specifications of the engine are given in Table 6, and the schematic diagram of the experimental arrangement is shown in Figure 2.

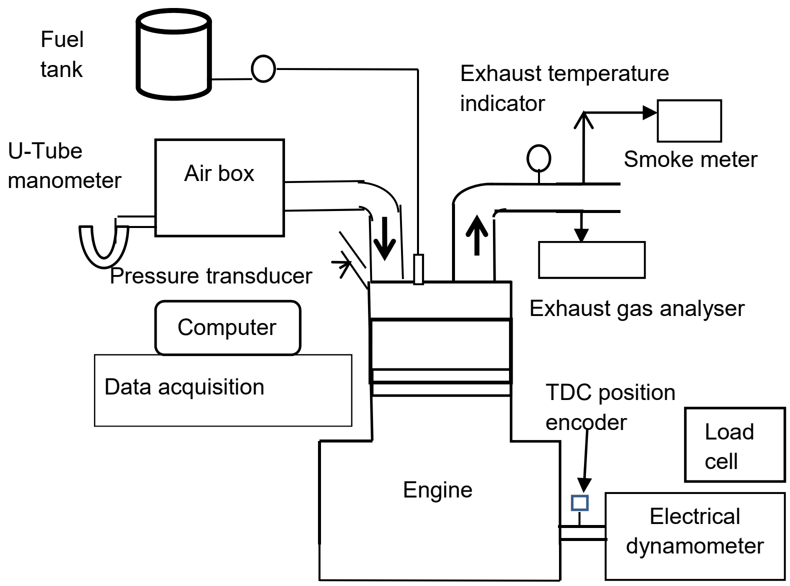

Fig. 2 Experimental setup

Experiments were initially started with diesel and after the engine reached the warm up condition, it was switched over to the different JMETPO blends. A data acquisition system, in conjunction with a piezoelectric pressure transducer and crank angle encoder was used for the measurement of the cylinder pressure history. In all the cases, the pressure-crank angle diagrams were recorded and processed, to get the combustion parameters by the data acquisition system. A fuel level indicator was used for measuring the total fuel consumption. A U-tube manometer connected with an orifice mounted on air box in the suction was used for measuring the intake air flow rate. A K-type thermocouple was installed to measure the exhaust gas temperature. After conducting all the tests with the blends, the engine was again run on diesel, to ensure that there was no fuel trace of the JMETPO blends, to prevent any deposits, and cold starting problems.

Table 6 Engine Specifications

Make/Model	**Kirloskar TAF 1**
Brake power, kW	4.4
Rated speed, rpm	1500
Bore, mm	87.5
Stroke, mm	110
Piston Type	Bowl-in-piston
Compression Ratio	17.5:1
Nozzle Opening pressure, bar	200
Injection Timing,°CA	23

Injection Type	Pump-line-nozzle injection
Nozzle Type	Multi hole
No. of holes	3

4. Results and Discussion

4.1 Cylinder pressure history

Figure 3 shows the comparison of the cylinder pressure histories of the JMETPO blends with diesel at full load condition. In a compression ignition engine, the peak cylinder pressure depends on the burned fuel fraction during the premixed burning phase, i.e., the initial stages of combustion .The cylinder pressure characterizes the ability of the fuel to mix well with air and burn [13].

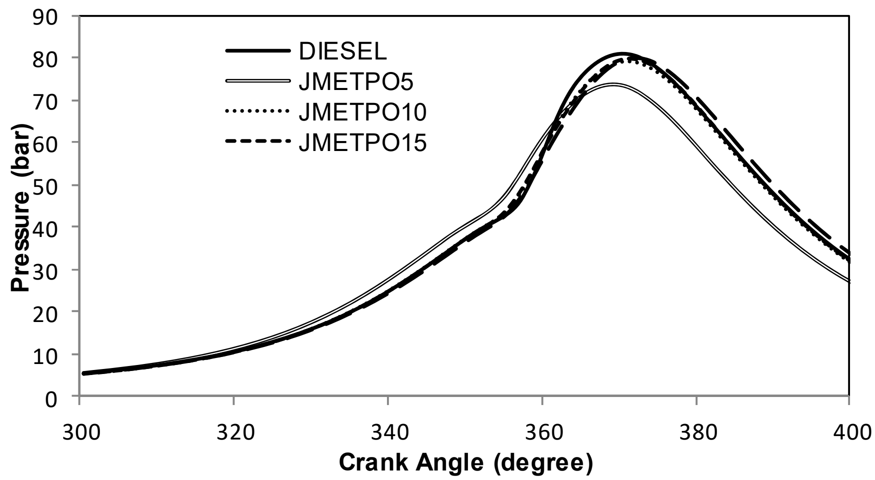

Fig. 3 Variation of cylinder pressure with crank angle

The JMETPO blends follow a cylinder pressure pattern similar to that of diesel at full load condition. The commencement of ignition for JMETPO blends is earlier than that of diesel at full load, which is approximately 1 ^{o}CA. The oxygen content and higher cetane number of JME are the reasons for the earlier ignition of these blends than that of diesel at full load.

4.2 Ignition Delay

The ignition delay is evaluated as the time difference measured in the crank angle between the start of injection and the start of ignition [13]. It is seen from Figure 4 that the ignition delay of diesel is longer in comparison with JMETPO blends at full load. This may be due to the higher cetane number of JME, which gives better ignition quality. And also the presence of oxygen in the JME results in improved chemical reactions and more complete combustion.

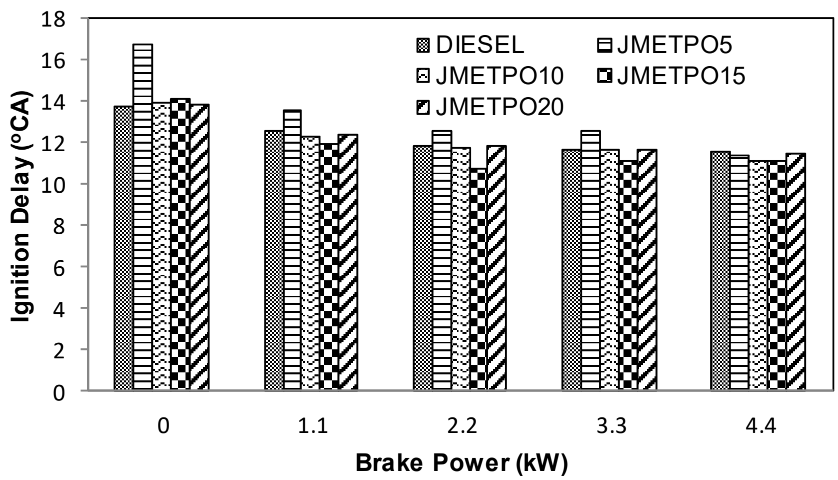

Fig. 4 Variation of ignition delay with brake power

The values of ignition delay for diesel, JMETPO5, JMETPO10, JMETPO15 and JMETPO20 are 11.51, 11.28, 11.01, 11 and 11.36 °CA respectively at full load. JMETPO15 shows the shortest ignition delay at full load among all the blends tested in this study.

4.3 Heat Release Rate

The amount of heat release in the premixed combustion of a CI engine depends on the ignition delay, air fuel mixing rate and the heating value of the fuel [14].

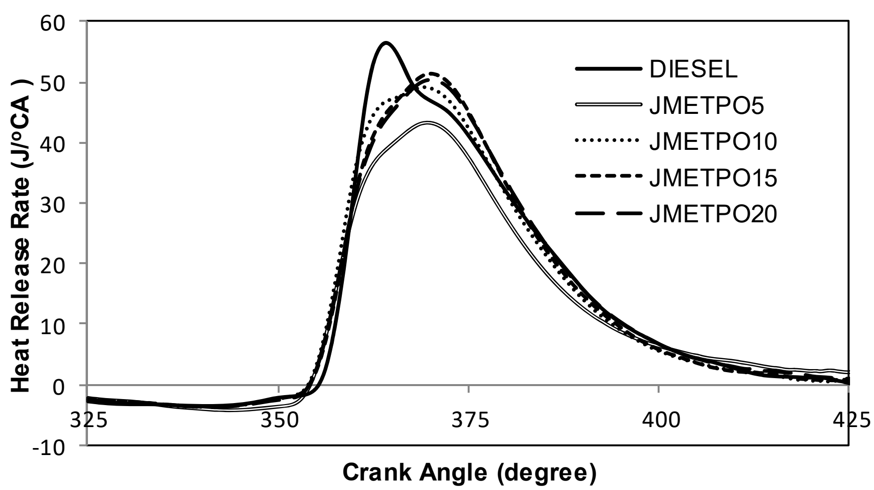

Fig. 5 Variation of heat release rate with crank angle

Figure 5 illustrates the heat release rate pattern with respect to the crank angle at full load. It is apparent from the figure, that the heat release rate is the highest for diesel and lowest for the JMETPO5 blend at full load. The diesel curve is followed by that of JMETPO15, JMETPO20, JMETPO10 and JMETPO5 at full load. The accumulation of diesel is more in the delay period, which releases the maximum heat, as it has a higher calorific value. The heat release rates for JMETPO blends are lower due to their shorter ignition delays and higher viscosities than that of diesel at full load.

4.4 Maximum Heat Release Rate

Figure 6 portrays the variation of maximum heat release rate with brake power for diesel and JMETPO blends. It can be observed, as the brake power increases, there is an increase in heat release rate throughout the combustion period for all the fuels tested. The maximum heat release rate at higher percentage of TPO in the JMETPO blend is lowered owing to lower calorific value of JME.

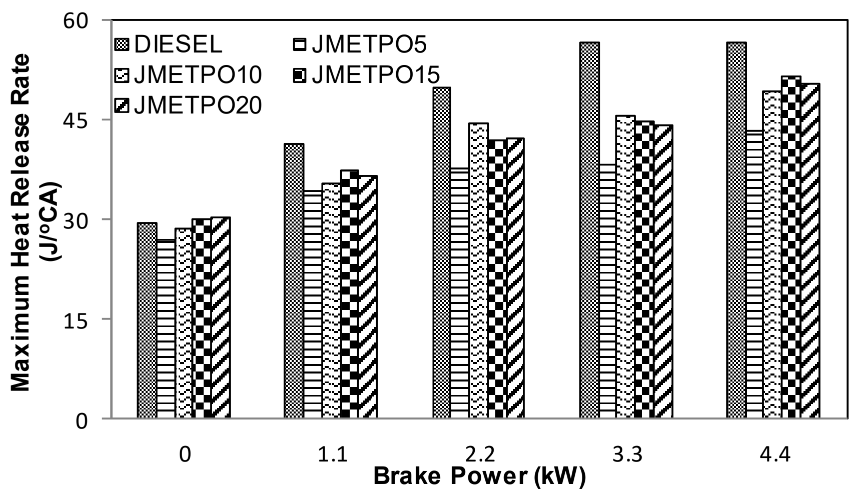

Fig. 6 Variation of maximum heat release rate with brake power

The JMETPO15 gives the maximum heat release rate compared to the other JMETPO blends. The maximum heat release rates for diesel and JMETPO15 are 56.41 and 51.36 J/°CA respectively at full load.

4.5 Combustion Duration

Figure 7 illustrates the variation of the combustion duration with brake power. It can be observed from the figure that the combustion duration increases with an increase in the brake power for all the tested fuels, which may be due to the increase in the quantity of fuel injected.

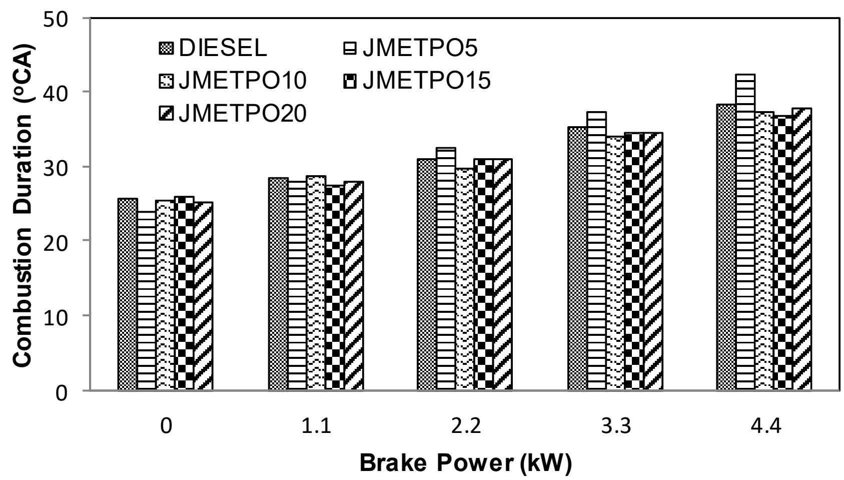

Fig. 7 Variation of combustion duration with brake power

It is also evident from the figure, that the combustion duration is shorter for JMETPO10, JMETPO15, and JMETPO20 compared to that of diesel operation. Increasing the TPO percentage in the JMETPO blends, results in longer combustion duration. This may be due to the high boiling point compounds present in the TPO, and its lower cetane number, which takes more time for the chemical reaction [15]. At full load, the values of the combustion duration for diesel are 38.34°CA, while the values are 42.31, 37.32, 36.68, and 37.8 for JMETPO5, JMETPO10, JMETPO15 and JMETPO20 respectively.

4.6 Cylinder Peak Pressure

The variation of the cylinder peak pressure at different values of brake power is shown in Figure 8.

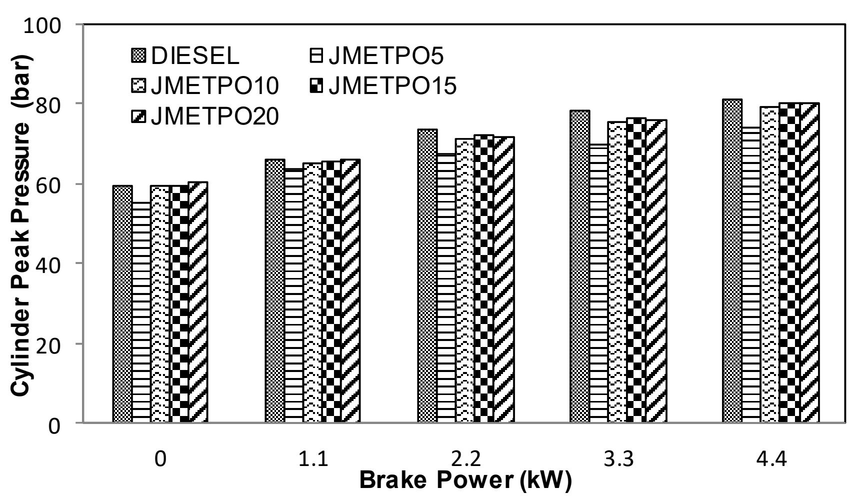

Fig. 8 Variation of cylinder peak pressure with brake power

More diesel might be accumulated in the delay period as a result of longer ignition delay and this is the reason for the highest cylinder peak pressure for diesel, than that of JMETPO blends at full load. The peak pressures for diesel, JMETPO5, JMETPO10, JMETPO15, and JMETPO20 at full load operation are 80.96, 73.71, 79.15, 79.79, and 79.95 bar at full load. JMETPO20 gives a higher peak pressure of 79.95 bar in comparison with the other JMETPO blends.

4.7 Maximum Rate of Pressure Rise

Figure 9 depicts the variation in maximum rate of pressure rise with brake power for diesel and the JMETPO blends. The rate of pressure rise is the first derivative of cylinder pressure that relates to the smoothness of the engine operation. The maximum rate of pressure rise increases initially with load, and then decreases due to the prominent influence of the premixed phase at lower loads, while the role of the diffusion phase of combustion remains significant at higher loads [16]. The maximum rate of pressure rise is higher for diesel at full load.

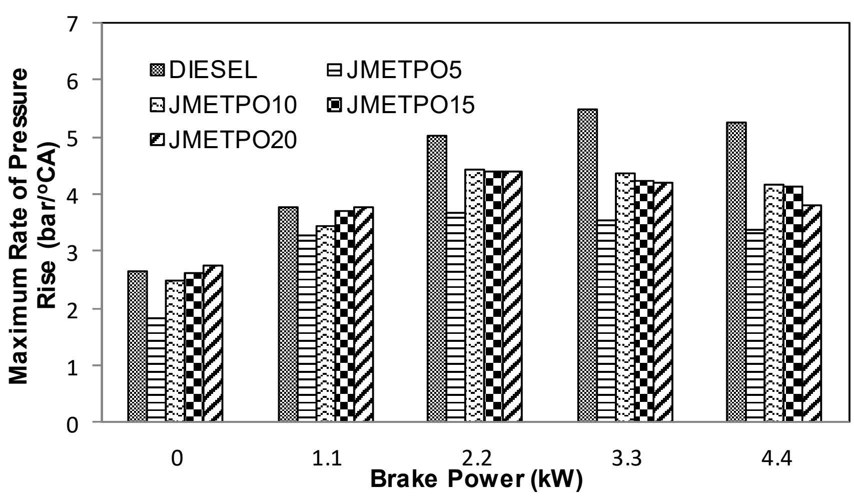

Fig. 9 Variation of maximum rate of pressure rise with brake power

The maximum rates of pressure rise are 5.25, 3.35, 4.16, 4.11 and 3.79 bar/°CA for diesel, JMETPO5, JMETPO10, JMETPO15 and JMETPO20 at full load respectively. Interestingly, the rates of pressure rise for the JMETPO blends are much lower than that of diesel except JMETPO10 and JMETPO20 at full load. In low and part load operations, the rate of pressure rise is unpredictable, because of the aromatic nature of the TPO.

5. Conclusions

In the present investigation, experiments were conducted in a single cylinder, 4 stroke, air cooled, DI diesel engine with JMETPO5, JMETPO10, JMETPO15 and JMETPO20. The conclusions of the investigation **are** summarized and given below.

- On the whole it is concluded that JMETPO blends can be used as fuel in diesel engine and exhibited similar combustion characteristics compared to that of diesel. JMETPO15 gives optimal result compared to other JMETPO blends.
- The cylinder peak pressure lowers by about 1 bar for JMETPO15 in comparison with diesel at full load.
- It is found that the ignition delay for JMETPO15 is shorter by 0.5 ^{o}CA to that of diesel at full load operation.
- The combustion duration for diesel is 38.34^{o}CA at full load. It decreased by about 1.66 ^{o}CA for JMETPO15.
- The maximum rate of pressure rise for all the JMETPO blends tested is found to be lower than that of diesel.
- Lower heat release rates are found with the JMETPO blends as compared to diesel during the premixed combustion phase. The maximum heat release rates for diesel and JMETPO15 are 56.41 and 51.36 J/^{o}CA respectively at full load.

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