PERFORMANCE, EMISSION, AND COMBUSTION CHARACTERISTICS OF A DIRECT INJECTION DIESEL ENGINE USING BLENDS OF PUNNAI OIL BIODIESEL AND DIESEL AS FUEL

by

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Fast-growing demand for automobile vehicles and depletion of fossil fuel forced the researchers to think for alternative fuel which can replace the diesel fuel. From this perspective, Punnai oil which is non-edible in nature is chosen as a feedstock for producing methyl ester. Punnai oil can be converted into biodiesel/methyl ester by transesterification process. From gas chromatography analysis it is found that biodiesel of Punnai oil contains linoleic, oleic and palmitic fatty acids. Presence of these fatty acids and in the Punnai oil biodiesel will enhance the combustion characteristics. To ascertain the suitability of Punnai oil biodiesel as a fuel for direct injection Diesel engine, the experimental work was carried out using a constant speed, four-stroke single-cylinder Diesel engine. Experimental results show that there is a decrease in brake thermal efficiency and an increase in NO_x and CO_2 emissions with increased concentration of biodiesel in the blend. Smoke, CO, and HC emissions were reduced significantly. At rated power, brake thermal efficiencies of diesel, B20, B40, B60, and B80 are 29.2%, 28.6%, 28.1%, 27.5%, and 27%, respectively, and NO_x emissions are in the order of 1516 ppm, 1547 ppm, 1553 ppm, 1567 ppm, and 1631 ppm. Smoke emission for diesel fuel was 50% whereas for B20, B40, B60, and B80, smoke emissions were 48%, 45%, 44%, and 43%. The same trend was observed for hydrocarbon emissions. Combustion characteristics of B20 blend closely follow the trend of diesel fuel. The maximum cylinder pressure of diesel and B20 are 68.3 bar and 67 bar, respectively, and maximum heat release rate of diesel and B20 are 56 kJ/m^3 °CA and 54 kJ/m^3 °CA, respectively.

Key words: *Diesel engine, exhaust emissions, combustion, performance, Punnai oil biodiesel*

Introduction

Petroleum energy resources are getting depleted. So, there is an imperative need to investigate non-polluting, renewable and efficient fuels for transport sectors and other fuel using sectors for their future needs. Increase in the cost of fossil fuel and environmental concern about pollution coming from automobile emission has caused the emergence of the production of biodiesel as a developing area. The economic feasibility of fossil fuel depends on the price and the cost of transportation to remote areas over long distances. So, the price of fossil fuel will increase in the future as a result of an increase in its demand. Biodiesel obtained from vegetable oils has been considered a promising choice to replace fossil fuel [1-3]. A search for

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alternative fuels which can be produced from locally available resources within the country is necessary. High thermal efficiency and large power generation have made diesel engines more attractive. Biodiesel has become more attractive because of its environmental benefits and considering it is derived from renewable resources and its biodegradable and non-toxic nature [4-6]. The environmental sustainability and the employability for the local community and promotion of agriculture have led to the preference for biodiesel as an alternate fuel for transport, agricultural and power sectors [7-9].

Biodiesel is mostly produced using the transesterification method. The process of transesterification has been found to be the simplest methodology of reducing viscosity in vegetable oil and minimizing operational and sturdiness problems. Properties like calorific value, iodine number, cetane number and acid value for biodiesel are similar to those seen in diesel. [10-12]. The poor stability and cold flow property associated with biodiesel can be overcome by blended with diesel and used without making any engine modification [13-15]. In diesel engines, a decrease in the emissions of CO, smoke, and the unburned HC is seen while a slight increase in NO_x emissions was observed with the use of methyl ester [16]. The food crops are not widely used for the production of biodiesel because of their high consumption and cost in domestic purpose. So, non-edible sources were considered for the production of methyl ester. The non-edible sources used in the past few decades are rubber seed, Jatropha, Punnai, Pongamia, and Mahua.

Raw Punnai oil was obtained from the kernel of Punnai tree (*Calophyllum Inophyllum*) is one of the available sources for the preparation of biodiesel because of large quantities available in Africa and Asia [17-19]. Punnai biodiesel has higher oil yielding capacity and higher heating value than other methyl esters like Pongamia, Neem, and Jatropha [20]. The objective of the present study is to experimentally investigate performance, combustion and emission characteristics of a direct injection (DI) Diesel engine operated with biodiesel derived from Punnai oil.

Materials and method

Production and characterization of biodiesel

The Punnai seeds used in the present study for biodiesel production were collected from the plants available in Kanyakumari district, Tamil Nadu, India. The collected seeds are Sun dried to separate the kernels by breaking the outer shell. Kernels are then dried and crushed to extract oil by allowing it to pass through a screw press. The extracted oil is then filtered and used as feedstock for biodiesel production.

The high fatty acids (FFA) content along with higher viscosity of Punnai oil deters its direct usage in internal combustion engines. Two-stage esterification processes with acid and base catalyst are proven to be robust and comprehensive for conditioning the fuel property for Diesel engine applications. Figure 1 shows the chemical reaction involved in two-stage transesterification.

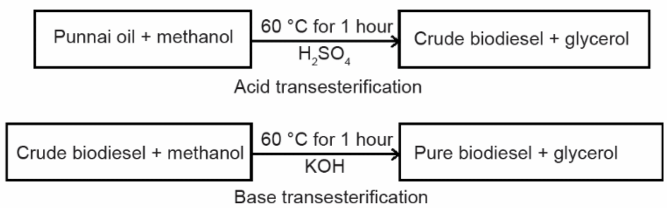

Figure 1. Chemical reaction involved in two-stage transesterification

In the first stage (acid) esterification process, Punnai oil was reacted with methanol and maintained at 60 °C for 1 hour with a stirring speed of 1000 rpm. Sulphuric acid is also added with the mixture. On completion of this reaction, the product is poured into a separating funnel for separating the glycerol. Then the layer, which contained impurities and glycerol, was drawn off and the another layer is separated for further processing.

In the second stage (alkaline/base) esterification process, products of the first step was reacted with methanol and KOH. This mixture is maintained at 60 °C for 1 hour with a stirring speed of 1000 rpm. On completion of this reaction, the product is poured into a separating funnel for separating the glycerol. Then the layer, which contained impurities and glycerol, was drawn off. Then the biodiesel was washed with distilled water and shaken gently at 60 °C to remove the entrained impurities and glycerol. The layer containing biodiesel was taken out to remove water and methanol. Finally, biodiesel was dried and filtered.

Fatty acid composition

The FFA composition of Punnai oil biodiesel was tested using gas chromatography as shown in fig. 2. It was found that Punnai oil biodiesel/methyl ester contains 24% saturated methyl esters and 76% unsaturated methyl esters. Table 1 shows the structural formula and FFA profile of the Punnai oil produced.

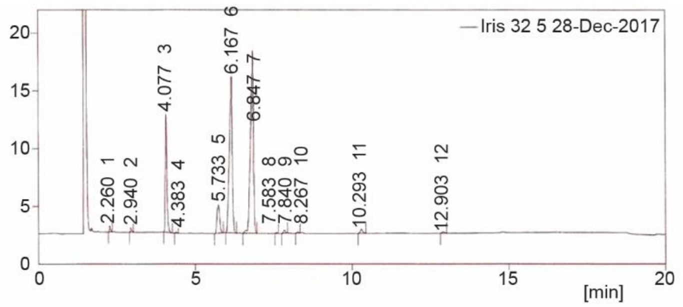

Figure 2. Chromatogram of Punnai oil

Table 1. Structural formula and FFA profile of Punnai oil

Fatty acid	C:N	Chemical structure	Chemical name	Formula	FFA composition
Lauric	C12:0	$CH_3(CH_2)_{10}COOH$	Dodecanoic	$C_{12}H_{24}O_2$	0.523
Myristic	C14:0	$CH_3(CH_2)_{12}COOH$	Tetradecanoic	$C_{14}H_{28}O_2$	0.428
Palmitic	C16:0	$CH_3(CH_2)_{14}COOH$	Hexadecanoic	$C_{16}H_{32}O_2$	14.878
Stearic	C18:0	$CH_3(CH_2)_{16}COOH$	Octadecanoic	$C_{18}H_{36}O_2$	6.226
Oleic	C18:1	$CH_3(CH_2)_7CH = CH(CH_2)_7COOH$	cis-9-Octadecenoic	$C_{18}H_{34}O_2$	34.29
Linoleic	C18:2	$CH_3(CH_2)_4CH = CHCH_2CH = CH(CH_2)_7COOH$	cis-9, cis-12-Octa-decadienoic	$C_{18}H_{32}O_2$	41.711
Linolenic	C18:3	$CH_3CH_2CH = CHCH_2CH = CHCH_2CH = CH(CH_2)_7COOH$	cis-9, cis-12, cis-15-Octadecatrienoic	$C_{18}H_{30}O_2$	0.069

Experimental set-up

The schematic diagram of the experimental set-up used for this experimental work is shown in fig. 3. The specification details relating an engine used for this investigation is given in tab. 2. A single-cylinder four-stroke air-cooled Diesel engine developing 4.4 kW at 1500 rpm was used for this work. This engine was coupled to a SWINGFILED eddy-current dynamometer with a control system. The engine used in the study was the direct injection (DI) type. Exhaust emission from the engine was measured with the help of AVL 444 DI GAS exhaust gas analyzer and smoke emission was measured with the help of the AVL 437 smoke meter.

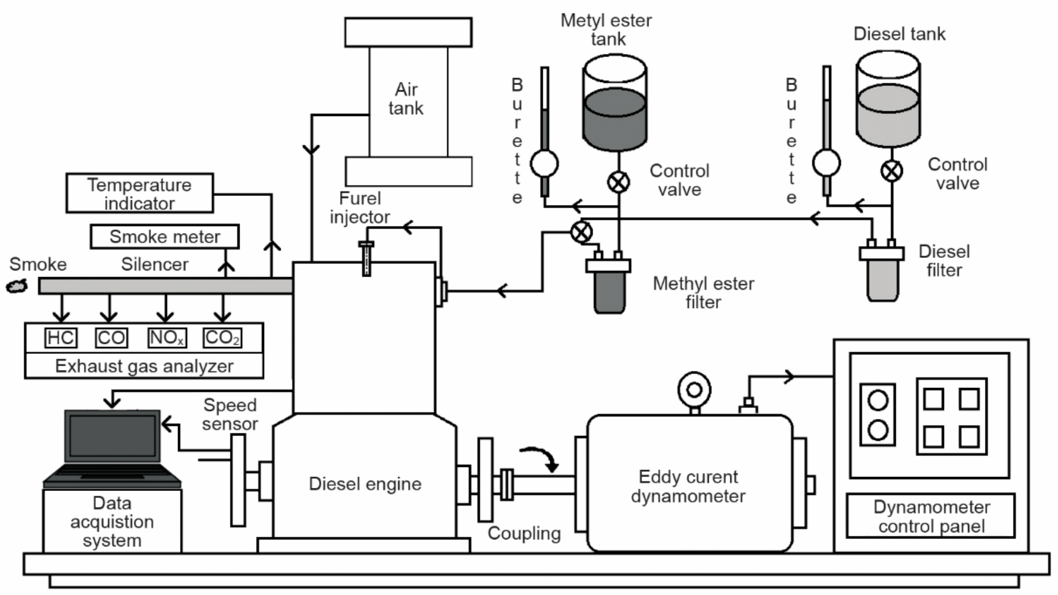

Figure 3. Schematic view of experimental set-up

Table 2. Test engine specifications

Make and model	Kirloskar TAF 1	Rated speed	1500 rpm
Number of cylinders	1	Rated power	4.4 kW
Type of cooling	Air cooling	Fuel injection timing	23° bTDC
Ignition	Compression ignition	Type of dynamometer	Eddy current dynamometer
Bore diameter	87.5 mm	Injection pressure	200 bar
Stroke	110 mm	Charging	Naturally aspirated
Compression ratio	17.5:1		

Experimental procedure

To carry out tests using biodiesel blends, the engine was first run with diesel until a steady operating condition was achieved. Then the fuel was changed to a biodiesel blend. After consumption of sufficient blend fuel, the data acquisition was started to ensure the removal of residual diesel in the fuel line. After each test, the engine was again run with diesel to drain all of the blends out of the fuel line. This procedure was followed for all blends. The different mixes of fuel prepared in different proportions on volume basis were named B20 (80% diesel, 20% Punnai oil biodiesel), B40 (60% diesel, 40% Punnai oil biodiesel), B60 (40% diesel, 60% Punnai oil biodiesel), B80 (20% diesel, 80% Punnai oil biodiesel). Fuel characteristics of Punnai oil biodiesel and standard diesel are shown in tab. 3. The characteristics and fuel properties were studied and the experimental procedure was adopted for evaluating the performance of a 4.4 kW, four-stroke and air-cooled Kirloskar make Diesel engine on these blends.

Table 3. Fuel characteristics of Punnai oil biodiesel and standard diesel

Properties	Standard diesel	Punnai oil biodiesel
Kinematic viscosity [cSt] at 40 °C	2.3	4.88
Density [kgm^{-3}] at 25 °C	810	867
Calorific value [$kJkg^{-1}$]	42500	38000
Flash point [°C]	55	160
Fire point [°C]	65	178
Cetane number	45	52

Error analysis

Error is associated with various primary experimental measurements and the calculations of performance parameters. Errors and uncertainties in the experiments can arise from instrument selection, condition, calibration, environment, observation, reading, and test planning. Uncertainties analysis is needed to prove the accuracy of the experiments. An uncertainty analysis was performed using the method described by Holman [21]. The list of instruments used for measuring various parameters and measurement techniques are presented in tab. 4. The list of instruments and the range, accuracy and uncertainties are given in tab. 5.

Table 4. Various parameters and measurement techniques

Instrument	Purpose	Make and model	Measurement techniques
Exhaust gas analyser	Measurement of HC, CO_2, CO, and NO_x emissions	AVL 444 DI GAS exhaust gas analyser	CO, CO_2, HC–NDIR (non-dispersive infrared sensor) O_2, NO_x – electro chemical sensor)
Smoke meter	Measurement of smoke emission	AVL 437 smoke meter	–
EGT indicator	Measurement of EGT	–	Chromel alumel (K-type) thermocouples
Speed measuring unit	Measurement of engine speed	–	Magnetic pickup type
Pressure transducer and charge amplifier	Measurement of cylinder pressure	AVL pressure transducer GH14D / AH01	–
Crank angle encoder	–	–	Magnetic pickup type
Load indicator	Loading device		Strain gauge type load cell

The total percentage of the uncertainty of this experiment was performed using the equation:

Table 5. List of instruments and the range, accuracy, and uncertainties

Instruments	Range	Accuracy	Percentage uncertainties
Gas analyzer	CO – 0 to 10% vol.	±0.02%	±0.2
	CO_2 – 0 to 20% vol.	±0.03%	±0.15
	HC – 0 to 20000 ppm	±15 ppm	±0.2
	NO_x – 0 to 5000 ppm	±20 ppm	±0.2
Smoke level measuring instrument	Opacity 0-100%	±0.1	±1.0
EGT indicator	0-900 °C	±1 °C	±0.15
Speed measuring unit	0-10,000 ppm	±10 rpm	±1.0
Load indicator	0-100 kg	±0.1 kg	±0.2
Burette for fuel measurement	-	±0.2 cm^3	±1.5
Digital stopwatch	-	±0.2 s	±0.2
Manometer	-	±1 mm	±1.0
Pressure pickup	0-110 bar	±1 bar	±0.1
Crank angle encoder	-	±1°	±0.2

Total percentage uncertainty =
= Square root of {(uncertainty of TFC)^2 + (uncertainty of BP)^2 + (uncertainty of BTE)^2 + (uncertainty of BSFC)^2 + (uncertainty of EGT)^2 + (uncertainty of UHC)^2 + (uncertainty of CO)^2 + (uncertainty of NO_x)^2 + (uncertainty of smoke opacity)^2 + (uncertainty of CO_2)^2 + (uncertainty of pressure pickup)^2 }
= square root of $\{(1.5)^2 + (0.2)^2 + (1.0)^2 + (1.5)^2 + (0.15)^2+(0.2)^2+(0.2)^2+(0.2)^2 +(1.0)^2 +(0.15)^2+ (1.0)^2\}$
= ± 2.77%

Results and discussion

The present work focuses on the influence of Punnai biodiesel on Diesel engine characteristics. Initially, the Diesel engine is allowed to run with diesel as base fuel then fueled with Punnai biodiesel under various engine loads of 0%, 25%, 50%, 75%, and 100% at a constant engine speed of 1500 rpm. All tested fuels are injected at a pressure of 200 bar with 23° bTDC injection timing. Finally, all the experimental results of Punnai oil biodiesel are compared with diesel fuel. The performance, combustion and emission characteristics are discussed in detail in the following section.

Performance characteristics

Performance parameters such as brake thermal efficiency (BTE) brake specific fuel consumption (BSFC) and exhaust gas temperature (EGT) are discussed.

Brake thermal efficiency

Figure 4 depicts the variations of BTE with brake power for all the blends of biodiesel and diesel. The BTE at rated power for standard diesel was seen as 29.2% and in the case of blends, it was 28.6% for B20, 28.1% for B40, 27.5% for B60 and 27% for B80. The

BTE decreased with an increased proportion of biodiesel in the blends. This could be attributed to the lower calorific value of the biodiesel when compared to diesel. Another reason could be the higher viscosity and density of the biodiesel blends. For B80 blend, the thermal efficiency was reduced to 27%. This is due to the higher density and viscosity of the blend and also due to the presence of heavier HC chains.

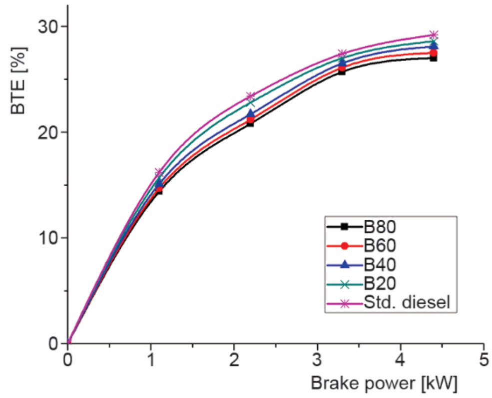

Figure 4. Variation of BTE with brake power

Brake specific fuel consumption

Figure 5 depicts the variations of BSFC with brake power for all the blends of biodiesel and diesel. There was an increase in BSFC decreased with an increase in brake power for all the tested fuels. Punnai oil biodiesel has about 11% lower heating value when compared to diesel resulting in increased BSFC. The BSFC increases with increasing biodiesel ratios in the blend**.** At rated power, the specific fuel consumption for standard diesel was 0.25 kg/kW per hour and in the case of blends, it was 0.28 kg/kW per hour for B20, 0.3 kg/kW per hour for B40, 0.32 kg/kW per hour for B60 and 0.33 kg/kW per hour for B80. The increase in BSFC may be attributed to higher viscosity and density of blends which influenced spray behavior and higher BSFC. The specific fuel consumption for diesel was found to be lower than Punnai oil biodiesel blends.

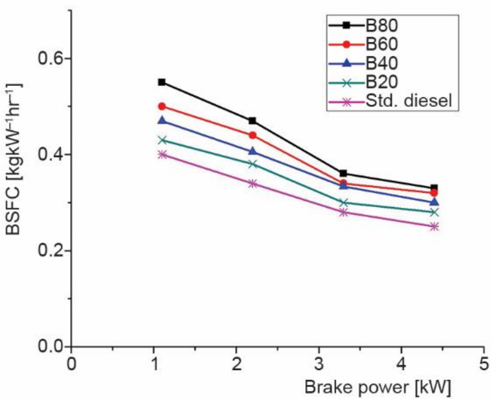

Figure 5. Variation of BSFC with brake power

Exhaust gas temperature

Figure 6 depicts the variations of EGT with brake power for all the blends of biodiesel and diesel. To indicate the cylinder combustion temperature, the engine exhaust temperature is considered one of the important parameters. It is a good parameter for analyzing exhaust emissions, especially NO_x. Biodiesel and its blends possess higher CN, poor atomization resulting from the higher viscosity of those fuels causes the presence of unburned fuels in the premixed combustion phase. These unburned portions continue to burn later in the diffusion combustion phase, leading to higher exhaust temperature. For all biodiesel blends, EGT is higher than diesel which will be due to the presence of oxygen and complete combustion.

Emission characteristics

Various emission parameters such as HC, CO, CO_2, NO_x and smoke opacity are measured and discussed in the following section.

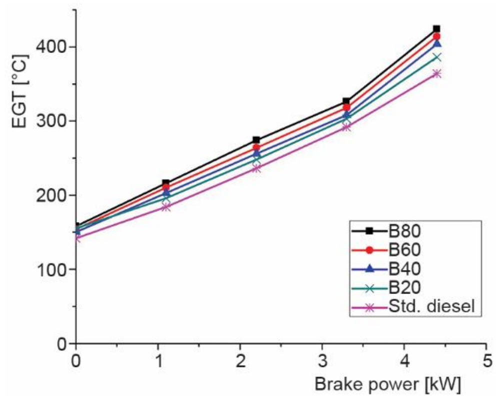

Figure 6. Variation of EGT with brake power

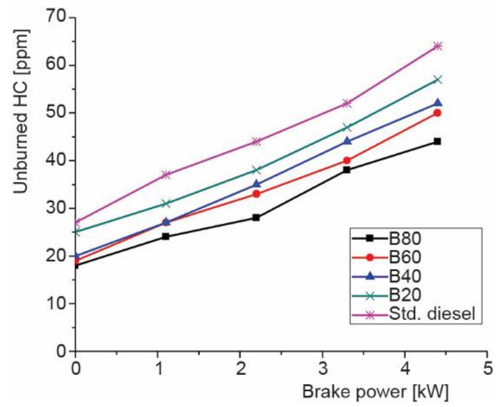

Figure 7. Variation of unburned HC with brake power

Unburned HC emissions

Figure 7 depicts the variations of unburned HC emissions with brake power for all the blends and diesel. The main reason for the formation of unburned HC in the exhaust is the trapping of fuel in the crevices during combustion. The unburned HC emission for standard diesel fuel at rated power was 64 ppm, whereas for blends it was 57 ppm for B20, 52 ppm for B40, 50 ppm for B60, and 44ppm for B80. The unburned HC emission was seen lower for B80 blend when compared to other blends and diesel. The reduced unburned HC emission for B80 could be due to complete combustion that resulted in higher EGT.

Carbon monoxide emissions

Figure 8 depicts the variations of CO emissions with brake power for all the blends and diesel. The CO emission for standard diesel fuel at rated power was 0.41%, whereas for blends it was 0.35% for B20, 0.3% for B40, 0.26% for B60, and 0.2% for B80. The CO is a highly poisonous gas. The main reason for the formation of CO is the partial oxidation of carbon compounds present in the fuel. The CO emission decreases with an increase in the percentage of the biodiesel in the blends. The decrease in CO emission for higher biodiesel blends could be due to complete combustion and higher combustion temperature. This is also attributed to the presence of higher oxygen molecules in the methyl ester, which improves complete oxidation of CO.

Oxides of nitrogen emissions

Figure 9 depicts the variation of NO_x emission with brake power for all the blends and diesel. The NO_x emission is an important component in the Diesel engine emissions. The formation of NO_x depends on various factors such as premixed combustion, in-cylinder pressure, in-cylinder temperature, oxygen content and residence time. Increase in NO_x levels with an increase in the amount of methyl esters in the blends was seen. The NO_x emission for standard diesel fuel at rated power was 1516 ppm whereas for blends it was 1547 ppm for B20, 1553 ppm for B40, 1567 ppm for B60, and 1631 ppm for B80. This increase in NO_x emission was due to shorter ignition delay and a lower rate of premixed combustion compared to diesel. Another reason could be because the average carbon chain length lower and the unsaturated compounds increase. The content of unsaturated compounds in biodiesel could have a greater impact on NO_x emission. The higher content of unsaturated compounds is also the reason for more NO_x emission [25].

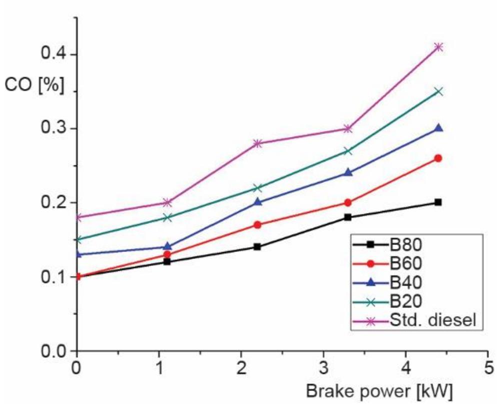

Figure 8. Variation of CO with brake power

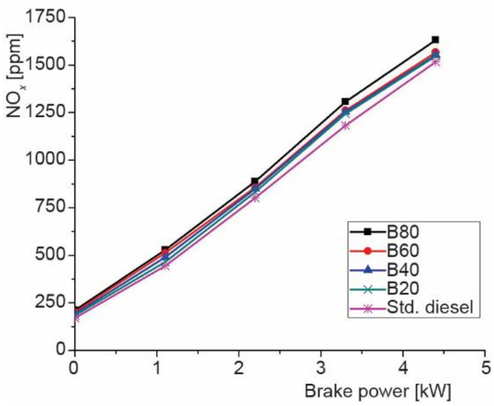

Figure 9. Variation of NO_x with brake power

Smoke emissions

Figure 10 depicts the variations of smoke opacity with brake power for all the blends and diesel. The smoke opacity for standard diesel fuel at rated power was 50% whereas for biodiesel blends it was 48% for B20, 45% for B40, 44% for B60, and 43% for B80. There was an increase in smoke emissions following an increase in brake power. However, there was a decrease in smoke emission with an increase in the biodiesel ratio. Better diffusive combustion could be the base for the reduction in smoke emission. The results showed a decrease in smoke emissions with increased oxygen content. The presence of oxygen in the biodiesel caused reduction in smoke emissions [22].

Carbon dioxide emissions

Figure 11 depicts the variations of CO_2 emissions with brake power for all the blends and diesel. The presence of oxygen in the blend increased CO_2 emission due to reaction with HC atoms of the fuel. The CO_2 emission for standard diesel fuel at rated power was 18% whereas for blends it was 20% for B20, 22% for B40, 23% for B60, and 24% for B80. More amount of CO_2 in engine exhaust indicates complete combustion of fuel and also higher EGT.

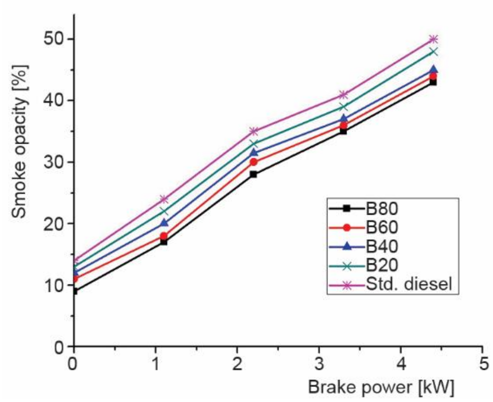

Figure 10. Variation of smoke opacity with brake power

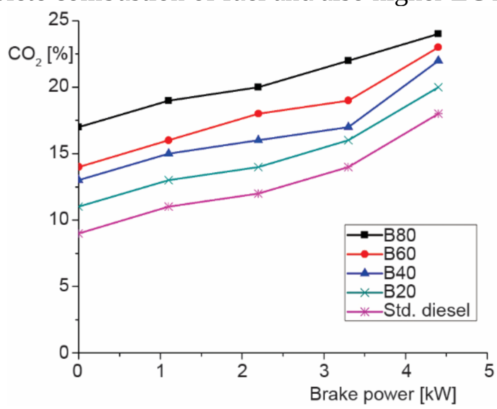

Figure 11. Variation of CO_2 with brake power

Combustion characteristics

The combustion characteristics like in-cylinder pressure, heat release rate, cylinder peak pressure, and ignition delay are measured and discussed in the following sections.

Cylinder pressure

Figure 12 depicts the variation of cylinder pressure with a crank angle (CA) for diesel and different blends of Punnai biodiesel with diesel at rated power. The peak pressures for the diesel, B20, B40, B60, and B80 Punnai oil biodiesel are 68.3 bar, 67 bar and 65 bar, 64 bar, and 63 bar, respectively, at full load. It is observed that the peak pressure decreased by 1.3 bar and 5.3 bar for B20, and B80, respectively, as compared to that of diesel fuel. It is also observed that maximum cylinder pressure occurs for diesel fuel. For blends, the cylinder pressure decreased with an increase in the proportion of biodiesel in the blend. This may be attributed to the lower heating value of biodiesel and early combustion of biodiesel blends. Peak pressure occurs at TDC for all the blends and diesel. In a compression ignition engine, the peak pressure depends on the amount of fuel taking part in the uncontrolled combustion phase, which is governed by the delay periods and premixed combustion phase. The higher cylinder pressure for B20 compared to other blends of Punnai oil biodiesel may be due to the comparable viscosity and lower heating value with diesel.

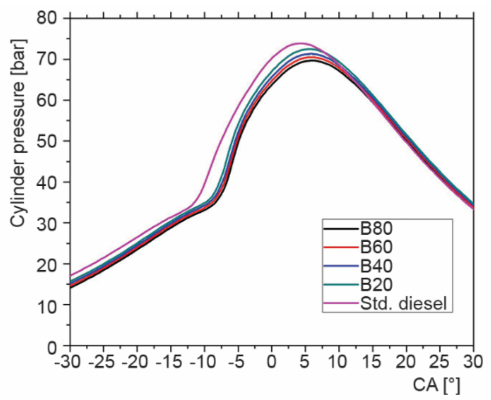

Figure 12. Variation of cylinder pressure with CA at full load

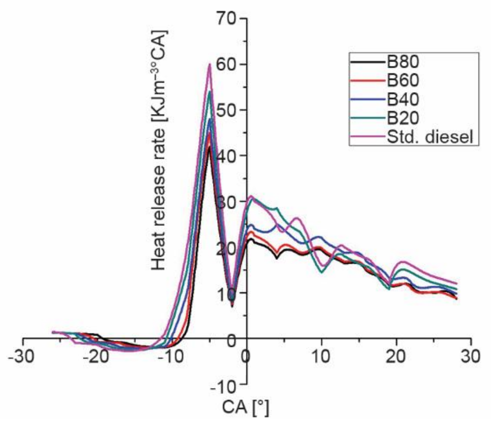

Figure 13. Variation of heat release rate with CA at full load

Heat release rate

Figure 13 depicts the variation of heat release rate with CA for diesel and different blends of Punnai biodiesel with diesel. In a Diesel engine, combustion proceeds in three distinguishable stages. In the first stage, the rate of burning is generally very high and lasts for only a few °CA. It corresponds to the period of rapid cylinder pressure. The second stage corresponds to a period of the gradual decrease in the cylinder pressure. This is the main heat release period and ends at 40-50 °CA. Normally around 80% of the total fuel energy is released in the first two-stages. In the third stage of combustion, around 20% of the total fuel energy is released. The magnitude of the initial peak of heat release in the premixed combustion phase depends on the ignition delay period [23].

The comparison of the rate of heat release with CA at full load for diesel and Punnai oil biodiesel blends is presented in fig. 10. The peak heat release rate for diesel, B20, B40, B60, and B80 is 56 kJ/m^3 °CA, 54 kJ/m^3 °CA, 53 kJ/m^3°CA, 52 kJ/m^3 °CA, and 51 kJ/m^3 °CA, respectively, at rated power. It can be observed that the heat release is decreased for the Punnai oil biodiesel blends. This may be due to the poor atomization and vaporization of fuel leading to more accumulation of fuel during the ignition delay period. This may lead to excess burning during the diffusion phase. The lower heat release rate of Punnai oil biodiesel as compared to diesel is due to shorter ignition delay and lower premixed combustion phase. Also, it may be due to the lower heating value of Punnai oil methyl ester.

Cylinder peak pressure

Figure 14 depicts the variation of cylinder peak pressure with brake power for all the test fuels. The peak cylinder pressure in the Diesel engine also depends on the viscosity of the fuel. During the ignition delay, the droplets have sufficient time to spread with fresh air. Most of the fuel admitted would have evaporated and formed a combustible mixture with air, which results in complete combustion. The peak pressure decreases for all Punnai oil biodiesel blends, which have high viscosity that results in increased physical delay. The peak pressure for B20 varies from 50 bar to 67 bar, for B80, it varies from 46 to 63 bar, whereas for diesel, it varies from 52 bar to 68.3 bar, from no load to full load (*i. e.* 100% load). This may be due to the high viscosity and low volatility of the biodiesel higher blends which increases the ignition delay period during the pre-mixed combustion phase.

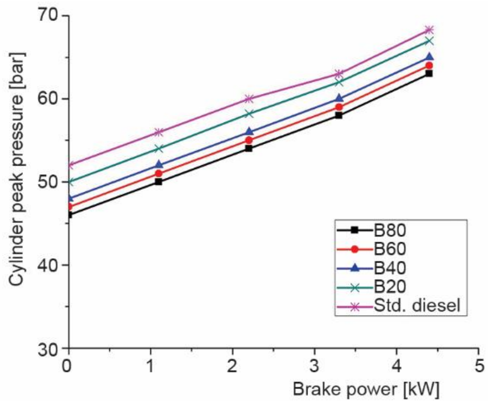

Figure 14. Variation of cylinder peak pressure with brake power

Ignition delay

Figure 15 illustrates the variation of the ignition delay for diesel and Punnai oil biodiesel blends. The ignition delay decreases with the increase in load for all the fuels. This may be due to higher combustion temperature and exhaust gas dilution at higher loads. Ignition delay is calculated as the period from the start of injection to the start of combustion in terms of the CA. The ignition delay for B20, B40, B60 and B80 are 16.5 °CA, 16 °CA, 15.5 °CA, and 15 °CA, respectively, whereas for diesel it is 17 °CA at full load. The shorter ignition delay for blends may be attributed to the higher cetane number of fuel. The cetane number of Punnai oil biodiesel is 52. The presence of oleic and palmitic fatty acids may split in to smaller compounds when it enters the combustion chamber resulting in higher spray angles and earlier ignition as reported in [24]. The identical trend is obtained for Punnai oil biodiesel blends, as Punnai oil biodiesel has linoleic, oleic, and palmitic fatty acid as major composition [25].

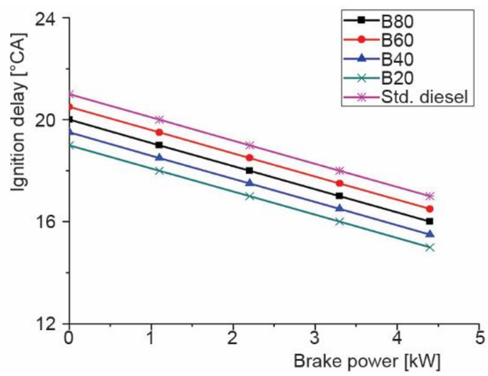

Figure 15. Variation of ignition delay with brake power

Conclusions

Performance, emission and combustion characteristics were investigated using biodiesel derived from Punnai oil in the blended form with diesel on a single-cylinder four-stroke Diesel engine. The BTE of biodiesel blends was similar to that of diesel. At rated power, BTE of standard Diesel, B20, B40, B60, and B80 were 29.2%, 28.6%, 28.1%, 27.5%, and 27%, respectively. At rated power NO_x emission and smoke emission showed a trade-off between them. Higher combustion temperature due to the presence of oxygen content resulted in higher NO_x and lower smoke emissions. The NO_x emissions were in the order of 1516 ppm, 1547ppm, 1553ppm, 1567 ppm, and 1631 ppm. Smoke opacity for diesel fuel was 50% whereas for B20, B40, B60, and B80, smoke emissions were 48%, 45%, 44%, and 43%. A similar trend was observed for HC emissions. Combustion characteristics like cylinder pressure, heat release rate and ignition delay are similar to those of diesel. It is inferred that the performance of the B20 blend is closer to that of diesel in terms of BTE. Hence, B20 blend is suggested as a fuel for Diesel engines.

Nomenclature

B20 – 80% diesel and 20% Punnai oil biodiesel
B40 – 60% diesel and 40% Punnai oil biodiesel
B60 – 40% diesel and 60% Punnai oil biodiesel
B80 – 20% diesel and 80% Punnai oil biodiesel
BSFC – brake specific fuel consumption
BTE – brake thermal efficiency
EGT – exhaust gas temperature

References

[1] Senthil Kumar, S., K. *et al.,* Performance Analysis of Compression Ignition Engine Using Rubber Seed Oil Methyl Ester Blend with the Effect of Various Injection Pressures, *Thermal Science, 20* (2016), Suppl. 4, pp. S1083-S1090
[2] Barnwal, B. K., Sharma, M. P., Prospects of Biodiesel Production from Vegetable Oils in India, *Renewable and Sustainable Energy Reviews, 9* (2005), 4, pp. 363-378
[3] Polat, S., An Experimental Study on Combustion, Engine Performance and Exhaust Emissions in a HCCI Engine Fuelled with Diethyl Ether–Ethanol Fuel Blends, *Fuel Processing Technology, 143* (2016), Mar., pp. 140-150
[4] Devan, P. K., Mahalakshmi, N. V., Utilization of Unattended Biodiesel of Paradise oil as Fuel in Diesel Engine, *Fuel, 88* (2009), 10, pp. 1828-1833
[5] Devan, P. K., Mahalakshmi, N. V., Study of the Performance, Emission and Combustion Characteristics of a Diesel Engine Using Poon Oil-Based Fuels, *Fuel Processing Technology, 90* (2009), 4, pp. 513-519
[6] Agarwal, A. K., Biofuels (Alcohols and Methyl Ester) Applications as Fuels for Internal Combustion Engines, *Progress in Energy and Combustion Science, 33* (2007), 3, pp. 233-271
[7] Aarthy, M., *et al.*, Enzymatic Transesterification for Production of Biodiesel Using Yeast Lipases: An Overview*, Chemical engineering research and design, 92* (2014), 8, pp. 1591-1601
[8] Ghaly, A. E., *et al.*, Production of Biodiesel by Enzymatic Transesterification: Review, *American Journal of Biochemistry and Biotechnology, 6* (2010), 2, pp. 54-76
[9] Devan, P. K., Mahalakshmi, N. V., A Study of the Performance, Emission and Combustion Characteristics of a Compression Ignition Engine Using Biodiesel of Paradise Oil–Eucalyptus Oil Blends, *Applied Energy, 86* (2009), 5, pp. 675-680
[10] Perumal, V., Ilangkumaran, M., Experimental Analysis of Engine Performance, Combustion and Emission Using Pongamia Biodiesel as Fuel in CI Engine, *Energy, 129* (2017), June, pp. 228-236
[11] Vasquez, M. C., *et al.*, Hydro Treatment of Vegetable Oils: A Review of the Technologies and its Developments for Jet Biofuel Production, *Biomass and Bioenergy, 105* (2017), Oct., pp. 197-206
[12] Goembira, F., Saka, S., Advanced Supercritical Methyl Acetate Method for Biodiesel Production from Pongamia Pinnata Oil, *Renewable Energy, 83* (2015), Nov., pp. 1245-1249
[13] Murugesan, A., *et al.,* Production and Analysis of Bio-Diesel From Non-Edible Oils – A Review, *Renewable and Sustainable Energy Reviews, 13* (2009), 4, pp. 825-834

[14] Dwivedi, G., Sharma, M. P., Prospects of Biodiesel from Pongamia in India, *Renewable and Sustainable Energy Reviews*, *32* (2014), Apr., pp. 114-122
[15] Rao, M. S., Anand, R. B.. Production Characterization and Working Characteristics in DICI Engine of Pongamia Biodiesel, *Ecotoxicology and Environmental Safety, 121* (2015), Nov., pp. 16-21
[16] Murugesan, A., *et al.,* Production and Analysis of Bio-Diesel from Non-Edible Oils–A Review, *Renewable and Sustainable Energy Reviews, 13* (2009), 4, pp. 825-834
[17] Sanjid, A., *et al.,* Performance and Emission of Multi-Cylinder Diesel Engine Using Biodiesel Blends Obtained from Mixed Inedible Feedstocks, *Journal of Cleaner Production, 112* (2016), Jan., pp. 4114-4122
[18] Atabani, A. E., Aldara, da Silva Cesar, Calophyllum Inophyllum L. – A Prospective Nonedible Biodiesel Feedstock, Study of Biodiesel Production, Properties, Fatty Acid Composition, Blending and Engine Performance, *Renewable Sustainable Energy Rev, 37* (2014), Sept., pp. 644-655
[19] Mosarof, M. H., *et al.,* Optimization of Performance, Emission, Friction and Wear Characteristics of Palm and Calophyllum Inophyllum Biodiesel Blends, *Energy Conversion and Management, 118* (2016), June, pp. 119-134
[20] Monirul, I. *et al.,* Assessment of Performance, Emission and Combustion Characteristics of Palm, Jatropha and Calophyllum Inophyllum Biodiesel Blends, *Fuel*, (2016), doi:10.1016/j.fuel.2016.05.010
[21] Holman, J. P., *Experimental Techniques*, Tata McGraw Hill Publications, New York, USA, 2003
[22] Sajjad, H., *et al.,* Influence of Gas-to-Liquid (GTL) Fuel in the Blends of Calophyllum Inophyllum BIO-DIESEL and Diesel: An analysis of Combustion-Performance-Emission Characteristics, *Energy Conversion and Management*, *97* (2015), June, pp. 42-45
[23] Rao, G. L. N., *et la.,* Experimental Studies on the Combustion and Emission Characteristics of a Diesel engine Fuelled with Cooking Oil Biodiesel and its Diesel Blends, *International Journal of Applied Science Engg & Tech, 4* (2007), 2, pp. 64-70
[24] Heywood, J. B., Automotive Engines and Fuels: A Review of Future Options, *Prog Energy Combust Sci, 7* (1981), 3, pp. 155-84
[25] Bibin, C., P. Seenikannan, Experimental Analysis of Energy Recovery from and Internal Combustion Engine Exhaust Using Rankine Cycle, *Advanced Materials Research, 768* (2013), Sept., pp. 158-163

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