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Study of Performance and Emission Characteristics Of A 4-Stroke CI Engine Fuelled with Composite Biodiesel of Pork Fat and Pongamia Pinnata

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Abstract— Recent analysis has shown that biodiesel has proved to be one of the major alternatives for fossil fuels. The research by experimentation of these biodiesel fuels in a CI Engine offers a range of edible and non-edible oils apart from methyl esters as substitute for the diesel fuel and promotes future possibilities of Biodiesel as an alternative fuels for transportation sector.

In this study, biodiesel derived from Pork fat (Lard) and Pongamia Pinnata (Honge) is blended with diesel in different proportions and used for testing of engine performance and emission characteristics. The experiments disclose that the composite blends of pork fat, honge and diesel as a fuel reduces the overall fuel consumption without decrease in engine performance and thereby reducing dependency on fossil fuels.

Index Terms— Biodiesel, Pork fat (Lard), Pongamia pinnata (Honge), performance and emission characteristics.

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1 Introduction

Energy demand will still increase considerably in the upcoming years due to population growth and gradual rise in living standards, especially in developing countries. To satisfy this demand, the energy sources will become more complementary than competitive [1]. All energy options must be kept open to provide the most appropriate responses, at both environmental and economic point of view.

Hydrocarbons will play a major role in the future, particularly in the transport and petrochemical sectors [9]. The major part of all energy sources comes from petroleum, charcoal and natural gas apart from hydropower and nuclear energy [5]. They will remain difficult to substitute in the short and medium terms. Based on these conclusions, the technological solutions that will ensure the future energy needs and mobility should be developed by considering the finite nature of hydrocarbon resources and the problem of climate change. Thus, as a sustainable development perspective, it is necessary to ensure a long term energy supply, while protecting the local and global environment (reduce negative environmental impacts, i.e. greenhouse gas emissions). All these factors make it necessary to research and develop sustainable renewable energy sources. Biomass sources, especially animal fats provided by slaughter waste, oils and greases from restaurant from have attracted much attention as an alternative energy source [8]. However, the viscosity of vegetable and animal fat oil is higher than that of petroleum diesel. Hence transesterification process is used to reduce the viscosity of the raw oil [14].

Biofuels are renewable, non-toxic and can be produced locally from agricultural resources and slaughterhouses. Studies show that, without any engine modifications, the operating characteristics of CI engine fuelled with biodiesel blends showed improved performance when compared with that of petroleum diesel [3]. It is observed that major exhaust pollutants like CO, CO_2 and HC are reduced when biodiesel is used [15]. However, it is observed there is a slight increase in nitrous oxide emissions when compared with that of engine fuelled with petroleum diesel [16].

Biodiesel from various oils such as sunflower, coconut [13], soybean and palm have been successfully tested on CI engines. However, they are edible and are expensive [12]. Therefore biodiesel production from such oils is not economical. Hence non-edible oils like Karanja (Pongamia pinnata) are attractive due to easy availability and low cost production [2], [10]. Honge or karanja oil is a thick yellow-orange to brown oil which is extracted from seeds of Pongamia tree. Lard is obtained from any part of the pig where there is a high proportion of adipose tissue. It can be rendered by steaming it or boiling it in water and then separating the insoluble fat from the water, or by the use of dry heat. Pork Lard can be potential alternative fuel for an unmodified diesel engine because of its high oil content (around 80%) for biodiesel production [4].

2 Methodology

Biodiesel extracted from Pongamia pinnata (Honge) is procured from National Institute of Technology, Karnataka.

Biodiesel preparation from pork fat involves the following set of procedures:

2.1 Collection and extraction of waste pork fat:

Pork lard contains very high fat content. These can be obtained from any part where there is a high concentration of fatty tissue [4]. Generally, the fats are discarded at a throw away price. Oil can be extracted from the fats by dry rendering.

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In this process, the fat is exposed to high heat in a pan or oven without the presence of water.

2.2 Determination of free fatty acid content (FFA %) of the lard oil:

Free fatty acids are carboxylic acid with a long chain aliphatic chain in either saturated or unsaturated form. Determination of FFA percentage is the most prominent step in biodiesel preparation, as it decides what type of catalytic reaction should be preferred for transesterification process. The following steps have to be carried for determining the FFA content in raw oil:

Preparation of 0.1N sodium hydroxide (NaOH) solution:

Weigh out 4 gram NaOH using a weighing scale.Add the weighed NaOH into 1L distilled water and stir till the NaOH completely dissolves in the water. The 0.1N NaOH solution is ready for use.

Titration and calculation:

Take 25mL 0.1N NaOH [7] solution in a clean and dry burette. Measure 10g of raw oil in a clean and dry conical flask. Add a few drops of phenolphthalein indicator to it. Titrate the mixture against 0.1N NaOH solution in the burette till a persistent faint pink colour is obtained. Note the end point value. Free Fatty acid content can be calculated using the formula –

FFA= {(28.2*Normality of NaOH*titration value)/ (weight of oil taken)} (1)

Table 1: FFA Calculation

Trail number	Weight of the oil taken (g)	Normality of NaOH	Titration end point (mL)	Free Fatty Acid content (%)
1.	10	0.1	0.4	0.1128
2.	10.4	0.1	0.4	0.1084

2.3 Biodiesel preparation:

There are two methods used for the preparation of biodiesel. The criteria for selection of the type of process to be selected are based on the presence of Free Fatty Acid (FFA) content in the oil.

If the FFA content is less than 2.5%, then single stage (Alkali base) process has to be undertaken.

If the FFA content is more than 2.5%, then double stage process (Acid + alkali based catalyst) process has to be undertaken [6].

The FFA content in lard oil is found to be 0.1128% which is less than 2.5%. Therefore, single stage reaction has to be carried on.

The following are the steps to be followed for alkali catalyst reaction:

Transesterification process:

Measure 1 later of raw oil and transfer it into a 3-neck round bottom flask. Place the flask over a magnetic stirrer. Put the magnet pellet into the flask. Fix the reflex condenser to the central neck of the 3- neck flask. Connect the water pipe line to the condenser and check up for water circulation from the tap to condenser and outlet. Switch on the magnetic stirrer and adjust the speed of the stirrer between 600 to 800rpm. Setup the heating to 60^{o}C.Take 300mL of methanol in a beaker. Add the required amount of NaOH based on FFA% in the methanol based on the formula-

Quantity of NaOH = 3.5+ FFA value of the raw oil (2)
= 3.5 + 0.1106 = 3.6106g

Fig. 1: 3-Neck Flask with Reflex Condenser

Stir the mixture well till NaOH completely dissolves in methanol. The solution is called Methoxide mixture. Once the temperature is set to 63°C, slowly pour the Methoxide solution into the three neck flask through one of the side necks. Maintain this process for about 90 minutes. Ensure the temperature is 63°C – 65^{o}C throughout the process. After 90 minutes, transfer the contents into a separating funnel and allow the glycerine to settle. Drain out the glycerine through the bottom.

Fig. 2: Transesterified Oil in Separating Funnel

FFA= {(28.2*Normality of NaOH*titration val-

Washing of Bio-diesel:

Transfer the Bio-diesel in the plastic "Washing funnel" and spray 500ml of warm water into the flask. Allow it to settle for 15 minutes. Drain the bottom layer (soap water).Repeat the procedure till pH value reaches 7.

Fig. 3: Washing Funnel

Drying of Bio-diesel:

Transfer the washed Bio-diesel in to a 1L beaker Heat the Bio-diesel to a temperature of 100°C till the moisture evaporates. Allow the Bio-diesel to cool gradually. Filter and store the Bio-diesel in a clean, dry container.

Yield:

After washing and drying process, the amount of biodiesel is measured using measuring cylinder. It is estimated that, 2.75 litre of biodiesel is obtained from 3 litre of raw pork fat

3 Nomenclature

Table 2

Nomenclature Of Biodiesel Blends

Sample	Pork fat (% volume)	Pongamia pinnata (%volume)	Petroleum diesel (%volume)
B10	5	5	90
B15A	5	10	85
B15B	10	5	85
B20	10	10	80
B25A	10	15	75
B25B	15	10	75
B30	15	15	70

4 Fuel property test

4.1 Specific gravity:

The fuel density affects engine performance because fuel injection pumps meter fuel by volume, not by mass. The hydrometer is dipped and the reading is noted.

4.1 Flash point:

Flash point for various blends of composite biodiesel and petroleum diesel is determined using Cleveland open cup flash point apparatus.

4.3 Kinematic viscosity:

Redwood viscometer is used to determine the kinematic viscosity of the fuel. Equation used to find Kinematic viscosity at T°C is:

$$V= [(0.00226 \times R) - (1.79/R)] \text{ Stokes, when } 34<R<100 \quad (3)$$

$$V = [(0.00247 \times R) - (0.5/R)] \text{ Stokes, when } R>100 \quad (4)$$

Where R= redwood seconds

4.4 Calorific value:

Bomb calorimeter is used to determine the calorific value of the biodiesel. Equation to calculate the calorific value of the fuel is:

$$\text{Calorific value} = [W\Delta T1-(E1+E2)]/ [M2-M1] \quad (5)$$

Where,

M1= Empty weight of the crucible (g)

M2= Weight of the crucible with oil (g)

E1= Heat liberated by nichrome wire (cal)

E2= Heat liberated by cotton thread (cal)

ΔT1= Increase in temperature (°C)

Table 3

Comparison Of Fuel Properties

Samples	Flash point(°C)	Kinematic viscosity (stokes)	Density (g/cc)	Calorific value (MJ/kg)
B10	62	0.012318065	0.82358	42.54669407
B15A	50	0.020337576	0.839	42.31944552
B15B	55	0.008133333	0.82752	42.62130642
B20	66	0.0163825	0.83062	42.39425867
B25A	64	0.020337576	0.83512	42.16901743
B25B	64	0.020337576	0.84572	42.46874411
B30	68	0.0163825	0.84142	42.24369855
DIESEL	59	0.008133333	0.8234	42.70104

5 ENGINE PERFORMANCE AND EMMISION CHARACTERISTICS TEST

The compression ignition engine used for the study of composite biodiesel is a single cylinder, four stroke, direct injection, and air cooled engine. The performance of composite biodiesel and its blends are studied in comparison with diesel fuel [11]. The composite biodiesel is mixed with the standard diesel in an external tank, according to the needed ratios. The schematic representation of the test system is shown in the figure with the engine specification in the table below. The engine is coupled with the eddy current dynamometer to apply different engine loads.

The engine is started on petroleum diesel fuel and warmed up. Then the parameters like the speed of operation, fuel consumption and load are measured. After the engine reached the stabilized working condition, emissions are measured using a Multigas analyser which determines the amount of CO, HC and NOX released during exhaust. After that the baseline data is generated and the corresponding results are obtained. The engine is then operated with blends of B10, B20, B30, B15A, B15B, B25A and B25B additives for different load condition [14]. At every operation the engine speed has to be checked and maintained about 1500rpm. The different performance and emission parameters analysed in the present investigations are specific fuel consumption (SFC), exhaust gases like carbon dioxide, carbon monoxide, nitrogen oxides, hydrocarbons are measured using the multi-gas analyser.

Table 4
Engine Specifications

Sl. No.	Parameters	Specifications
1	Make	Kirloskar
2	Model	TV1
3	Type	4 Stroke Single Cylinder
4	Power	5.2kW
5	Bore	87.5mm
6	Stroke	110mm
7	Cooling	Water Cooled
8	Speed	1500rpm
9	Fuel	Diesel
10	Type of Fuel Injection	Direct Injection
11	Compression ratio	17.5:1
12	Engine Capacity	661cc
13	Type of Dynamometer	Eddy Current , Moment arm length 185mm

6 RESULTS AND DISCUSSIONS

Table 5
Engine Performance

Sample	Load (kg)	B.P (kW)	B.S.F.C (kg/kWh)	B.T.E (%)
B10	4.5	1.28335	0.30003	28.20
	9	2.56671	0.32087	26.37
	13.5	3.85007	0.36671	23.07
	18	5.13343	0.36098	23.44
B15A	4.5	1.28335	0.30173	28.19
	9	2.56671	0.33622	25.30
	13.5	3.85007	0.37357	22.77
	18	5.13343	0.32688	26.02
B15B	4.5	1.28335	0.36270	23.29
	9	2.56671	0.34137	24.74
	13.5	3.85007	0.35171	24.02
	18	5.13343	0.34137	24.74
B20	4.5	1.28335	0.31918	26.60
	9	2.56671	0.34265	24.78
	13.5	3.85007	0.35303	24.05
	18	5.13343	0.32361	26.25
B25A	4.5	1.28335	0.38404	22.23
	9	2.56671	0.34450	24.78
	13.5	3.85007	0.35494	24.05
	18	5.13343	0.32537	26.25
B25B	4.5	1.28335	0.37657	22.51
	9	2.56671	0.34888	24.29
	13.5	3.85007	0.35945	23.58
	18	5.13343	0.34888	24.29
B30	4.5	1.28335	0.34207	24.91
	9	2.56671	0.32782	25.99
	13.5	3.85007	0.35762	23.82
	18	5.13343	0.32782	25.99
DIESEL	4.5	1.28335	0.39148	21.54
	9	2.56671	0.37254	22.63
	13.5	3.85007	0.38496	21.90
	18	5.13343	0.41246	20.44

The experiments are conducted on a direct injection compression engine for various blends of biodiesel and the results are tabulated. Performance characteristics such as brake power, specific fuel consumption, and brake thermal efficiency is calculated. Various emissions such as hydrocarbons, carbon monoxides, carbon dioxides and nitrous oxides are noted.

6.1 Brake thermal efficiency (BTE)

It is defined as the ratio of brake power and the energy of the fuel combustion. Figure 4 shows the variation of brake thermal efficiency (η_{BTE}) with brake power for different biodiesel blends and petroleum diesel at a compression ratio of 17.5:1. It is observed that, the blends B20 and B25A indicated the maximum brake thermal efficiency at a full load condition. Also blends B10 and B15A produced maximum efficiency at minimum load as per the figure.

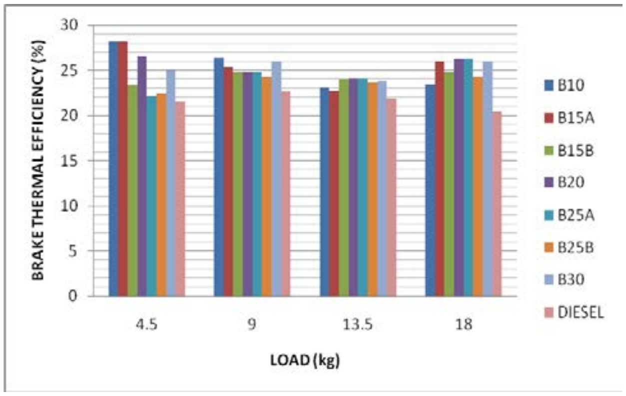

Fig. 4 : Load v/s Brake Thermal Efficiency

6.2 Brake Specific Fuel Consumption (BSFC)

BSFC is the measure of fuel efficiency of any heat engine that burns fuel and produces power. Figure 5 shows the comparison of brake specific fuel consumption with respect to brake power for different biodiesel blends and that of petroleum diesel. It can be inferred that blends B10 and B15A showed least fuel consumption at minimum load. However at full load condition, blends B15A, B20, B25A and B30 showed least fuel consumption.

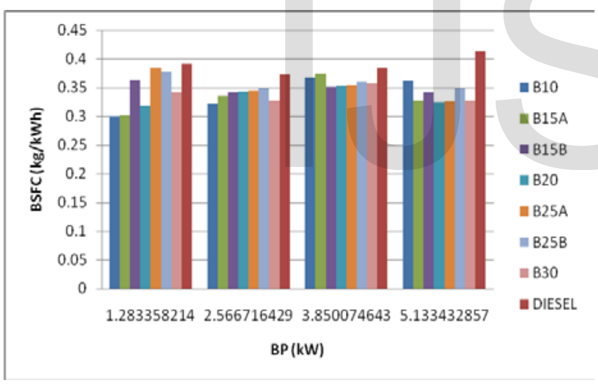

Fig. 5: Brake Power v/s Brake Specific Fuel Consumption

Table 6
Emission Characteristics

Sample	Load (kg)	CO (% by vol)	HC (ppm)	CO_2 (% by vol)	NOX (ppm)
B10	4.5	0.07	17	2.7	174
	9	0.05	24	6	588
	13.5	0.32	45	9.6	681
	18	1.12	38	8.4	540
B15A	4.5	0.07	21	2.6	148
	9	0.04	28	5.7	558
	13.5	0.24	45	8.5	592
	18	0.83	38	8.9	586
B15B	4.5	0.07	22	2.6	153
	9	0.04	27	5.7	573
	13.5	0.18	45	8.6	615
	18	0.79	34	8.9	591
B20	4.5	0.07	32	2.6	155
	9	0.05	32	5.9	563
	13.5	0.18	44	8.7	674
	18	0.89	42	8.9	574
B25A	4.5	0.06	30	2.5	152
	9	0.05	30	5.8	544
	13.5	0.16	43	9.1	672
	18	0.76	38	9.3	592
B25B	4.5	0.07	30	2.7	150
	9	0.05	30	5.7	508
	13.5	0.22	45	9.3	689
	18	0.85	46	9.9	644
B30	4.5	0.07	32	2.6	149
	9	0.05	30	5.8	574
	13.5	0.25	50	9.2	634
	18	0.84	38	8.5	544
DIESEL	4.5	0.07	38	2.8	130
	9	0.04	32	6.4	567
	13.5	0.51	51	8.9	590
	18	1.91	56	9.1	525

6.3 Carbon monoxide (CO) emissions

Figure 6 shows the variation of CO emissions against different loads for various biodiesel blends along with petroleum diesel. From the figure it is evident that, at lower loads all the blends along with diesel produced nearly same CO emissions. However with increase in load, the blend B25A produced least CO emissions.

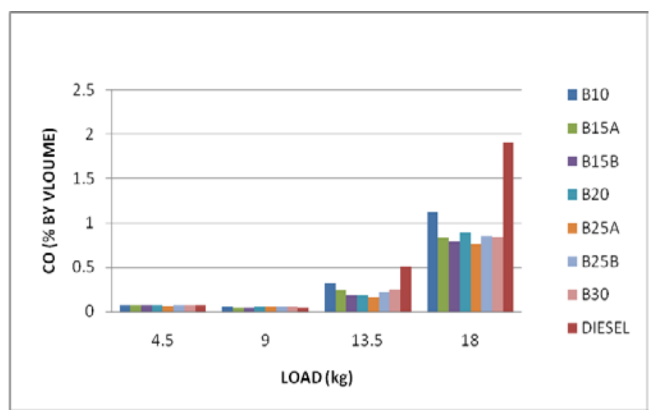

Fig. 6: Load v/s Carbon monoxide

6.4 Nitrous oxide (NOx) emissions

Figure 7 shows the variation of nitrous oxide (NOx) emissions against applied load for various blends along with petroleum diesel. It is observed that, biodiesel blends produced emissions higher than that of diesel.

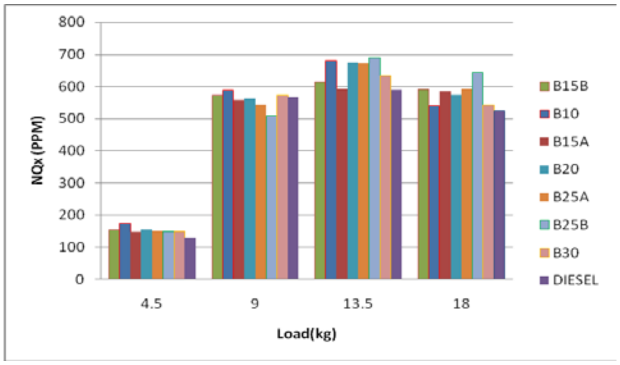

Fig. 7: Load v/s NOx

6.5 Hydrocarbon (HC) Emissions

Figure 8 shows the variation of Hydrocarbon (HC) emissions against different loads for various biodiesel blends and petroleum diesel. It is observed that B10 blend produced the least hydrocarbon emissions for most of the applied loads.

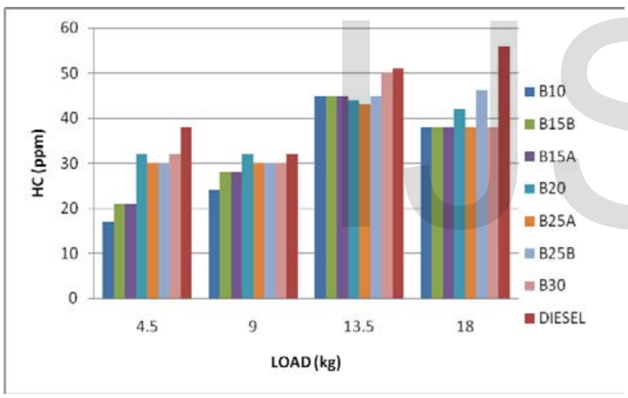

Fig. 8: Load v/s Hydrocarbon

6.6 Carbon dioxide (CO_2) emissions

Figure 9 shows the variation of carbon dioxide emissions against different loads for various biodiesel blends and petroleum diesel. It is observed that for lower loads B10 blend produced higher CO_2 emissions, whereas at higher loads B10 produced lesser CO_2 emissions.

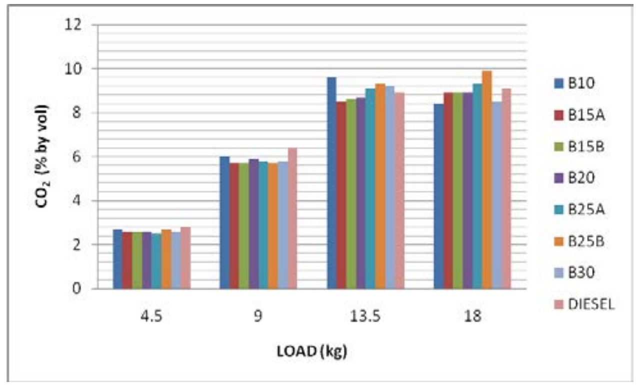

Fig. 9: Load v/as Carbon dioxide

7 Conclusion

At full load, B20 and B25A provided the maximum brake thermal efficiency of 26.25%.The blend B25A produced least carbon monoxide emission of 0.76% (by volume) at full load. Nitrous oxide emissions of all biodiesel blends are found to be greater than that of petroleum diesel. Blend B10 produced least hydrocarbon emissions for different loads. However at full load, along with B10; B15A, B15B, B25A and B30 produced low hydrocarbon emissions. B10 produced high CO_2 emissions for different loads. However at full load, observations show that the same blend produced the least carbon dioxide emissions.

Therefore it can be inferred that B25A provided better thermal efficiency and low specific fuel consumption along sufficient emission characteristics.

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