International Journal of Modern Trends in Engineering and Research
www.ijmter.com
e-ISSN No.:2349-9745, Date: 2-4 July, 2015

Diesel Engine Performance and Emission Characteristics with Chicken Fat Biodiesel Compared to other Biodiesels

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Abstract-The rapid diminishing of fossil fuel resources, limited in nature and concerns of environment were the reasons for exploring the biodiesel use as petroleum based fuel substitute. Even though biodiesel is gaining worldwide attraction as a proper substitute for petroleum diesel, the cost of biodiesel is highly undesirable aspect in usage. The main reason for high price is the cost of feedstock. Hence biodiesel produced from cheap feedstock waste chicken fat could be used for biodiesel production to fulfill energy demand and alternative to petroleum diesel.
The present work is focused on the fuel properties of biodiesel produced from waste chicken fat and performance & emission characteristics of 3.72 kW diesel engine when running with chicken fat biodiesel. Also its suitability is evaluated in comparison with other biodiesels like corn biodiesel, waste cooking oil biodiesel, sunflower biodiesel and petroleum diesel in terms of diesel engine performance & emission characteristics. Results show that it is possible to usethe chicken fat biodiesel in the existing diesel engine without any engine modification. The higher brake thermal efficiency and lower brake specific fuel consumption were observed with chicken fat biodiesel compared to other biodiesels. However slightly lower performance was obtained with chicken fat biodiesel compared to petroleum diesel. Slightly lower NO_X and higher HC & CO emissions were obtained with chicken fat biodiesel when compared to other biodiesels. Compared to petroleum diesel 20.08% higher NO_X and 43.18% & 21.05% lower HC & CO were observed with chicken fat biodiesel.
Keywords-Performance, Emission, Chicken fat biodiesel and Diesel engine

1. INTRODUCTION

Many researchers around the world have explored several alternative fuel resources like biodiesel produced from seed oils and non-edible oils. The requirement of land for grown up plants to produce seeds is one of the major problems and there is a threat for food scare when edible oil seeds are used for producing biodiesel. According to national biodiesel policy an indicative target of 20% by 2017 for the blending of biodiesel was proposed and as far as possible feedstock for biodiesel production must be taken up from non-edible oil seeds and bio waste.
Even though biodiesel is gaining worldwide acceptance as a good substitute for diesel, the cost of biodiesel is the main undesirable aspect associated with biodiesel usage. The main reason for high price is the raw materials used for the production. Feedstock is a major problem for biodiesel production in terms of availability and cost. The feedstock used for biodiesel production currently are mainly high quality food grade vegetable oils such soya bean oil (mainly USA), rapeseed oil (mainly EUROPE) and

palm oil etc. These feedstock costs are more than 85% of total cost of biodiesel production. Waste chicken fat is freely available feedstock for biodiesel production. Biodiesel which can be produced from waste chicken fat is an alternative fuel for diesel engine. Biodiesel production is safe passage for waste chicken fat disposal also.

In India the average chicken meat consumption for the year 2013 is 2.08 kg per person per year. While processing the chicken meat, a considerable quantity of waste in the form of yellow fat and skin is removed as it is not good for health. This chicken fat contains large quantity of saturated fat and less unsaturated fat. Consuming saturated fats raise levels of cholesterol in blood, which clogs arteries over time, increasing risk of having a heart attack or stroke. To dispose off waste chicken fat Biodiesel manufacture is the best route. Therefore it makes commercial, environmental and health sense to use this waste chicken fat biodiesel in existing diesel engines without any modification.

Jagadale S.S and Jugulkar L.M [1]studied single cylinder, 7.5HP power at 1500rpm constant speed, Kirloskar diesel engine characteristics using blends of chicken fat based biodiesel. They observed that thermal efficiency, specific fuel consumption, volumetric efficiency and mechanical efficiency of the engine with chicken fat biodiesel (CFBD) blend with diesel are nearly equal to pure diesel. They reported that chicken fat is one of the cheap raw materials for making biodiesel. K Srinivasa Rao et al.[2]investigated DI-CI engine characteristics with preheated chicken fat biodiesel. They obtained performance and emission characteristics very close to petroleum diesel with preheated chicken fat biodiesel blend. NO_X emissions are more for chicken fat biodiesel compared petroleum diesel.

ErtanAlptekin et al.[3]used one of the low cost feedstock such as chicken fat for biodiesel production. They studied the effect of catalyst type, reaction temperature and reaction time on the fuel properties such as density, viscosity, flash point, pour point, acid value and heat of combustion. KambizTahvildari A et al.[4]studied and determined properties of chicken fat biodiesel. They concluded that waste chicken fat is the one of suitable stock material for biodiesel production. SelvaIlavarasiPanneerselvam et al.[5]attempted to use chicken fat as low cost sustainable potential feed stock for biodiesel production. The study on the biodiesel production process, optimization of chicken fat showed that the quantity of catalyst, amount of methanol, reaction temperature and reaction time are the main factors affecting the production of chicken fat methyl ester. The optimal values of these parameters for achieving maximum conversion of oil to ester depend on the chemical and physical properties of these fats.

Dwivedi et al.[6]studied diesel engine performance and emission analysis using biodiesel from various oil resources. Their findings are significant reduction of HC and CO and increase NO_X with biodiesel when compared to diesel. The emission changes comparison between B100 and B20 fuels are summarized. The reduction of HC emissions are 67% and 20% for B100 and B20 fuels respectively. The CO emission reductions are 48% and 12% for B100 and B20 fuel respectively. But the increase of NO_X emission for B100 and B20 fuel are 10% and 2% respectively when compared diesel fuel. From their study it was concluded that the significant reduction in emissions were observed with B20 blend fuel. Murugesan et al.[7] aimed to study the prospects of introducing vegetable oils and their derivatives as fuel in diesel engine. Their results show that the use of biodiesel in a conventional diesel engine caused substantial reduction in unburned HC and CO.

Guru et al. (2010) [8] studied the impact of chicken fat biodiesel with magnesium as additive in a single-cylinder, direct injection (DI) diesel engine by analysing the performance and emission characteristics. Engine tests were run with a blend of 10 % chicken fat biodiesel and diesel fuel (B10) at full load conditions by varying the engine speed from 1800 to 3000 rpm. The results showed that, the engine torque was not significantly changed with the addition of 10 % chicken fat biodiesel, while the specific fuel consumption increased by 5.2 % due to lower heating value of biodiesel. Further, the in-cylinder peak pressure rose marginally and emissions like CO and smoke decreased by 13 % and 9 % respectively with increase in NOx emission by 5%. Evangelos G. Giakoumis[9] conducted a detailed statistical investigation in order to assess the average values of all physical and chemical properties of most biodiesels. Twenty six different biodiesels including four animal fat biodiesel properties ware investigated in his study. In his study, he mentioned that the B20 fuel blend is the most popular blend. He also mentioned in his study that the lower densities of fuel favoring lower NO_X emission. The study of Tomic et al.[10] is compared the exhaust emission of sunflower biodiesel with fossil fuel in a 4-cylinder, DI with 48kW rated power engine. The exhaust gas emission implied that the addition of biodiesel reduced the content of CO as well as EGT, but it increased the NO_X.

K Srinivasa Rao et al.[11]studied diesel engine performance and emission characteristics fueled with corn methyl ester. They observed decreased BTE, increased BSFC, decreased HC & CO and increased NO_X with corn methyl ester compared to diesel. SehmusAltun (2011)[12] studied performance and exhaust emissions of a DI diesel engine fueled with waste cooking oil and inedible animal tallow methyl ester. The experimental results showed compared with diesel fuel, biodiesel fuels resulted in reduction in brake torque, an increase in brake specific fuel consumption and reduction in carbon monoxide.

II. MATERIALS AND METHODS

The present work is carried out to study performance and emission characteristics of single cylinder 4-sroke direct injection diesel engine fueled with chicken fat biodiesel and compared them with other biodiesels like corn biodiesel (CBD), waste cooking oil biodiesel(WCBD),, sunflower biodiesel(SFBD) and petroleum diesel (PD). The performance characteristics include Brake Thermal Efficiency (BTE), Brake Specific Fuel Consumption (BSFC) and emission characteristics carbon monoxide (CO), unburnt hydro carbons (HC) and oxides of nitrogen (NO_X) were considered for the study.

2.1 Fuel Properties

The CFBD and other biodiesels produced by transesterification process were used to test the diesel engine for this investigation.The various properties of CFBD,PD,CBD, WCBD,SFBD and ASTM standard specification for biodiesel are given in the Table 1. The important properties of CFBD compared to others are discussed below.

Iodine Value:

The iodine number is a parameter used to determine the degree of unsaturation in biodiesels. This number indicates the mass of iodine in grams that is necessary to completely saturate, by means of a stoichiometric reaction, the molecules of 100g of given oil. There is specifications require that biodiesels used in compression ignition engines have a maximum value of Iodine value of the order of 120. The idea behind this specification is that high fuel iodine values indicate propensity for polymerization resulting in deposit formation. This means that some of the investigated FAMEs have to be excluded from use in pure form in engines. Diesel has very low iodine value, whereas biodiesels have higher. Hence the degree of unsaturation is more for biodiesels compared to diesel. The CFBD iodine value is also higher than PD but compared to other biodiesels it is much lower.

Table 1Properties of CFBD and other biodiesels compared with PD

Property	**Unit**	**PD**	**CFBD**	**CBD**	**WCBD**	**SFBD**	**ASTM Standards**(D6751)
Density	g/cc	0.831	0.862	0.882	0.88	0.885	0.87-0.89
Viscosity at 40^{o}C	cSt	2.58	4.93	5.32	5.75	5.10	1.9-6.0
Flash Point	^{o}C	50	160	165	162	169	130 minimum
Calorific value	kJ/kg	42500	40170	38600	37880	37800	37500
Cetane number	-	48	57	52	56.2	51.9	48-70
Iodine value	g Iodine/100 g	38	74	120	85.1	118.6	120 maximum
Acid value	mg KOH/g	-	0.32	0.19	0.41	0.32	0.5 maximum
Degree of unsaturation	-	-	0.8	1.45	1.09	1.57	-
chain length	-	-	17.42	17.79	17.69	17.92	
Oxidation stability	h	-	8.7	3.0	5.0	1.3	> 3 h
C	%	87	77.83	76.61	76.9	76.9	-
H	%	13	11.97	11.52	12.02	11.84	-
O	%	0	10.10	10.98	10.77	10.98	-

Cetane Number:

One of the most influential properties of the fuel is the dimensionless cetane number (CN), which represents the ignitability of the fuel, particularly critical during cold starting conditions. Low cetane numbers lead to long ignition delay, i.e. long time between fuel injection and start of combustion. Consequently, the lower the CN the more abrupt the premixed combustion phase, leading also to higher combustion noise radiation. On the other hand, higher cetane numbers promote faster auto-ignition of the fuel, and often lead to lower NOx emissions particularly during low-load. The cetane number of biodiesel is usually higher than that of the conventional diesel fuel. It has also been argued that the effect of blending biodiesel on the CN is approximately linear for mixtures of biodiesels with diesel fuel. For biodiesels Cetane number decreases as the number of double bonds increases. CN of CFBD is greater than all biodiesels promote faster auto ignition which reduces ignition delay during combustion.

Density:

The density of a material or liquid is defined as its mass per unit volume. Many researchers prefer the dimensionless term specific gravity, which is defined as the ratio of the density of a substance to the density of a reference substance (usually water). Biodiesel fuels are, in general, characterized by higher density than conventional petroleum diesel, which means that volumetrically-operating fuel pumps will inject greater mass of biodiesel than conventional diesel fuel. This in turn will affect the air−fuel ratio hence the local gas temperatures and NOx emissions. Actually, it has been argued that there exists a correlation between density and NOx emissions, with lower densities favoring lower NOx. Density increases with the increase in the number of double bonds, which means that the more unsaturated the originating oil. The higher the density of the derived methyl ester, and the greater the fuel mass that will be injected if a diesel-tuned engine is run on biodiesel. From the table 3.1 it is observed that among all biodiesels CFBD density is lower but is still higher compared to PD. This may become the reason for lower BSFC of CFBD compared to all biodiesels.

Heating Value/Calorific Value:

The heating values are measures of fuels heat of combustion. Biodiesel contains on average 10−12% w/w oxygen, which leads to proportionally lower energy density and heating value, thus more fuel needs to be injected in order to achieve the same engine power output. The higher the oxygen content, hence the lower the heating value. The calorific value of CFBD is higher because it contains higher carbon and lower oxygen compare to other biodiesels.

Kinematic Viscosity:

Viscosity is a measure of the resistance of a fluid which is being deformed by either shear or tensile stress. For the case of liquid fuels, the less viscous the fluid is, the greater its ease of movement (fluidity). In a diesel engine, higher viscosity leads to less accurate operation of the fuel injectors, and to poorer atomization of the fuel spray; these inefficiencies are exaggerated during cold starting. Moreover, the reduced fuel leakage losses in the (mechanical) fuel pump owing to higher kinematic viscosity lead also to higher injection pressures and, hence, mass of injected fuel.

Oxidation Stability:

One of the major issues that limit the use of biodiesel as a fuel in compression ignition engines is its poor oxidation stability. It is observed that only a few of the investigated biodiesels fulfill the ASTM specification of 3h oxidation stability. The oxidation stability of CFBD is 8.7h which is far higher compared to other. This is mainly due to presence of less number of double bonds.

The fatty acids composition of CFBD and other biodiesels are given Table 2. From the fatty acid composition of biodiesels it is observed that poly unsaturated fatty acids of SFBD > CBD > WCBD > CFBD. Hence possibility of NO_X emission may also be arranged accordingly.

Table 2 Fatty acid composition of CFBD and other biodiesels

Fatty acid	Wt (%)			
	CFBD	**CBD**	**WCBD**	**SFBD**
Myristic (14:0)	0.73	-	0.67	0.04
Palmitic (16:0)	24.06	11.81	15.69	6.26
Palmitoleic (16:1)	5.65	0.12	0.73	0.06
Stearic (18:0)	6.42	2.13	6.14	3.93
Oleic (18:1)	42.43	27.35	42.84	20.77
Linoleic (18:2)	18.83	57.74	29.36	67.75
Linolenic (18:3)	1.06	0.63	2.03	0.15
Eicosenoic (20:1)	0.41	0.33	0.56	0.13

2.2 Test Engine Setup

Single cylinder, 3.72 kW rated power, constant speed (1500 rpm), direct injection, water cooled, naturally aspirated, stationary CI engine coupled with eddy current dynamometer is used for the experimental study. The detailed technical specifications of the engine are given in the Table 3. The experimental setup used for the study is shown in Fig. 1.The set up consist of

1. Single cylinder diesel engine.
2. Eddy current dynamometer to measure load torque or power.
3. Data acquisition system to read all required data.
4. Display panel to display all necessary temperatures, air flow and fuel consumption, etc.
5. Computer to record all necessary data.

Table 3 Engine specifications

Manufacture and type	Kirloskar Oil Engine and AV1
Engine	Single Cylinder Direct Injection Compression Ignition
Admission of air	Naturally aspirated
Bore / Stroke&Compression ratio	80 mm / 110 mm&16.5:1
Max power / Rated speed	3.72 kW / 1500 rpm
Dynamometer	Eddy Current Dynamometer
Method of cooling&Type of starting	Water cooled&Type of starting

2.3 Exhaust Gas Analyzer

INDUS make model205exhaust gas analyzer is used to investigate emission characteristics. Carbon mono oxide (CO), Hydro carbon (HC) and oxides of nitrogen (NO_X) emissions can be measured using exhaust gas analyzer. The analyzer uses the principle of Non-Dispersive Infra-Red (NDIR) for measurements. Fig. 2 shows the exhaust gas analyzer used for this investigation. The technical specifications of exhaust gas analyzer are given in Table 4.

Fig. 1 Experimental setup

Fig. 2 Exhaust Gas Analyzer

Table 4 Exhaust gas analyzer specifications

Exhaust Gas Analyzer make and model:INDUS make and PEA 205		
Type of Emission	Range	Resolution
NO_X (ppm)	0-5000	1

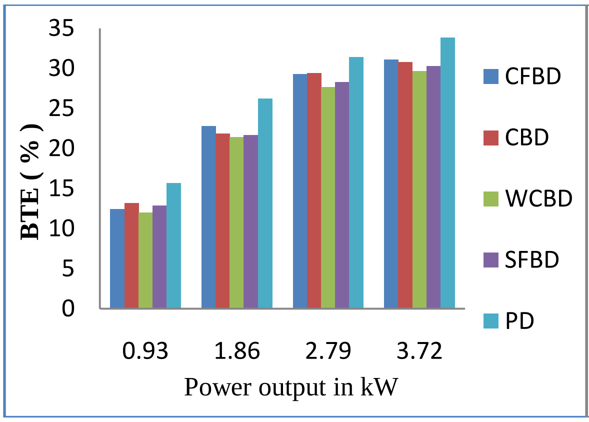
HC (ppm)	0-15000	1
CO (%)	0-15.0	0.01

RESULTS AND DISCUSSIONS

The comparisons among biodiesels CBD, WCBD,SFBD and PD compared to CFBD in terms of engine performance and emission characteristics are explained as follows.

3.1 Brake Thermal Efficiency (BTE)

Figure 3 shows the variation BTE with engine power outputfor all fuels. It is observed that BTE for all fuels increases with power output. BTE of CFBD is greater than all other biodiesels all power outputs. But compared to PD lower BTE was observed with CFBD. Figure 4 indicates % variation of BTE at 3.72 kW engine power output for all fuels compared to CFBD. At full load CBD, WCBD and SFBD records 1.02%, 4.75% and 2.63% lower BTE compared CFBD. This is due to slightly higher calorific value of CFBD compared to other biodiesels. Compared to PD 8.77% lower BTE was measured with CFBD. The difference in calorific values of fuels may be the reason for this.



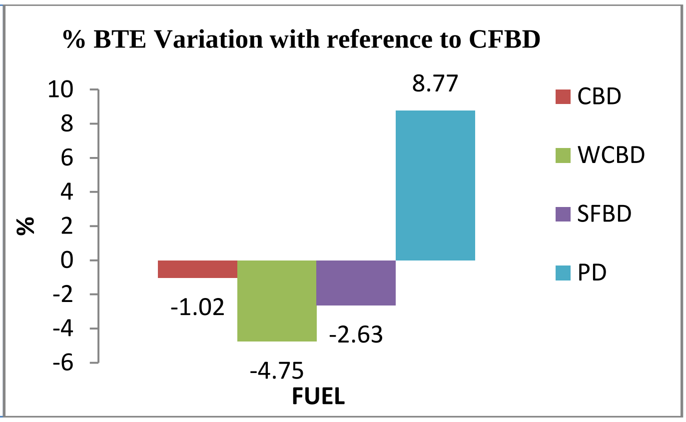
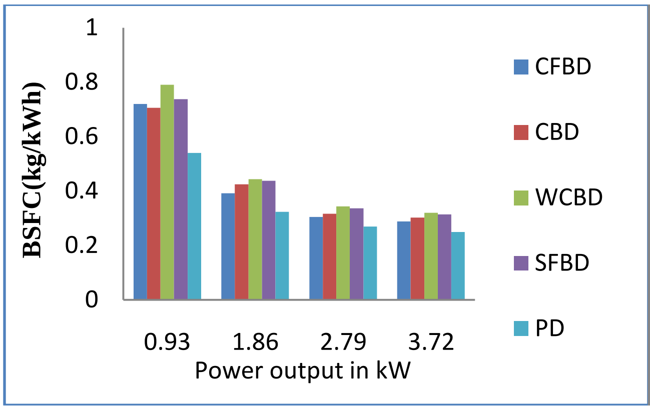


Fig. 3 Variation ofBTE at different power outputFig 4 % of BTE variation compared with CFBD at 3.72 kW load

3.2 Brake Specific Fuel Consumption (BSFC)

For all fuels BSFC decreases with engine load as shown in figure 5. The BSFC of fuels CFBD, CBD, WCBD, SFBD and PD are measured as 0.2879, 0.302, 0.32, 0.314 and 0.25 kg/kWhr at full engine load. The BSFC of CFBD is lower than CBD, WCBD, SFBD fuels and compared to diesel BSFC of CFBD is slightly higher. The % variation of BSFC of all fuels compared to CFBD is shown in figure 6. At maximum power output CBD, WCBD and SFBD measures 4.89, 11.14 and 9.06% higher BSFC compared to CFBD. But with PD 13.16% lower BSFC is observed compared to CFBD. It was mainly due to difference in energy (Calorific value) of respective fuels.



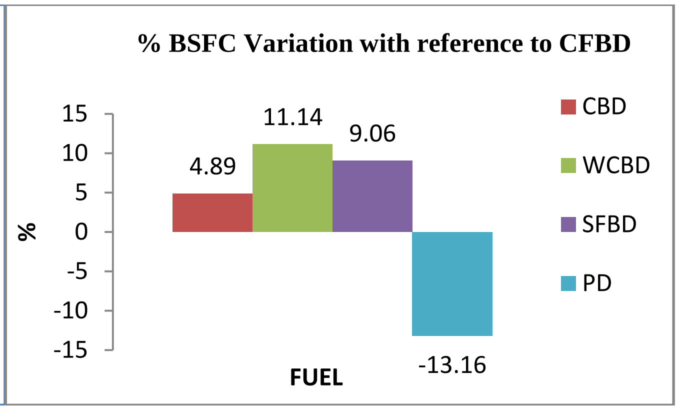
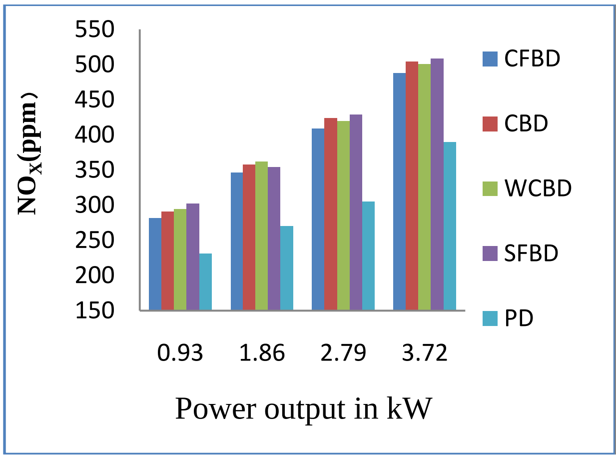


Fig. 5 Variation ofBSFC at different power outputFig. 6 % of BSFC variation compared with CFBD at 3.72 kW load

3.3 Oxides of Nitrogen (NO_X)

NO_X emission increases for all fuels with engine load as shown in figure 7. It is observed that NO_X emissions of all biodiesels are higher than CFBD at all power outputs. But NO_X emission of PD is very much lower than all fuels. At full load the % variation of NO_X emission of CBD, WCBD, SFBD and PD compared to CFBD are observed as +3.27, +2.66, +4.09 and -20.08 as shown in figure 8. The lower oxygen content is the reason for lower NO_X emission of CFBD compared to other. For PD the NO_X emission is very low due to no oxygen content.



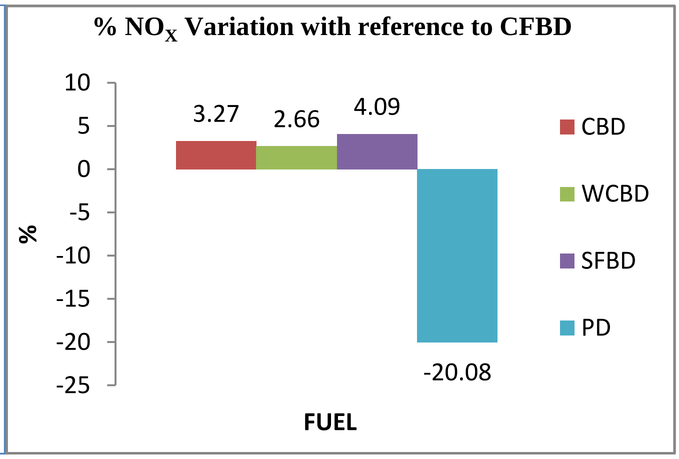
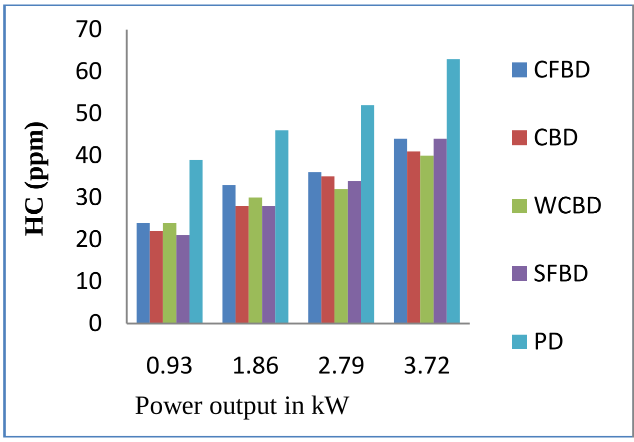


Fig. 7 Variation ofNO_X at different power outputFig. 8 % of NO_X variation compared with CFBD at 3.72 kW load

3.4 Hydrocarbon Emission (HC)

The variation of HC emission all fuels with engine power output is given in figure 9. Increasing power output increases the HC emissions for all fuels. HC emissions point of view all biodiesels other than CFBD observed better results. The % variation of all fuels compared to CFBD at maximum power output 3.72 kW is shown in figure 10. At full load compared to CFBD 6.81%, 9.09% and 2.27% lower HC emissions are observed for CBD, WCBD and SFBD respectively. But PD records 43.18% more HC emissions compared to CFBD. The oxygen content of biodiesels leads to complete and effective combustion resulted lower HC emissions compared to PD.



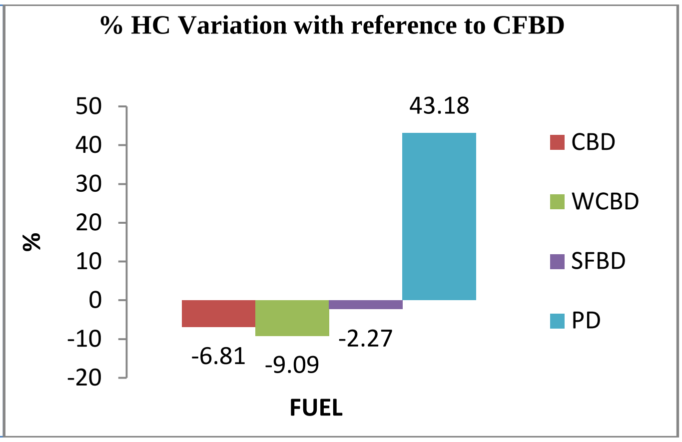
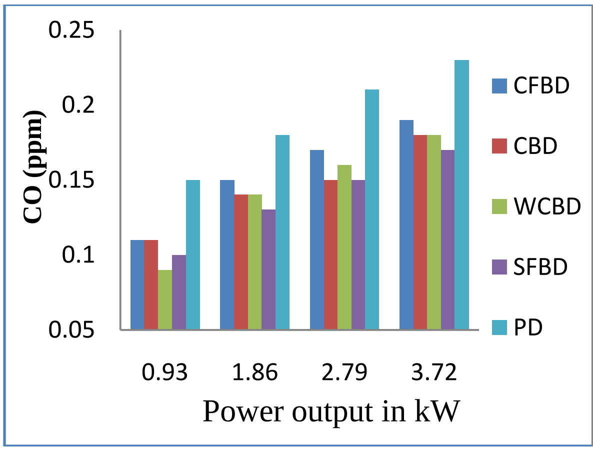


Fig. 9 Variation ofHC at different power outputFig. 10 % of HC variation compared with CFBD at 3.72 kW load

3.5 CO Emissions

The variation of CO emission for all fuels with respect to engine power output is given in figure 11. It is observed that CO emission for all fuels increases with power output. Lower CO emissions are observed for all biodiesels compared to PD. The % variation of CO emissions with reference to CFBD at maximum power output is shown in figure 12. The CBD, WCBD and SFBD produced 5.26%, 5.26% and 10.52% of lower CO emissions compared to CFBD. But PD observed 21.05% higher CO emissions compared to CFBD. The reason for lower CO emissions of all biodiesels is presence of oxygen in fuel.



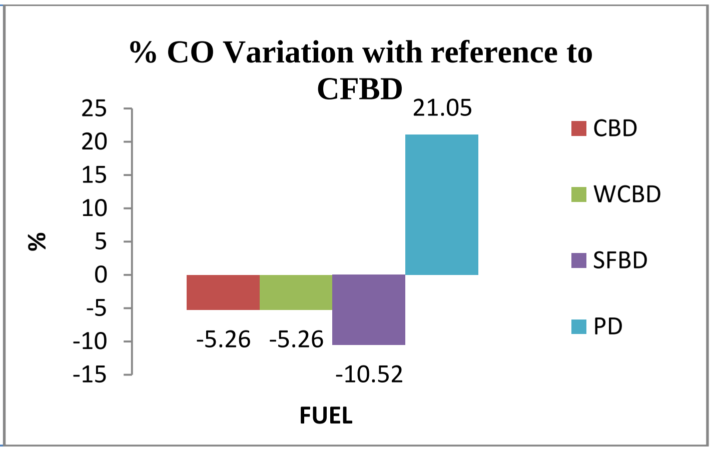


Fig. 11 Variation ofCO at different power outputFig. 12 % of CO variation compared with CFBD at 3.72 kW load

CONCLUSIONS

Based on the experimental investigation on diesel engine performance and emission characteristics, the following conclusion were drawn

- BTE for all fuels increased with engine power output. The CFBD observed very close BTE to PD. Compared other biodiesels the CFBD measured higher BTE. This may be due to higher calorific value of CFBD compared to other biodiesels.
- BSFC of all biodiesels & PD decreased with increase of power output. For all loads the BSFC of CFBD is lower than other biodiesels. Compared to PD, CFBD shown slightly higher BSFC. At

full load CBD, WCBD& SFBD measured 4.99, 11.14& 9.06% higher BSFC compared to CFBD. However 13.16% lower BSFC was observed for PD compared to CFBD at full load.

- Increased NO_X was observed for all fuels with engine load. Higher temperatures of combustion may be the reason for higher NO_X at full load. Compared to CFBD, the CBD, WCBD, SFBD& PD NO_X emissions were measured as +3.27, +2.66, +4.09& -20.08% at 3.72kW power output. More oxygen content of biodiesels compared to PD may be the reason for higher NO_X
- Lower HC & CO emissions were observed for all biodiesels compared to PD for all engine loads. CFBD obtained slightly higher HC & CO emissions compared to other biodiesels;however these emissions are very less compared to PD. Oxygen present in the biodiesels leads to complete combustion results in lower HC & CO emissions.
- Hence it was concluded that the CFBD favored lower emissions without loss of much in performance compared to PD. The other biodiesels CBD, WCBD, SFBD emissions are very low, but less in performance than CFBD.

ACKNOWLEDGEMENTS

The Authors thank the management and principal of **Sai Spurthi Institute of Technology, Sathupally, India, 507303,** for providing necessary experimental facilities and support.

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