J Ther Eng, Vol. 9, No. 4, pp. 1070−1077, July, 2023

Journal of Thermal Engineering
Web page info: https://jten.yildiz.edu.tr
DOI: 10.18186/thermal.1334240

Research Article

Comparative analysis of carbon particle emissions from exhaust of an IC engine using HSD and blends of HSD and Honge/Jatropha biodiesel

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ARTICLE INFO

Article history
Received: 15 November 2021
Accepted: 09 November 2022

Keywords:
Biodiesel; Carbon Particulate Emission; IC Engine Exhaust; Honge; Jatropha

ABSTRACT

In spite of the surge in solar and wind energy in the recent years, the IC engines, particularly the diesel engines may be expected to stay on for the next 30 years at least. In this context, it is imperative to find alternative fuel sources for petro diesel, at least in part. Inedible oil based biodiesels are one good option for India. There is a slight decrease in performance of a diesel engine when run with biodiesel blends. It is also feared by some that pollution from exhaust gas by using biodiesel blends may be higher.

This paper summarizes the results of experiments carried out on biodiesel blends with diesel to determine the amounts and particle sizes of carbon particulate matter emissions in engine exhaust. Blends of two esterified oils, viz., Honge (Pongamia Pinnata) and Jatropha, with petro diesel were used to operate a single-cylinder, four-stroke diesel engine. Blend ratios used were 5%, 10%, 15%, and 20%. The carbon particles in exhaust were collected on an INDICA filter paper for 5 minutes. The carbon content was ascertained by the standard procedure, and the size of particles was found by microscopic examination. Further ANOVA of the data was carried out separately for the Honge and Jatropha blends.

The results from the experiments are clear and interesting. Both Honge and Jatropha blends increase the amount of carbon particulates in engine exhaust when compared with diesel. Carbon particulates increase with increase in load on the engine. Increase of blend ratio generally increases the carbon in exhaust in case of Jatropha blends. The behaviour with Honge blends is different. While blend H5 has highest carbon in exhaust at low loads, at high loads, H10 has the maximum carbon in exhaust.

Blending with Honge or Jatropha biodiesel increases the carbon particle size in exhaust. While the size of carbon particles with diesel is < 20 μm, it is > 20 μm with all blends, increasing with load or blend ratio. In all cases, lower loads result in finer carbon particles in exhaust.

The study helps in concluding that both Honge and Jatropha blends could be used in diesel engines, Honge being superior. Though the PM level in the exhaust will be higher with blending, the particle sizes will be much larger and hence causing less health hazard. Further, idling (no load), or low loads should be avoided since these result in smaller carbon particles.

Cite this article as: Gowda B PB, Chandrashekar R, Kumar S M, Vn A. Comparative analysis of carbon particle emissions from exhaust of an IC engine using HSD and blends of HSD and Honge/Jatropha biodiesel. J Ther Eng 2023;9(4):1070−1077.

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This paper was recommended for publication

Published by Yıldız Technical University Press, İstanbul, Turkey

INTRODUCTION

While there may be differences of opinion regarding continued use of IC engines in transport and other sectors, it is certain that the IC engines, particularly the Diesel engines will continue to be in operation for at least the next 30 years. Hence there is scope for replacing the diesel fuel completely or partially by other fuels like alcohol and biodiesels. Some countries have made it mandatory to use blended fuels [1]. In the Indian context, reducing use of diesel and thereby reducing import of petroleum crude is of utmost importance. This is because petroleum crude accounts for 25% of Indian imports [2].

Various attempts have been made for using blended fuels for diesel engines [3-5]. Researchers have also contributed by studies blending Honge (Pongamia Pinnata), Jatropha, Cottonseed, Simarouba, and other oils with diesel [5-9]. In the Indian context, use of non-edible vegetable oils like Pongamia Pinnata (Honge oil) and Jatropha oil as HSD substitutes have caught the attention and many agencies, which have gone ahead with implementation even when systematic research in this direction is scanty. However, most of the studies have focused on engine performance, and the few which have investigated pollution aspects have concentrated mainly on CO2, HC, NOX and PM emissions from exhaust of IC engines using blended fuels [10,11]. Information on the size of PM, particularly carbon particles, and the relation of particulate quantity and particulate size to factors like blend ratio and engine load is lacking. This paper describes a study carried out on a four-stroke, single cylinder IC engine using diesel and blends of Honge and Jatropha biodiesels with diesel.

While non-edible vegetable oils and their blends with HSD show promise of use in IC engines, they have the disadvantage of higher flash and ire points as well as lower calorific value in comparison with HSD (Table 1). Hence 100% vegetable oils are not usually considered and only blends with HSD as the major component are considered. In case blends with higher percentage of vegetable oils are employed, some modifications in the IC engines may become necessary for maintaining minimum performance levels.

EXPERIMENTATION

This section describes the details of materials used, methodology adopted and procedures of experimentation. A single-cylinder, 4-stroke, 5 hp Kirloskar Engine with belt Brake Dynamometer was used for the experiments. The fuels used were base high speed diesel (HSD) and blends of HSD with esterified Honge or Jatropha oil, as shown in Table 2.

Table 1. Comparison of Properties of HSD, Honge Oil and Jatropha Oil

Property	HSD		Honge		Jatropha	
Density, kg/m^3	866.2 – 86.2		52.6 – 1020.8		34.2- 1000.2	
Kinematic Viscosity, cst	30 ^{0}C	45 ^{0}C	30 ^{0}C	45 ^{0}C	30 ^{0}C	45 ^{0}C
	5.55	3.95	8.55	4.18	5.014	2.722
Flash Point, oC	46		230		240	
Fire Point,	55		247		259	
Calorific Value, Kcal/kg	42700		29900		32800	

Table 2. Description of different fuels/oils and blends

Fuel/Oil/Blend	% of Diesel	% of Oil	Symbol
HSD (High Speed Diesel)	100	-	HSD
Pongamia Oil (Honge Oil)	-	100	H
Jatropha Oil	-	100	J
Pongamia-Diesel Blend- 5%	95	05	H5
Pongamia-Diesel Blend- 10%	90	10	H10
Pongamia-Diesel Blend- 15%	85	15	H15
Pongamia-Diesel Blend-20%	80	20	H20
Jatropha -Diesel Blend- 5%	95	05	J5
Jatropha -Diesel Blend- 10%	90	10	J10
Jatropha -Diesel Blend-15%	85	15	J15
Jatropha -Diesel Blend- 20%	80	20	J20

The following experimental procedure was followed:

1. The engine was started by manual cranking.
2. The engine was first run on a no-load condition and allowed to stabilize.
3. The required engine speed was attained by adjusting the throttle valve.
4. The engine was loaded using belt-brake dynamometer and a constant speed was maintained by adjusting the throttle.
5. The time taken for 10cc of fuel consumption was noted.
6. The above procedure was repeated for different fuels (Table 2) at different loads varying from 0 to 80% of maximum.
7. All experiments were repeated thrice and the results are tabulated

While the smoke density was determined by use of a gas analyzer (Bangalore Metro Gas Analyzer) based on constant volume sampling technique (BOSH) and was expressed in ppm and percent [12], the analysis of carbon particle content an size in the exhaust emissions was carried out by a procedure reported by Kundu et al., 1994 [13], collecting carbon samples on INDICA filter paper (Grade: HM 2, Size: 12.5 CM)[14][15].

All the experiments were laid out in completely randomized design with three replications. The results were subjected to ANOVA and conclusions were based on the statistical analysis. Predictive equations for Weight of Carbon in the exhaust gas (C) in terms of type of fuel used (F) and Load on the engine (L) were developed by using MATLAB software.

RESULTS AND ANALYSIS

Photographs of Carbon Samples

A representative photograph of exhaust gas is shown in Figure 1. Similar carbon samples were collected for different fuels at different loads on normal engine set up. From Figure. 1, it can be clearly seen that the Sample 0 (no load) appears to be brighter indicating minimum amount of large size particles.

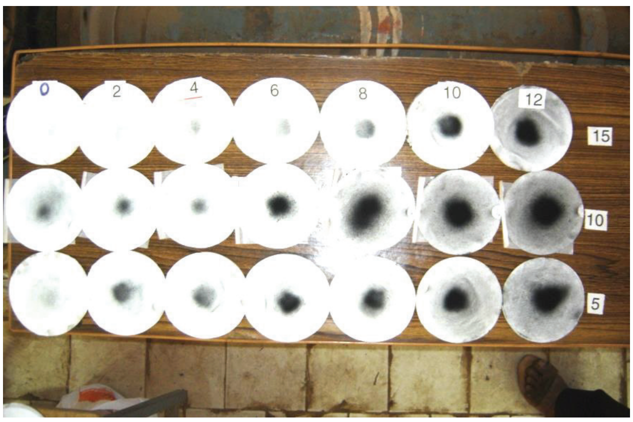

Figure 1. Carbon samples for H5, H10, and H15 for different loads.

From such photographs (and others not shown here), it can be surmised that the carbon emission generally increases with increasing loads for all the blends.

The gradation of particulate collection from minimum to maximum under low and high loading conditions for various blends is depicted below:

Low Loads: H15 → H20 → H10 → H5

High Loads: H15 → H20 → H5 → H10

In case of Jatropha blends, the carbon emission generally increases at increasing loads.

Low Loads: J5 → J10 → J15 → J20

High Loads : J5 → J10 → J15 → J20

The smoke analysis for smoke density at 80% load (assumed operating load) with different fuels and their blends is shown in Figure 2. Highest smoke density was observed in case of pure Jatropha oil followed by pure Honge oil. Minimum smoke density was observed in case of H5 and then in H10.

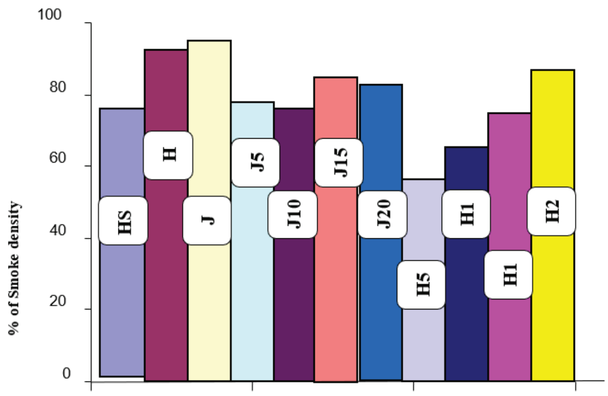

Figure 2. Smoke Analysis with different Blends.

In general, smoke density increaseS in the following order:

H5 → H10 → H15 → HSD → J10 →
J5 → J20 → J15 → H20 → H J

Micrographs of Exhaust Gas Carbon Particles (EGC) for HSD and Blends. Four representative micrographs of exhaust gas carbon particles (EGC) for HSD and blends under various loads are shown in Figures 3 to 7.

Observing all the micrographs shown in Figures 3-7 (and others not shown here), it can be inferred that

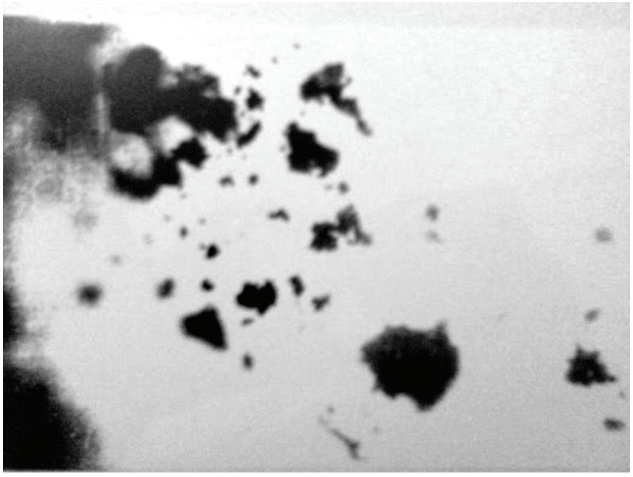

Figure 3. EGC for HSD at 6 kg load.

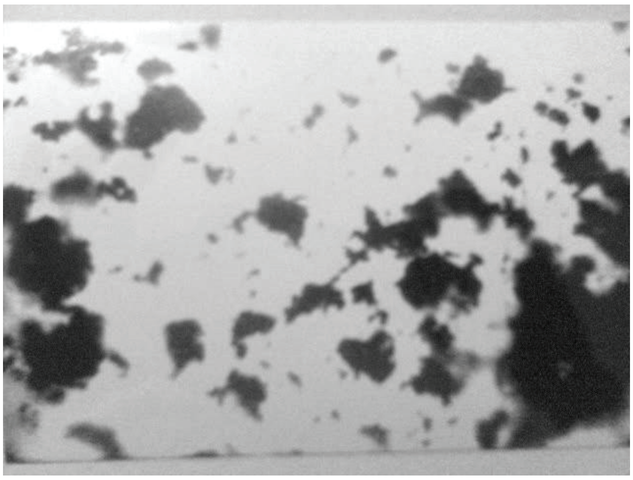

Figure 4. EGC for H10 at 8 kg Load.

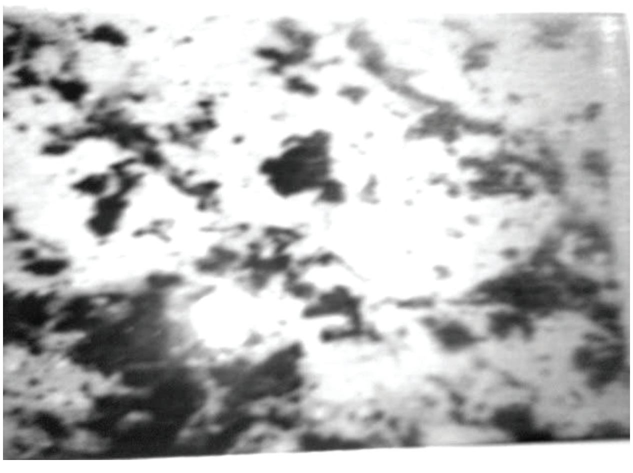

Figure 5. EGC for H20 at 10 kg Load.

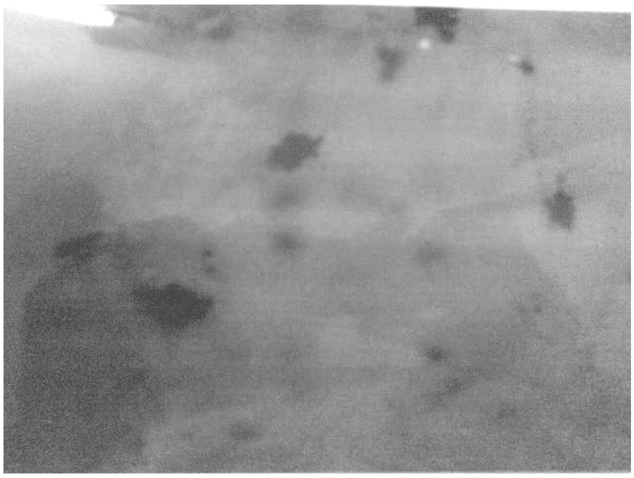

Figure 6. EGC for J10 at 4 kg load.

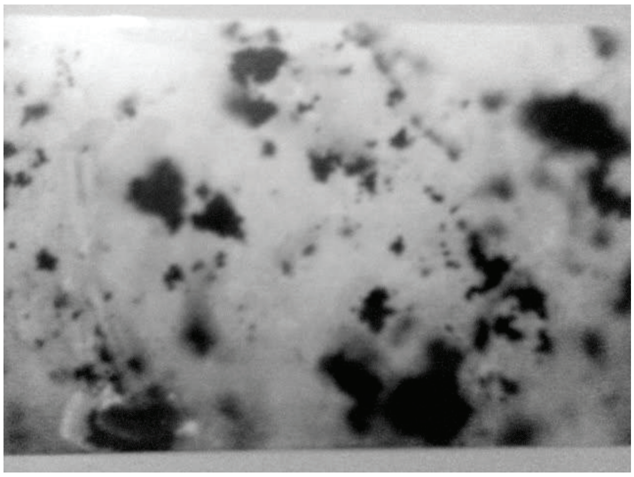

Figure 7. EGC for J20 at 10 kg Load.

combustion improves with increasing loads for all blends as represented by lower dark patches of carbon deposits.

Particulate Matter Size

The results of particulate size (PM) by microscopic measurements in emissions of Honge oil and its blends at different engine loading are presented in Table 3.

The emissions of engine with HSD yielded smallest size of PM varying from 10 microns at zero loading to 20 microns at maximum loading of 12 kg. The size of PM increased with increase of load on the engine. These values of PM with HSD were the lowest at any given load when compared to oil blends. Largest size of PM were obtained when the engine was run on Honge (Pongamia) oil (H) varying from 37 microns at zero load to the largest value of 55 microns at maximum loading. Increase of load of the

Table 3. PM, Partial Size in microns in emissions with different fuels – HSD, Honge and its blends in HSD

Load, kg	HSD	5% (H5)	10% (H10)	15% (H15)	20% (H20)	100% H
0	10	22	30	31	32	37
2	15	25	28	34	35	40
4	18	27	30	35	37	43
6	17	30	33	39	40	48
8	18	33	37	40	37	51
10	18	35	39	40	40	52
12	20	37	39	41	43	55

engine yielded consistent increase in size of PM in all the trials.

In case of oil-HSD blends it was observed that the percent of oil in the blend had a profound effect on size of PM in the emissions. Higher the oil content larger was the size of PM in all the blends H5 to H20. This inferred that size of PM in the emissions is dependent on the type of fuel and also on the level of loading the engine. This hypothesis was tested statistically as detailed below.

Dependent variable, size of particulate matter, PM, was analyzed with respect to independent variables load at 7 levels and fuel at 6 levels (3 replicates) in Factorial Design Experiments. The result of the analysis is presented in the following ANOVA (Table 4).

The results of the analysis confirmed the dependence of PM on both LOAD and FUEL with high level of significance, fuel blend being the higher contributing factor.

Similarly, the results of the trials with Jatropha oil and its blends in HSD are presented in Table 5. These were the mean values of three replicates. HSD emissions yielded smallest PM where as Jatropha oil yielded largest size PM. Size of PM increased with increase of Jatropha oil content in the blends. Loading of the engine was also found to affect the size of PM, higher the load larger is the size.

The data of all these experiments were subjected to statistical analysis on randomized experimental design. The results confirmed the strong influence of both type of fuel (blend) and load on particulate matter size (ANOVA, Table 6).

Table 4. ANOVA for Honge Blends (Tests Between-Subjects: LOAD, FUEL, Dependent Variable: PM)

Source	Type III Sum of Squares	df	Mean Square	F
Corrected Model	12685.5(a)			
Intercept	141738.7			
LOAD	2165.6	6	360.94	27.73**
FUEL	10519.9	5	2103.97	161.65**
Error	1483.8	114	13.02	
Total	155908.0	126		
Corrected Total	14169.3	125		
	$R^2 = 0.895$			

** Significant at 0.001

Table 5. Particulate Matter Size in microns in Emissions with Different Fuels – HSD, Jatropha (J) and its blends in HSD

Load (kg)	HSD	5% (J5)	10% (J10)	15% (J15)	20% (J20)	100% (J)
0	10	20	26	30	28	33
2	15	22	25	36	30	38
4	18	27	28	32	32	39
6	17	25	28	33	32	37
8	18	31	30	38	31	48
10	18	33	37	44	41	50
12	20	35	37	42	40	51

Table 6. ANOVA for Jatropha Blends (Tests Between-Subjects: LOAD, FUEL, Dependent Variable: PM)

Source	Type III Sum of Squares	df	Mean Square	F
Corrected Model	11064.357(a)	41	269.862	8.659
Intercept	121644.643	1	121644.643	3903.037
FUEL	7986.929	5	1597.386	51.253**
LOAD	2374.190	6	395.698	12.696**
FUEL * LOAD	703.238	30	23.441	.752
Error	2618.000	84	31.167	
Total	135327.000	126		
Corrected Total	13682.357	125		

** Significant at 0.001

Here again it is seen that while both load and fuel blend are significantly contributing factors in determining the particle size, the fuel blend has the higher contribution.

These results of PM with Jatropha oil are graphically presented in the Figure 8.

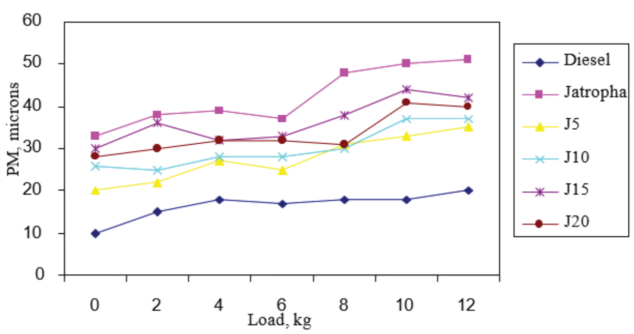

Figure 8. Particle size of carbon in exhaust for different blends.

A linear relationship was found between LOAD and PM for different blends and the results of the analysis are presented in the following Table 7.

Table 7. Results of linear relationships of PM Vs. LOAD in various fuels

Fuel	Slope	Intercept	γ^2
HSD	0.64	12.71	0.73
J5	1.27	19.96	0.94
J10	1.05	23.82	0.85
J15	1.04	30.21	0.73
J20	1.02	27.38	0.76
J100	1.55	32.96	0.87
Jatropha			

The size of exhaust particles in emissions of Diesel engines could be increased by blending Honge (Pongamia) oil or Jatropha oil with HSD. Blending of oil with HSD was found to be more beneficial from environmental pollution point of view as larger PM is less dangerous than the smaller ones. Running of diesel engines at no load and low loading conditions should be avoided as it would result in particles of smaller size which is not desired.

Carbon percent in exhaust emission

The % carbon in the exhaust emission determined for various fuels at different loads are summarized and presented below.

Carbon percent in exhaust emission for Honge Blends

Figure 9 shows the variation of % Wt. of C at different load conditions for HSD and blends of Honge oil. The experimental data was subjected to statistical analysis and the results are presented in ANOVA ((Table 4). The analysis indicated strong influence of both independent variables LOAD and FUEL on dependent variable % Wt. of Carbon in the exhaust. However there was no interaction effect of LOAD and FUEL on C.

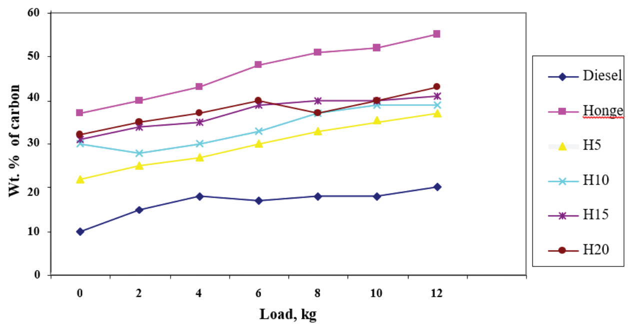

Figure 9. Dependence of weight of carbon in exhaust at different Honge blends.

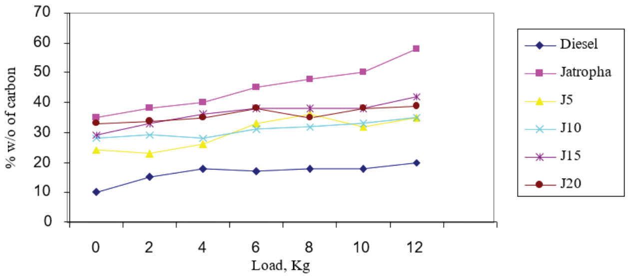

Figure 10. Dependence of weight of carbon in exhaust at different Jatropha blends.

Carbon percent in exhaust emission for Jatropha Blends

The size distribution of carbon particles analyzed in the emission against different engine loads for Jatropha and its blends are shown in Figure 10. In all the cases, no load condition yielded smaller size carbon particles. Lowest carbon particle size was observed in case of HSD and the maximum size was noted in case of pure Jatropha oil when the loading was highest.

The experimental data was subjected to statistical analysis and the results are presented in ANOVA (Table 5). The analysis indicated strong influence of both independent variables LOAD and FUEL on dependent variable % Wt. of Carbon in the exhaust. However, there was no interaction effect of LOAD and FUEL on % Wt of C.

CONCLUSIONS

1) The need for conserving petroleum products, developing new energy sources and alternate fuels and reducing atmospheric pollution has become the focus of research. Among alternate fuels, use of vegetable oils, diesel-vegetable oil blends and Bio-diesel have been the subject matter of recent research. In the Indian context, use of non-edible vegetable oils like Pongamia Pinnata (Honge oil) and Jatropha oil as HSD substitutes have caught the attention and many agencies have gone ahead with implementation even when systematic research in this direction is scanty.
2) Blending of HSD-Honge and HSD-Jatropha up to 20% blending can be used in single cylinder, 4-stroke diesel engine without engine modifications.
3) Smoke content in exhaust gas doesn't show a consistent relation to the blend percentage. Higher percentage blends or Honge appear to have lesser carbon percentage at both high loads and low loads.
4) Blending HSD with Honge or Jatropha increases the size of smoke particles in exhaust gas, then being beneficial from an environmental angle.
5) The present study has identified Honge and Jatropha blends up to 20% as the blends which show maximum promise for use as fuels in diesel engines, without pre-treatment of fuel or any engine modification (for using these blends), but with exhaust carbon particle quantity and size either superior to or at least equal to HSD.
6) Honge oil blends have been found to be superior to Jatropha oil blends in respect of carbon particle emissions in the engine exhaust.

AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

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