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Emission evaluation on 3-hole and 4-hole nozzle diesel engine with Jatropha and Pongamia (Karanja) mixed bio oil

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Abstract

The present study aims in developing an alternative energy solution for compression ignition engine with mixed bio oils from Jatropha and Pongamia (Karanja) vegetable. The high viscosity of the oil was reduced by preheating and transesterification process. The properties of the oil namely viscosity, density, calorific value and flash point were evaluated. The exhaust emissions of a single cylinder diesel engine were examined using 3 hole (3H) and 4 hole (4H) nozzle with 80:20 diesel and biodiesel ratio. The 3H nozzle exhibits the optimum emission levels as per the Indian norms. At no load condition, both 3H and 4H have the emission with same NO_X composition while 4H produces more CO_2 and least CO and HC. As the load increases the NO_X gases emission increases wherein 4H produces more NO_X gas than 3H nozzle. CO gas stabilized to 0.01% from the load of 2 kg itself for 4H whilst the 3H nozzle stabilized on 8 kg.

Keywords: Biodiesel, Transesterification, Engine, Gas analyzer, Emission, Nozzle

Introduction

The entire world is concentrating on renewable alternative sources of energy in order to reduce the dependency on nonrenewable energy sources such as crude oil. The world is augmenting about the depletion of fossil fuels and environmental degradation. With increasing cost and unavailability, countries that are imports these fossil fuels are greatly affected such as India which fulfils 70% of their crude oil need by import. In India, the requirement for diesel is 4–5 times higher than petrol. Due to the unavailability of petroleum products and its increasing cost, optimum methods has to be developed for alternative fuels especially for diesel to full or partial replacement [1]. In addition, the extensive use of fossil fuels is also increased the production of greenhouse gases, especially CO_2, thus exacerbating the greenhouse effect. Bio fuels have the potential to reduce both fossil fuel reliance and the release of CO_2 to the atmosphere [2].

Hence, a harmonious correlation with sustainable development, energy conservation and management, efficiency and environmental preservation has become highly pronounced in the present context [3]. It has been found that the bio oils, very similar diesel, can be produced easily and are renewable from the crops. Furthermore, bio oils have almost similar energy density, cetane number, heat of vaporization and stoichiometric air/fuel ratio compared to mineral diesel fuel [3]. Abundant researchers have proved that the harmful exhaust emissions cutback and comparable engine performance with diesel fuel can be attained by utilizing biodiesel as a fuel in diesel engines. Researchers are coming up with a variety of biodiesel and blend fuels so as to reduce the reliance on fossil fuels that can be used with existing engines with or without any engine amendments [4, 5].

However, straight bio oils cannot be used directly in engines because bio oils or their blends with diesel pose various long-term operational and durability problems in compression ignition engines. Several techniques are proposed to reduce the viscosity of bio oils such as blending, pyrolysis, micro-emulsion and transesterification. It has been reported that transesterification is an effective process to overcome all these problems associated with bio oils [6].

Mahua methyl ester (*Madhuca indica*) biodiesel produced by transesterification route from non-edible oil is one of the potential candidates recognized from investigations with 0.18 Mt. expected annual production

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prospective in India [4]. Investigation on 4-cylinder direct injection diesel engine for identifying the effect of biodiesel blends on the gaseous emission proves that the HC and CO emissions decreased whereas the brake thermal efficiency and the NO_X emissions increased for the blended fuels [7]. It was also reported based on the experimental results that if Pungamia methyl ester (PME) biodiesel is utilized as fuel replacement in diesel engine, it will protect the environment by means of lower emission compared to the diesel. Reduction of 8.9, and 8.2% in the greenhouse gases of CO and HC is noted [8]. It is experimentally proven that there is noteworthy drop in CO, unburned hydrocarbon and smoke emissions for all biodiesel blends when compared to diesel fuel. However, marginally higher NO_X emission is identified for PME biodiesel than that of petroleum diesel [9].

Conversely the change of fuel injection system with high injection pressure and small nozzle diameter size is also an effective method to improve fuel spray characteristics and mixture preparation process for reduction in particulate matter and gaseous emissions [10]. Also, study on the effect of number of nozzle holes (12 numbers) geometry on the spray characteristic of biodiesel fuel reports that the particle distribution (atomization) increases due to more particle collision with each other which leads to complete burning of fuel. Constant volume combustion in a diesel engine increases with increase in the number of nozzle holes [11]. Injector hole number has certain influence on the engine performance and emissions because both parameters take important influence on the spray parameters like droplet size and penetration length and thus on the combustion process [7].

The objective of this work is to explore the possibility of using Jatropha and Pongamia bio oils as alternative to fossil fuels and to identify the properties of these biodiesel fuels. Further, it is aimed to evaluate their emission levels by using 3 hole (3H) and 4 hole (4H) nozzle diesel engine under different loading conditions to select the appropriate nozzle. The obtained emission results of the biodiesel blend are compared with the emission level of existing biodiesel blends.

Materials and methods

Biodiesel preparation

Transesterification methodology has been followed for biodiesel production with Jatropha and Pongamia (Karanja) vegetable bio oils. The experimental setup shown in Fig. 1 consists of a magnetic stirrer with heating setup at the bottom which supplies heat to the oil bath and the magnetic rotational energy to the mix flask content through magnetic pellet. The oil bath consists of silicon oil and the round bottom flask is placed on it without touching the bottom surface of bath. The round bottom flask is connected to the condenser on the top in which water is circulated continuously with the help of an electric pump. The opening located above the condenser can be utilized to pour reactants and the temperature is checked through thermometer by dipping in the oil bath.

Fig. 1 Biodiesel production setup

The biodiesel processing steps consist of: (1) Pre-treatment & Pre-heating; (2) Acid Esterification process; (3) Base transesterification process; and (4) Bubbling Process.

Step 1: All solid and visible impurities are filtered and cleaned from the Jatropha and Pongamia oils and are mixed at the ratio of 1:1 at 800 rpm with the help of a magnetic stirrer. The oil mixture is heated up to 110 °C for removing the moisture content.

Step 2: When a carboxylic acid is treated with an alcohol and acid catalyst, an ester is formed (along with water) and the reaction is called as acid esterification (Fischer esterification). The second step involves conversion of free fatty acid content in the bio oil into fatty acid esters.

Mixture of Jatropha and Pongamia oils were taken in the reactor that has a magnetic stirrer, condenser and thermometer as shown in Fig. 2. Methanol is added at 1:3 (oil:methanol) volume ratio and stirred at low speed for 10 min. Sulfuric acid at 3 vol% is also added and stirred for 60 min and the reaction temperature is maintained between 65 and 70 °C. After the reaction esterified oil is transferred to the separating flask, it is kept alone for 8 h and then the sediments were removed to collect the esterified oil from the flask.

Step 3: This step involves the process of exchanging the alkoxy group (R”) of an ester compound with another alcohol (R’) with the aid of a strong base catalyst. Esters with larger alkoxy groups can be made from methyl or

Fig. 2 Acid esterification process

ethyl esters in high purity by heating the mixture of ester, base and large alcohol by evaporating the small alcohol to drive equilibrium. On the whole, Fatty acid esters of esterified oil are converted into fatty acid methyl ester in this step.

Sodium hydroxide 0.5% by weight and 1:3 methanol by volume with oil were taken into the reactor and stirred till NaOH completely dissolved in the methanol by forming sodium methoxide solution. The esterified oil is added into sodium methoxide solution followed by vigorous mixing by means of magnetic stirrer in the reactor. The required temperature of 65 °C is maintained throughout the reaction time of 60 min and the mixture is poured into a separating flask. Then the mixture is allowed to settle for overnight by gravity into a clear golden liquid biodiesel at the top and glycerol at the bottom as illustrated in Fig. 3.

Step 4: This is the process of removing moisture and soap content in the prepared biodiesel. It involves mixing of distilled water with biodiesel (1:5) at a temperature of 60 °C. After few hours of settling, it is separated and pure biodiesel is obtained wherein this process is repeated until the soap content is almost removed as given in Fig. 4.

The prepared biodiesel is tested for various physical properties like viscosity, density, calorific value, flash point and fire point and pH value. Table 1 shows the obtained properties of the developed fuel wherein kinematic viscosity and absolute viscosity are measured by Redwood viscometer (ACUTEK, A-220B), density is measured by Hydrometer (Mehta Sales Corporation), flash point and fire point are measured by Cleveland open cup apparatus (Aditya Scientific Instruments, RAP 132) and calorific value is measured by Bomb calorimeter (Unique lab equipments, RSBT5) for the blended biodiesel.

Experimental setup for emission analysis

The experiments were conducted on a single cylinder, four strokes, 3.5 kW, water cooled direct injection compression-ignition engine coupled with eddy current dynamometer as shown in Fig. 5a. The fuel flow rate was measured at each

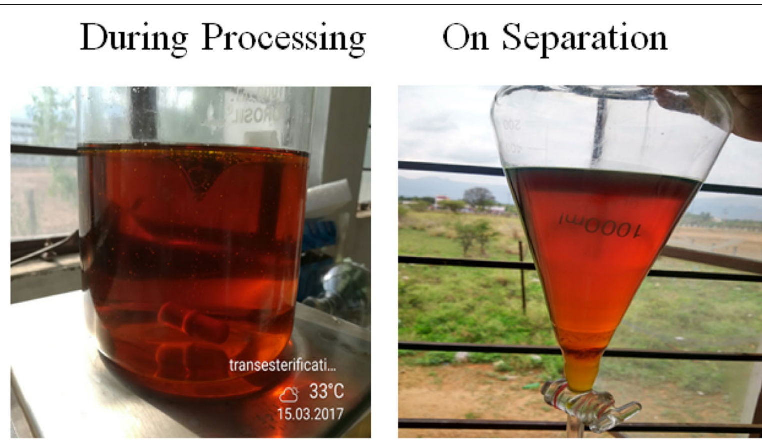

Fig. 3 Base transesterification process

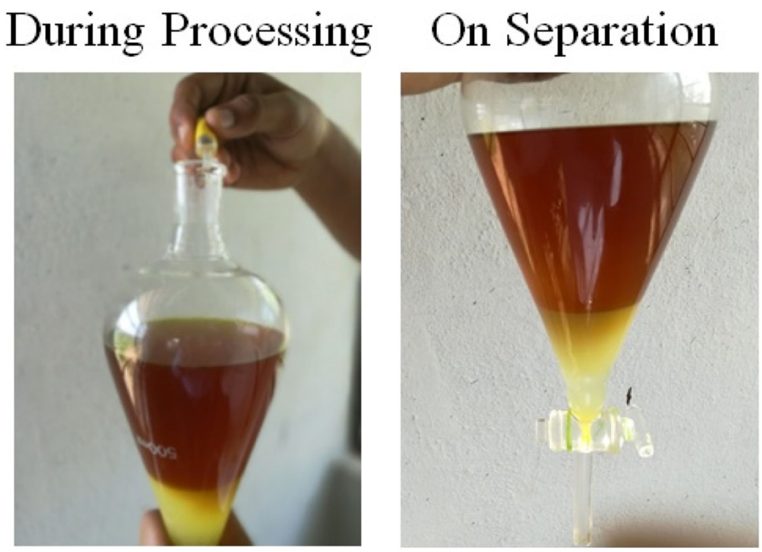

Fig. 4 Bubbling process

load by noting down the time taken for the consumption of known quality of fuel (10 cm^3 or 0.01 L) from a burette. Initially, the engine is started and allowed to warm-up for about 10 min and the engine speed is kept constant at 1500 rpm for all load conditions. All experiments were conducted for B20 blend with 3H and 4H nozzles for comparing the emission level of the engine.

The emission tests were carried out for all load conditions with nickel and zinc coated catalytic converter. The emissions (CO, HC, CO_2 and NO_X) were measured by AVL DiGAS 444 gas analyzer (Fig. 5b). The utilized gag analyzer is capable of measuring 0–10%vol of CO, 0–20,000 ppm of HC, 0–20%vol of CO_2 and 0–5000 ppm of NO_X.

Results and discussion

CO emission

CO is produced when incomplete combustion happens in the combustion chamber and it usually tends to reduce with increases in load. CO is a colorless and odourless toxic gas which is slightly denser than air is difficult to identify in naked eye. Exposure to 100 ppm or more CO can be dangerous to human health because it gets dissolved to hemoglobin easily and cause severe damage to cells. Table 2 shows the level of different gases in engine emission under different loading conditions.

At the idling phase, i.e., at no load condition of the engine, 4H nozzle produced the least CO gas and the stabilized to 0.01% from 2 kg of load onwards while the CO gas stabilized for 3H nozzle on 8 kg as illustrated in Fig. 6a. CO emissions for utilized B20 are found to be low and it can be accredited to the more efficient utilization of the biodiesel with more number of holes in nozzle [7]. Since the number of holes in 3H nozzle is less, it creates more concentrated diesel distribution and poor fuel atomization and as a result it ends in higher local equivalence ratio in the high fuel reactivity regions [12]. Consequently, partial oxidation of mixtures takes place in the fuel rich regions which tends to produce more CO. Figure 6a also confirms that the CO emission is less for biodiesel blend when compared to diesel alone in both 3H and 4H nozzles.

HC

HC present in the exhaust gas is the waste unburned fuel from the combustion chamber. It shows the amount of effective combustion happening inside the engine. For greater efficiency the HC presence must be nearly zero which is very difficult to achieve. While analyzing the observed data shown in Fig. 6b, it is clearly evident that the HC composition increases with increase in load up to some level and decreases slightly. At idle condition, 3H nozzle produced more HC and it gradually increased while the 4H nozzle had the least value than 4H throughout all the load values. So it can be said that more combustion takes place in the 4H nozzle than 3H nozzle. As the number of hole in the nozzle increases,

Table 1 Properties of biodiesel and diesel

Properties	Biodiesel	Diesel
Density (kg L^{-1})	0.880	0.832
Kinematic viscosity at 50 °C mm^{-2} s^{-1}	5.5	1.3 to 6.2 (As per grade)
Flash point (°C)	54	62
Fire point (°C)	68	64
Calorific value (MJ kg^{-1})	41.5	45.5
pH value	7.5	7

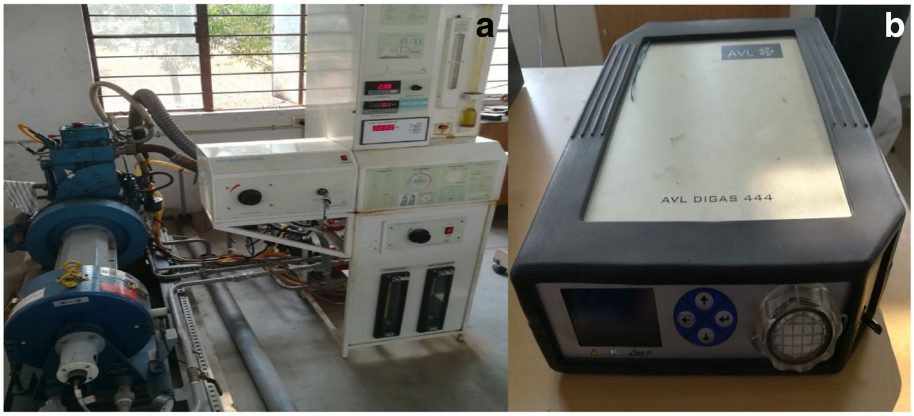

Fig. 5 (**a**) Computerized VCR Engine Setup (**b**) Gas Analyzer

the HC emission also decreases [7]. Figure 6b also proves that the HC emission is less for biodiesel blend when compared to diesel in both 3H and 4H nozzles.

CO_2

In the idling stage of engine, 4H produces more CO_2 and when load increases, both 3H and 4H produce the same amount of CO_2 [9]. With increasing the load, 3H started to stabilize first followed by the 4H nozzle as shown in Fig. 6c. The CO_2 emission increases due to efficient combustion because CO_2 is produced with complete combustion of fuel. As a result, CO_2 emissions increased while increasing the number of hole in injection nozzle [7]. Figure 6c also confirms that the CO_2 emission is less for biodiesel blend when compared to diesel in both 3H and 4H nozzles.

NO_X

With idle condition of engine, both 3H and 4H have almost same NO_X composition whereas NO_X gases increased as the load increases and 4H nozzle produces more NO_X gases when compared to 3H as demonstrated in Fig. 6d. This reduced NO_X gas emission by 3H nozzle is mainly due to decreased combustion temperature [13]. NO_X emissions are significantly decreased with reduced nozzle holes, as fewer nozzle holes produce more concentrated diesel distribution [11, 12]. Similarly, NO_X emissions increase as load increases due to increase in the gas temperature in combustion chamber [14]. It has been reported that biodiesel fuels having higher cetane number produce lower nitric oxide (NO_X formation) when used in diesel engines.

It can be identified from the Table 3 that the emission level of engine differs according to the type of oil used and number of nozzle holes. Similar to other biodiesel blends, the emission level of different gases varies when the number of holes in nozzle changes. When compared to the other biodiesel blends, the developed Jatropha & Pongamia based biodiesel blend gives comparatively low gas emission. Hence the developed novel biodiesel can be utilized as an alternative fuel source instead of high polluting fossil fuels. Figure 6d also confirms that the NO_X emission is less for biodiesel blend when compared to diesel in both 3H and 4H nozzles.

Conclusions

Biodiesel is successfully prepared from Pongamia and Jatropha oil through transesterification process with

Table 2 Emission level under different loading conditions

LOAD (kg)	CO (%vol)				HC (ppm)				CO_2 (%vol)				NO_X (ppm)			
	Biodiesel		Diesel		Bio diesel		Diesel		Bio diesel		Diesel		Bio diesel		Diesel	
	3H	4H	3H	4H	3H	4H	3H	4H	3H	4H	3H	4H	3H	4H	3H	4H
0	0.03	0.02	0.08	0.05	6	1	14	6	0.5	0.5	0.63	0.59	80	80	110	100
2	0.02	0.02	0.06	0.04	9	1	17	9	0.4	0.5	0.58	0.58	110	110	140	120
4	0.02	0.01	0.05	0.04	12	2	16	12	0.4	0.5	0.54	0.57	120	140	180	140
6	0.02	0.01	0.04	0.03	14	6	16	14	0.4	0.4	0.54	0.53	130	210	230	160
8	0.01	0.01	0.03	0.02	17	8	15	14	0.4	0.4	0.52	0.52	170	220	240	190
10	0.01	0.01	0.03	0.02	18	10	17	12	0.4	0.4	0.5	0.51	220	230	250	230
12	0.01	0.01	0.03	0.02	14	6	16	8	0.4	0.4	0.49	0.5	210	220	250	240

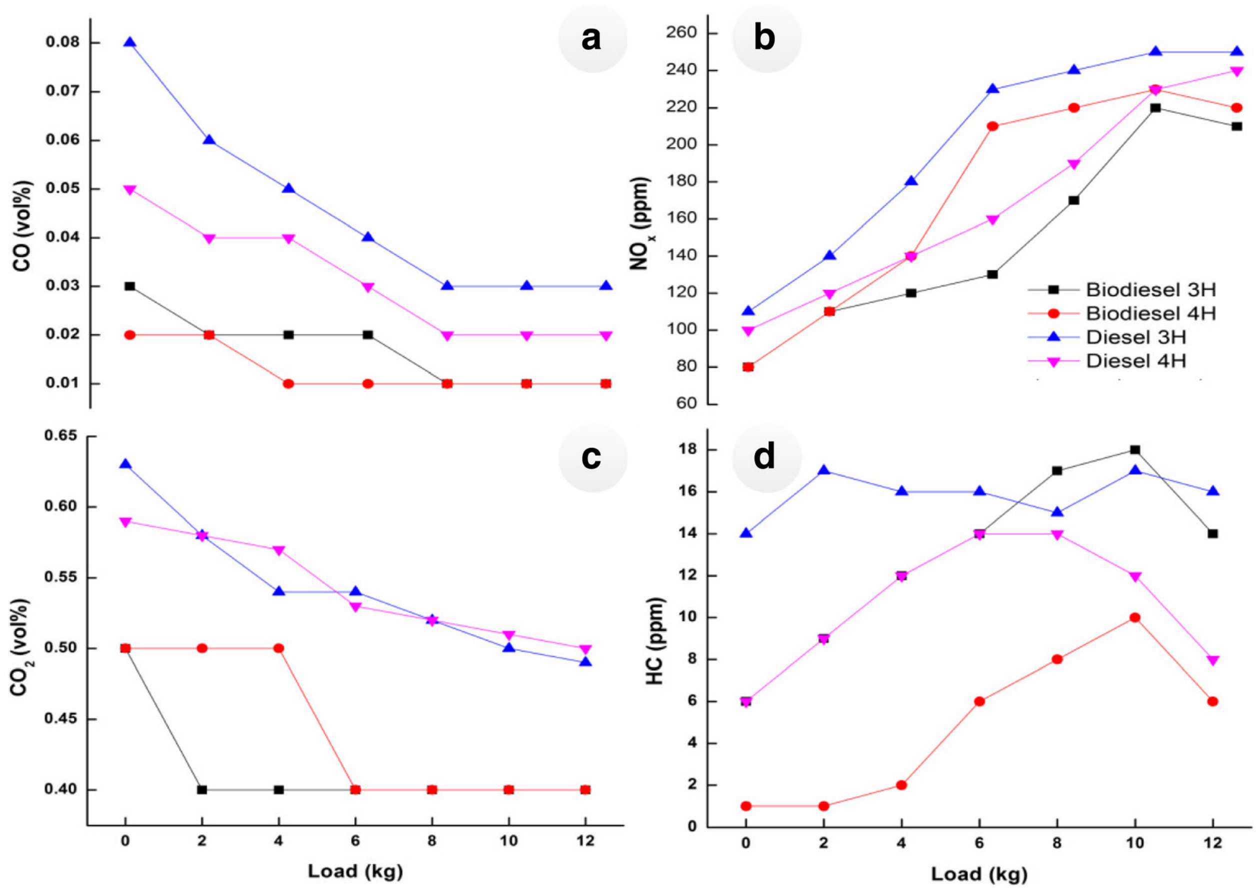

Fig. 6 Gaseous emission as a function of load. (**a**) CO, (**b**) NOx, (**c**) CO_2, (**d**) HC

sodium hydroxide as catalyst and the effect of nozzle performance is checked for B20 biodiesel blend. The following conclusions were made from the experimental results

- In terms of CO emission, 4H nozzle produces less when compared to 3H nozzle and CO level stabilizes at lower loading condition for 4H.
- HC emission of 4H nozzle exhibits the least value throughout all load values which proves more combustion in the 4H nozzle.
- Both 3H and 4H have nearly same NO_X composition when no load is applied in the engine. As the load increases, the NO_X gases increase due to increase in temperature in which 4H nozzle produces more NO_X gases than 3H.
- CO_2 emission follows reverse trend when compared to CO and HC gas emissions, i.e., 4H nozzle produces more CO_2 as a result of higher combustion temperature than 3H nozzle. And at higher loading conditions, both the nozzles produce the same amount of CO_2.

The emission level of developed Pongamia and Jatropha oil based B20 biodiesel blend is comparatively low when compared to other oil based biodiesels. Hence, the developed novel biodiesel can be utilized as an alternative fuel source instead of high polluting fossil fuels.

Table 3 Comparison of gas emission by different biodiesels

S. No.	Type of oil	Diesel:Bio oil	CO (%vol)		HC (ppm)		CO_2 (% vol)		NO_X (ppm)		Ref
			3H	4H	3H	4H	3H	4H	3H	4H	
1	Pongamia	80:20	0–0.28	–	10–68		–	–	150–1200	–	[14]
2	Honge Oil	80:20	0.15–0.38	0.13–0.37	65–102	60–99	–	–	600–1150	607–1120	[15]
3	Mahua seed oil	80:20	0.04–0.05	–	35–38		–	–	90–850	–	[16]
4	Jatropha & Pongamia	80:20	0.01–0.03	0.01–0.02	0–12	6–18	0.4–0.5	0.4–0.5	80–220	80–230	–

Authors' contributions
SKN carrided out Bio Diesel extraction process, participated in the sequence alignment and drafted the manuscript. PP participated in the emission analysis. GPM and RP participated in the design of the study and performed the result analysis. All authors read and approved the final manuscript.

Competing interests
The authors declare that they have no competing interests.

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