Environmental Science and Pollution Research (2019) 26:8633–8639
https://doi.org/10.1007/s11356-019-04288-x

RESEARCH ARTICLE

Experimental investigation of diesel engine performance fuelled with the blends of *Jatropha curcas*, ethanol, and diesel

Kutuva Rajaraman Kavitha[1] · Nagappan Beemkumar[1] · Rajendiran Rajasekar[1]

Received: 2 October 2018 / Accepted: 16 January 2019 / Published online: 1 February 2019

Abstract

Nonrenewable fossil fuels show increased demand and with fossil fuels at a rapid depleting stage, there seems to be an increase in requirement for alternative fuels too. Biofuels and blended fossil fuels are one of a kind. Nonedible jatropha (*Jatropha curcas*) oil-based methyl ester was produced and mixed with ethanol and blended with conventional diesel in various compositions. Jatropha biodiesel is used because of its great blending capacity with diesel. Sodium hydroxide is used as a catalyst which allows miscibility between ethanol and diesel. In present epoch, the paucity of fossil fuels and its adverse impact have driven researchers to focus on alternative fuels. Biodiesel is one of the most favorable and promising alternatives in the application of automobiles, boilers, gas turbines, etc. This study targets at finding the engine performance and emission characteristics under various load conditions on Kirloskar single-cylinder VCR research engine by blending both jatropha biodiesel and ethanol with base diesel at various compositions. Both jatropha biodiesel and ethanol have high calorific value which is a most important factor for engine power production. The performance analysis showed that the biodiesel blend of 98% diesel with 1.5% jatropha biodiesel and 0.5% (D98J1.5E0.5) of ethanol had a significant improvement in the engine performance than the conventional diesel.

Keywords *Jatropha curcas* · Kirloskar engine · Jatropha oil · Ethanol · Diesel · Performance analysis · Efficiency

Introduction

Presently, the major source of air pollution is due to the exhaust emission from the diesel engines. Automobiles generally use gasoline as fuel in the internal engine, but technological advances have led to the design of cars that run on electricity and even water.

Kathirvelu et al. (2017) investigated the performance of an engine with the biodiesel obtained from jatropha seeds and fish waste. The results showed that the brake thermal efficiency (BTE) was slightly lower than the diesel whereas the efficiency of the engine was found to be higher for jatropha oil methyl ester than fish oil methyl ester. HC (hydrocarbon), CO (carbon monoxide), and soot emissions were found to be lower than the diesel whereas NO_x (oxides of nitrogen) and exhaust gas temperature were found to be higher than the diesel. Also, jatropha oil methyl esters seem better than fish oil methyl esters. Comparative studies were carried out for oxidation and storage stability of mahua biodiesel with that of jatropha biodiesel and mineral diesel by Acharya et al. (2017). The biodiesel blended with various blending ratios from 10 to 90% (B10 to B90) were prepared for the experimental purpose. The experimental results showed that the oxidation stability seemed to be satisfied with 20% of jatropha biodiesel and 30% blending of mahua biodiesel but showed steady increase with equal percentage blending of the biodiesels. An experimental investigation by Madiwale et al. (2018) with jatropha, soyabean, palm, and cottonseed biodiesel of the different blending ratios are performed to enhance the performance of the engine and to reduce harmful exhaust emissions. They have used ethanol as an additive in the blends at a constant ratio of 5%, and the experiment was carried out on the single-cylinder four-stroke VCR electric start diesel engine. The investigation results showed a significant improvement in brake power and brake-specific fuel consumption with the addition of ethanol as an additive for jatropha, soyabean, palm, and cottonseed biodiesel. Among all fossil fuels, diesel in particular has played a critical role in all major

Responsible editor: Philippe Garrigues

✉ Nagappan Beemkumar
beem4u@gmail.com

[1] School of Mechanical Engineering, Sathyabama Institute of Science and Technology, Chennai, India

sectors such as transportation, power, industry, marine, and agriculture owing to fuel economy, reliability, and rigidity. But they emit hazardous emissions like NO_x, HC, PM, and smoke which causes several global hazards. *Jatropha curcas* is a plant that belongs to the Euphorbiaceae family (Sadhik Basha and Anand 2014). Within this genus, there are more than 170 species distributed around the world, especially in tropical regions. This plant comes from Central America (Mexico), and it is possible to obtain an oil yield higher than 1500 kg per hectare. This oil is adequate to be used as a raw material in the biodiesel production. *Jatropha curcas* is gaining more attention as a feedstock for biodiesel production due to its incompetence with food crops (Silitonga et al. 2017). Furthermore, adverse climatic conditions such as high temperature, low moisture content, and soil fertility do not affect its productivity (Balat 2010; Ong et al. 2013; Yusuf et al. 2011). Alternative fuels should be eco-friendly, be easily available at a low cost, and fulfill the basic requirements without sacrificing engine operational performance (Deepak and Avinash 2007).

An experimental investigation by Forson et al. (2004) on the performance and emission with preheated jatropha biodiesel, untreated jatropha biodisel and its blends at different load conditions in a constant speed of 1500 rpm engine was performed, and the results prove jatropha biodiesel as a promising alternative fuel for compression ignition engines. Thermal efficiency was lower for unheated jatropha biodiesel compared to heated jatropha biodiesel and base diesel. The blend of 97.4% of pure diesel and 2.6% of jatropha biodiesel yielded a better engine performance. Also, Bhupendra Singh Chauhan et al. (2010, 2012) investigated that the engine performance with unheated jatropha biodiesel is slightly inferior to the performance with diesel fuel and concluded that the biodiesel derived from jatropha biodiesel will be the best substitute for diesel fuel in CI engine without any modifications. A study on the effects of engine design parameter followed by performance and emission characteristics of a diesel engine fuelled with jatropha methyl ester was conducted by Jindal et al. (2010). The experiment was conducted with various compression ratios along with injecting pressure. The results showed an increase in compression ratio and injection pressure that increases the brake thermal efficiency with a reduction in brake-specific fuel consumption with lower emissions. The use of biodiesel blends is limited due to its poor oxidative stability (Dinkov et al. 2009; Karthikeyan et al. 2018; Yuvarajan et al. 2017; Thangaraja et al. 2012). Tan et al. (2012) investigated exhaust emission at various blending of jatropha methyl ester with diesel from 5 to 100 volume percentages. They observed that with less effect on NO_x emission, CO emission is found to be increased with biodiesel at low engine loads and HC emission was reduced with increasing biodiesel fuels. Torres-Jimenez et al. (2011) made a study on the physical and chemical properties of ethanol–diesel fuel blends. The study reported that using additives to avoid phase separation and to raise the flash point, blends of diesel fuel with ethanol up to 15% can be used to fuel diesel engines.

In previous research (Dhandapani et al. 2012), both jatropha and ethanol have injected through intake port at constant rate for the evaluation of effect of fuel viscosity and combustion duration, and also blended with diesel with constant proportion for performance and emission characteristics. The present work aimed to investigates the effect of the engine performance and emission characteristics for different blending ratios of the Jatropha biodiesel, ethanol and diesel.

Materials and methods

Preparation of biodiesel

Jatropha biodiesel was prepared using commercial jatropha oil by transesterification process. In this process, potassium hydroxide is used as a catalyst and methanol as alcohol (Kishore Pandian et al. 2017; Radhakrishnan et al. 2018). Preheating of raw oil was performed to 70 °C followed by mixing to a solution containing catalyst and alcohol. The obtained mixture is heated again for 5 °C till the complete vaporization of methanol so that glycerol and ester were separated.

To perform the engine test, the prepared biodiesel was mixed with diesel and ethanol at different blending ratios namely, the first blend comprises of 90% diesel, 7.5% jatropha biodiesel, and 2.5% ethanol (D 90J7.5E1.25), where ethanol acts as a catalyst. The second blend comprises of 95% diesel with 3.75% jatropha biodisel and 1.25% (D95J3.75E1.25), and the third blend comprises of 98% diesel with 1.5% jatropha biodisel and 0.5% ethanol (D98J1.5E0.5). The physical and chemical properties of the prepared biodiesel blends are tested as per the ASTM standards and listed in Table 1.

Experimental setup

The experiments were performed on a water-cooled, single-cylinder, four-stroke, variable compression ratio (VCR) and electric start direct-injection diesel engine. The schematic layout and the photographic view of experimental setup are shown in Figs. 1 and 2, respectively. Table 2 shows the test engine specifications. The test engine is coupled to an eddy current type dynamometer for load variations. The AVL Digas 444 five-gas analyzer was employed for the measurement of CO, CO_2, NO_x, and HC emissions at different load conditions. Diesel engine output shaft is connected with the eddy current dynamometer, which is used to measure the power and torque. The load cell is connected to the dynamometer for varying the load on the engine (0–100%).

Table 1 Properties of fuel

Properties	Diesel	Jatropha oil	Ethanol	D90J7.5E2.5	D95J3.75E1.25	D98J1.5E0.5	Method
Calorific value (MJ/kg)	42.5	38.2	27	38.5	39	40	ASTM D240
Density (kg/m^3)	810	932	789	825	819	815	ASTM D4052
Flash point (°C)	48	240	15	72	65	64	ASTM D93
Cetane Index	46	38	8	49.2	47.54	44.63	ASTM D976
Kinematic Viscosity at 40 °C (m^2/s)	2.5×10^{-5}	4.2×10^{-5}	1.2×10^{-5}	2.17×10^{-5}	2.11×10^{-5}	2.45×10^{-5}	ASTM D445
C (% wt)	85.2	–	–	77.4	76.4	75.8	ASTM D5291
H (% wt)	12.7	–	–	11.5	12.01	11.8	ASTM D5291
O (% wt)	2.7	–	–	11.8	12.35	13.48	ASTM D5291

Uncertainty analysis

Every work includes some amount of uncertainty. These uncertainties mainly result of calibration, sensors, observations, test procedure, and environmental condition. In view of uncertainties, the preferred test results can be examined of any work. If a quantity to be measured "R" has a function of many self-regulating variables like $x_1, x_2, x_3, ..x_n$, then $R = R(x_1, x_2, x_3, ..x_n)$.

Let the measured quantity uncertainty be expressed as $W_R$and the independent variables uncertainties are expressed as $W_1, W_2, W_3, ...W_n$.

Subsequently, the uncertainty in the measured quantity is given by Eq. (1):

$$W_R = \sqrt{\left[\left(\frac{\partial R}{\partial x_1}W_1\right)^2 + \left(\frac{\partial R}{\partial x_2}W_2\right)^2 + \left(\frac{\partial R}{\partial x_3}W_3\right)^2 + \dots\dots\dots \left(\frac{\partial R}{\partial x_n}W_n\right)^2\right]} \quad (1)$$

where $W_R = \frac{\delta R}{R}$; $\pm\delta R$ is the error in R. The root-mean-square method is employed to examine the percentage of the uncertainty of different parameters such as smoke, BTE, HC, brake-specific fuel consumption (BSFC), CO, and NO_x emissions. The accuracy and uncertainty levels for the measured quantity are presented in Table 3.

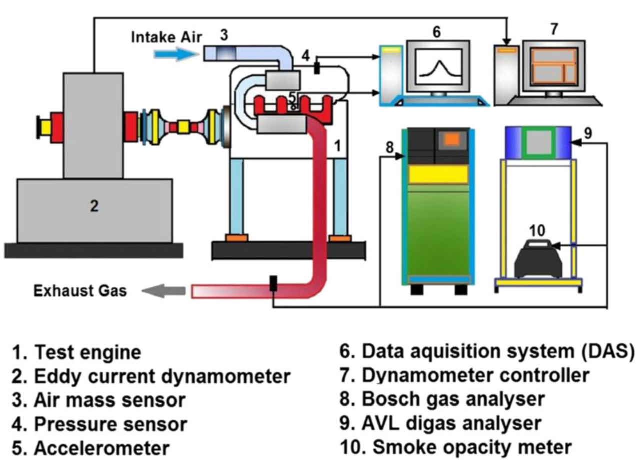

Fig. 1 Schematic layout of test engine

Results and discussion

The performance and emission characteristics of an engine fuelled with jatropha biodiesel–ethanol–diesel were evaluated by finding the BTE, BSFC, NO_x emission, CO_2 emission, CO emission, and HC emission.

BTE

The ratio of brake power (BP) to the energy in the fuel burned to produce this power is called brake thermal efficiency. It is used to evaluate how far an engine utilizes the heat from fuel to convert into energy. The variation of BTE with brake power for different blends is shown in Fig. 3. At 0.937 kW, compared with diesel, the brake thermal efficiency of the blends D90J7.5E2.5 and D95J3.75E1.25 was increased by 2.13% and 3.24%, respectively. Similar trend has been observed for the brake power output 3.467 kW. It was noticed that the BTE of biodiesel blends is higher than base diesel. This is due to better atomization, better combustion, and shorter ignition

Fig. 2 Photographic view of test engine

Table 2 Specifications of engine setup

Make	Kirloskar
Stroke	4
Cylinder	Single
Rated power	3.5 kW
Rated speed	1500 rpm
Bore diameter (D)	87.5 mm
Stroke (L)	110 mm
Compression ratio	17.5:1
Injection Timing	17° BTDC
Injection pressure	200 bar
Fuel pump plunger diameter	8 mm
Number of injector nozzle	4
Diameter of injector nozzle	0.32 mm
Cooling	Water-cooled
Position	Vertical
Data acquisition device	NI USB-6210, 16-bit, 250 kS/s

delay characteristics of biodiesel and ethanol blends. In addition, the atomization and mixing of biodiesel and ethanol blends with air is in uniform rate causing shorter breakup length, higher dispersion rate, and increased efficiency. These results are matched with the experimental results of Appavu et al. (2018), Devarajan (2018), and Mahalingam et al. (2018).

BSFC

BSFC is used to measure the fuel consumption rate for unit power output. The variations in the BSFC for the different blends are shown in Fig. 4. It can be seen that the BSFC of the blend D90J7.5E2.5 was decreased by 2.68% compared with diesel at 0.937 kW. Similar trends have been observed for all rated power outputs. It is also observed that the BSFC of the D95J3.75E1.25 blend was increased by 3.69% at 0.937 kW. In general, BSFC decreases with an increase in loads. Due to the presence of ethanol in the biodiesel blends, the BSFC of the high concentrated biodiesel blend was decreased with respect to lower density and viscosity. The combined effects of relative fuel density, viscosity, and blending proportions lead to these fluctuations (Yuvarajan and Venkata Ramanan 2016).

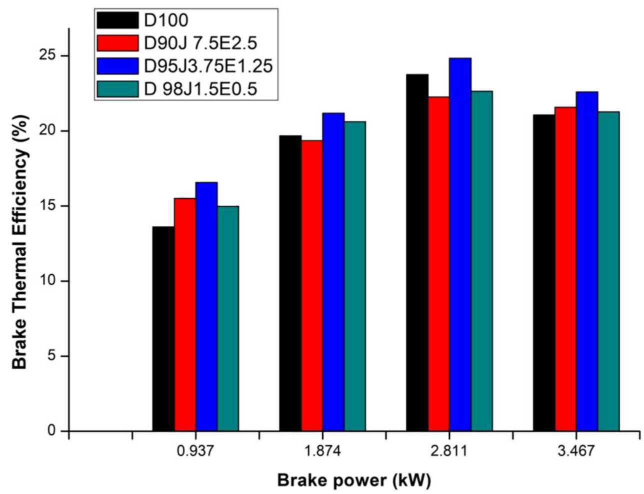

Fig. 3 Brake thermal efficiency

NO_x emission

Nitrogen oxide is a generalized term for NO and NO_2 represented as NO_x. The high temperature in the combustion chamber and the surplus availability of oxygen are the causes of formation for NO_x emission (Sudalaimuthu et al. 2018; Balan et al. 2018). Engine test was conducted for emissions using various blending properties of jatropha oil and ethanol under various load conditions. Figure 5 shows the NO_x emission levels for the various loads. The baseline data were generated using pure diesel. D90J7.5E2.5 shows moderate decrease in NO_x emission by 1.96%, 21.88%, 14.68%, and 15.56% for the power output 0.937, 1.874, 2.811, and 3.467 kW compared to base diesel, whereas D95J3.75E1.25 shows a marginal increase of NO_x emission by 0.39%, 0.29%, and 0.556% at 0.937, 2.811, and 3.467 kW, respectively, compared with base diesel. Generally, NO_x emissions from biofuels are higher than that of diesel. The possible reason is due to higher availability of oxygen in methyl esters when compared to diesel. The other possible reason is due to higher peak cylinder pressure of methyl esters over diesel originating high NO_x emissions (Devarajan et al. 2018; Siva et al. 2018; Ganesan et al. 2018).

Table 3 Accuracy and uncertainties

Parameters	Range	Accuracy	Uncertainties (%)
CO	0–15.0 vol.%	0.01 vol.%	± 0.5
HC	0–20,000 ppm vol.	± 1 ppm vol.	± 0.1
NO_x	0–5000 ppm vol.	± 1 ppm vol.	± 0.2
Smoke meter	0–100%	± 0.1%	± 1.2
Brake thermal efficiency	–	± 0.4	± 0.04
BSFC	–	± 0.02 kg/kW h	± 1.1

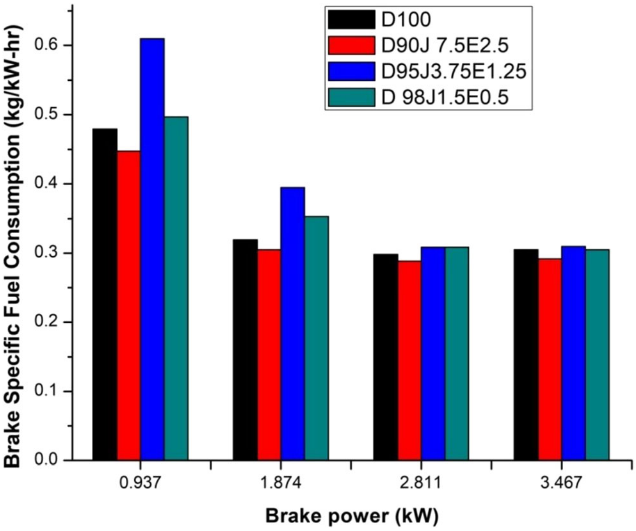

Fig. 4 Brake-specific fuel consumption

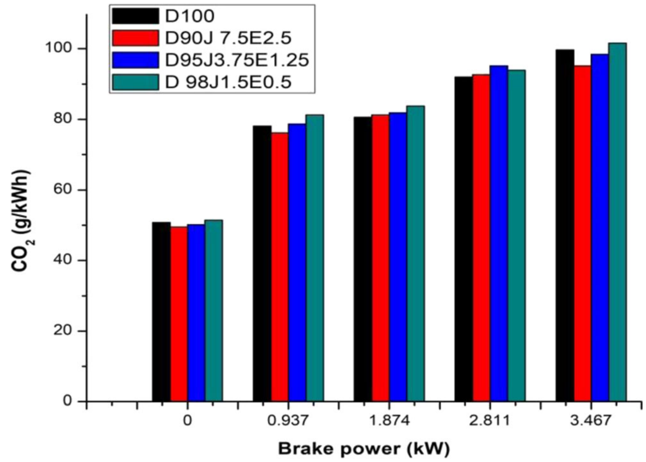

Fig. 6 CO_2 emission

CO_2 emission

Engine test was conducted for emissions using various blending properties of jatropha oil and ethanol under various load conditions. Figure 6 shows the CO_2 emission levels for various loads. The baseline data were generated using pure diesel. The CO_2 emission of D90J7.5E2.5 blend shows a marginal decrease by 0.02%, 0.03%, and 0.07% at 0, 0.937, and 3.467 kW power output, respectively, compared to diesel. It was observed that CO_2 emissions were marginally decreased with increasing of biodiesel blending. It is because of higher oxygen content in biodiesel when compared with base diesel which helps for complete combustion (Radhakrishnan et al. 2017; Rathinam et al. 2018; Yuvarajan et al. 2018; Senthilkumar et al. 2018).

CO emission

Carbon monoxide is formed because of the incomplete conversion of carbon atoms present in the fuel, and its main cause is due to an inadequate supply of oxygen during combustion (Arul Gnana Dhas et al. 2018; Balan et al. 2018). Figure 7 shows the CO emission levels for various loads. Engine test was conducted for emissions using various blending properties of jatropha oil and ethanol under various load conditions. The baseline data were generated using pure diesel. For the blend D98J1.5E0.5, a significant decrease of 0.01% and 0.02% at 0, 2.811, 3.467, and 0.937, 1.874 kW power output was observed. For the blend, D95J3.75E1.25 shows a marginal increase of 0.01% at 0, 1.874 kW, a marginal decrease of 0.01% at 2.811 kW, an increase of 0.04% at 0.937 kW, and a decrease of 0.04% at 3.467 kW than the base diesel. It was observed that CO emissions were decreased with the decrease of biodiesel blending. This effect is due to oxygen supply variation during engine operation (Joy et al. 2017; Yuvarajan and Venkata Ramanan 2016).

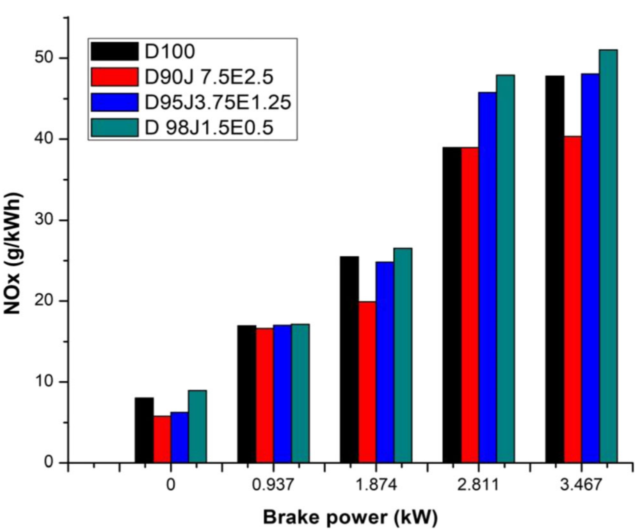

Fig. 5 NO_x emission

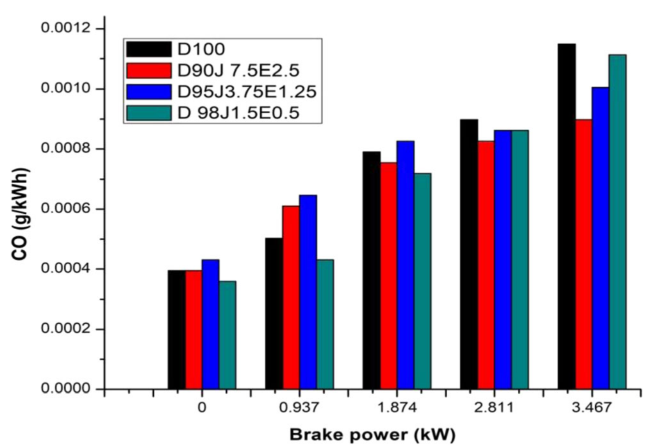

Fig. 7 CO emission

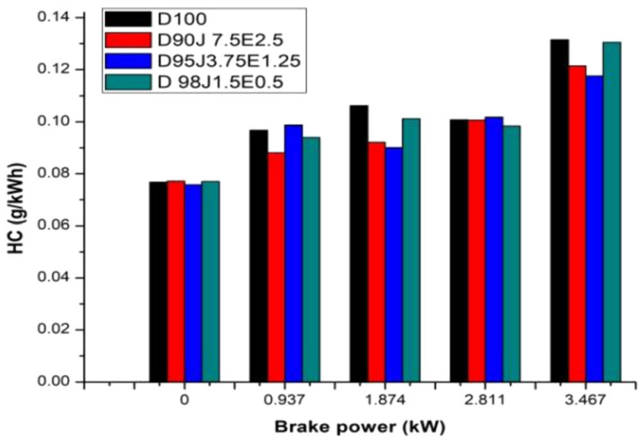

Fig. 8 HC emission

HC emission

Figure 8 shows the HC emission levels for various loads. The baseline data were generated using pure diesel. The blend D95J3.75E1.25 shows a marginal decrease of HC emission by 1.32% at initial power output and a drastic decrease of 15.21% at 1.874 kW and 10.6% at 3.467 kW power output. It was observed that HC emissions were decreased with increasing of biodiesel blending at all power outputs. It is because of higher oxygen content in biodiesel when compared with base diesel which helps for complete combustion.

Conclusions

The present experimental investigation was carried out on a single-cylinder four-stroke diesel engine. After the transesterification process, it was observed that the kinematic viscosity of *Jatropha curcas* oil gets reduced significantly than the diesel. The density of *Jatropha curcas* oil was higher, but calorific value seems to be lower than the diesel. The experimental output showed a significant improvement in performance with three blends and when the percentage of blend increases, performance also slightly increases. On the other hand, when the engine is running with biodiesel and its blend, emission such as HC, CO_2, and NO_x emissions were reduced with increasing of biodiesel blend whereas the CO emission was reduced with decreasing of the biodiesel blend. This was due to complete combustion of fuel and variation in the supply of oxygen to the engine. This result proves that jatropha with ethanol blend will act as a good substitute biofuel for a diesel engine in near future. However, there are variable parameters which can be evaluated in future such as by varying compression ratio, injection timing, and injection pressure.

References

Acharya N, Nanda P, Panda S, Acharya S (2017) A comparative study of stability characteristics of mahua and jatropha biodiesel and its blends. Journal of King Saud University – Engineering Sciences. https://doi.org/10.1016/j.jksues.2017.09.003

Appavu P, Jayaprabakar J, Beemkumar N, Yuvarajan Devarajan (2018) Effect of injection timing on performance and emission characteristics of palm biodiesel and diesel blends. J Oil Palm Res 30:674–681. https://doi.org/10.21894/jopr.2018.0057

Arul Gnana Dhas A, Devarajan Y, Nagappan B (2018) Analysis of emission reduction in ethyne–biodiesel-aspirated diesel engine. Int J Green Energy 15(7):436–440. https://doi.org/10.1080/15435075.2018.1473774

Balan KN, Yashvanth U, Booma Devi P, Arvind T, Nelson H, Devarajan Y (2018) Investigation on emission characteristics of alcohol biodiesel blended diesel engine. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects. https://doi.org/10.1080/15567036.2018.1549166

Balat M (2010) Potential alternatives to edible oil for biodiesel production—a review of current work. Energy Convers Manag 52: 1479–1492

Chauhan BS, Kumar N, Du Jun Y, Lee KB (2010) Performance and emission study of preheated Jatropha oil on medium capacity diesel engine. Energy 35:2484–2492

Chauhan BS, Kumar N, Cho HM (2012) A study on the performance and emission of a diesel engine fueled with Jatropha biodiesel oil and its blends. Energy 37:616–622

Deepak A, Avinash KA (2007) Performance and emissions characteristics of Jatropha oil (preheated and blends) in a direct injection compression ignition engine. Appl Therm Eng 27:2314–2323

Devarajan Y (2018) Experimental evaluation of combustion, emission and performance of research diesel engine fuelled Di-methyl-carbonate and biodiesel blends. Atmospheric Pollution Research. https://doi.org/10.1016/j.apr.2018.12.007

Devarajan Y, Munuswamy DB, Mahalingam A (2018) Investigation on behavior of diesel engine performance, emission, and combustion characteristics using nano-additive in neat biodiesel. Heat Mass Transf. https://doi.org/10.1007/s00231-018-02537-2

Dhandapani K, Pacharumuthu S, Nabi MN, Jnar ohan Einar Hustablends of d Terese Lovas (2012) Theoretical and experimental investigation of diesel engine performance, combustion and emission analysis fuelled with the ethanol, diesel and Jatropha methyl ester. Energy Convers Manag 53:322–331

Dinkov R, Hristov G, Stratiev D, Aldayin VB (2009) Effect of commercially available antioxidants over biodiesel/diesel blends stability. Fuel 88:732–737

Forson FK, Oduro EK, Hammond-Donkoh E (2004) Performance of jatropha oil blends in a diesel engine. Renew Energy 29(7):1135–1145

Ganesan S, Sivasubramanian R, Sajin JB, Ganesan S, Devarajan Y (2018) Performance and emission study on the effect of oxygenated additive in neat biodiesel fueled diesel engine. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects. https://doi.org/10.1080/15567036.2018.1549148

Jindal S, Nandawana BP, Rathore NS, Vashistha V (2010) Experimental investigation of the effect of compression ratio and injection pressure in a direct injection diesel engine running on Jetropha methyl ester. Appl Therm Eng 30:442–448

Joy N, Devarajan Y, Nagappan B, Anderson A (2017) Exhaust emission study on neat biodiesel and alcohol blends fueled diesel engine. Energy Sources Part A 40(1):115–119

Karthikeyan A, Nagappan B, Jayaraman J, GnanaDhas AA (2018) impact of antioxidant additives on the performance and emission characteristics of C.I engine fuelled with B20 blend of rice bran biodiesel. Environ Sci Pollut Res 25(18):17634–17644

Kathirvelu B, Subramanian S, Govindan N, Santhanam S (2017) Emission characteristics of biodiesel obtained from Jatropha seeds and fish wastes in a diesel engine. Sustain Environ Res 27(6):283–290. https://doi.org/10.1016/j.deri.2017.06.004.

Kishore Pandian A, Munuswamy DB, Radhakrishana S, Bathey Ramakrishnan RB, Nagappan B, Devarajan Y (2017) Influence of an oxygenated additive on emission of an engine fueled with neat biodiesel. Pet Sci 14(4):791–797. https://doi.org/10.1007/s12182-017-0186-x

Madiwale S, Karthikeyan A, Bhojwani V (2018) Properties investigation and performance analysis of a diesel engine fuelled with jatropha, soyabean, palm and cottonseed biodiesel using ethanol as an additive. Materials Today: Proceedings 5:657–664

Mahalingam A, Munuswamy DB, Devarajan Y, Radhakrishnan S (2018) Investigation on the emission reduction technique in acetone-biodiesel aspirated diesel engine. J Oil Palm Res 30:345–349. https://doi.org/10.21894/jopr.2018.0020

Ong HC, Silitonga AS, Masjuki HH, Mahlia TMI, Chong WT, Boosroh MH (2013) Production and comparative fuel properties of biodiesel from non-edible oils: Jatropha curcas, Sterculia foetida and Ceiba pentandra. Energy Convers Manag 73:245–255

Radhakrishnan S, Devarajan Y, Mahalingam A, Nagappan B (2017) Emissions analysis on diesel engine fueled with palm oil biodiesel and pentanol blends. J Oil Palm Res 29:380–386. https://doi.org/10.21894/jopr.2017.2903.11

Radhakrishnan S, Munuswamy DB, Mahalingam A (2018) Effect of nanoparticle on emission and performance characteristics of a diesel engine fueled with cashew nut shell biodiesel. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects 40:1–9. https://doi.org/10.1080/15567036.2018.1502848

Rathinam S, Sajin JAB, Devarajan Y, Arunkumar T (2018) Influence of water on exhaust emissions on unmodified diesel engine propelled with biodiesel. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects 40(21):2511–2517. https://doi.org/10.1080/15567036.2018.1503756

Sadhik Basha J, Anand RB (2014) Performance, emission and combustion characteristics of a diesel engine using carbon nanotubes blended jatropha methyl ester emulsions. Alex Eng J 53:259–273

Senthilkumar G, Sajin JB, Arunkumar T (2018) Evaluation of emission, performance and combustion characteristics of dual fuelled research diesel engine. Environ Technol:1–8. https://doi.org/10.1080/09593330.2018.1509888

Silitonga AS, Hassan MH, Ong HC, Kusumo F (2017) Analysis of the performance, emission and combustion characteristics of a turbocharged diesel engine fuelled with Jatropha curcas biodiesel-diesel blends using kernel-based extreme learning machine. Environ Sci Pollut Res 24(32):25383–25405

Siva R, Munuswamy DB, Devarajan Y (2018) Emission and performance study emulsified orange peel oil biodiesel in an aspirated research engine. Pet Sci 16:180–186. https://doi.org/10.1007/s12182-018-0288-0

Sudalaimuthu G, Rathinam S, Munuswamy DB, Thirugnanasambandam A (2018) Testing and evaluation of performance and emissions characteristics of water- biodiesel aspirated research engine. J Test Eval 48(5):20180306. https://doi.org/10.1520/jte20180306

Tan P, Hu Z, Lou D, Li Z (2012) Exhaust emissions from a light-duty diesel engine with Jatropha biodiesel fuel. Energy 39(1):356–362

Thangaraja J, Anand K, Mehta PS (2012) Experimental investigations on combustion, performance and emission characteristics of neat jatropha biodiesel and its methanol blend in a diesel engine. ASME Internal Combustion Engine Division Fat Technical Conference. https://doi.org/10.1115/icef2012-92041

Torres-Jimenez E, Jerman MS, Gregorc A, Lisec I, Dorado MP, Kegl B (2011) Physical and chemical properties of ethanol–diesel fuel blends. Fuel 90(2):795–802

Yusuf NNAN, Kamarudin SK, Yaakub Z (2011) Overview on the current trends in biodiesel production. Energy Convers Manag 52:2741–2751

Yuvarajan D, Venkata Ramanan M (2016) Experimental analysis on neat mustard oil methyl ester subjected to ultrasonication and microwave irradiation in four stroke single cylinder diesel engine. J Mech Sci Technol 30(1):437–446. https://doi.org/10.1007/s12206-015-1248-x

Yuvarajan D, Dinesh Babu M, BeemKumar N (2017) Emissions analysis on diesel engine fuelled with cashew nut shell biodiesel and pentanol blends. Environ Sci Pollut Res 24(14):13136–13141

Yuvarajan D, Dinesh Babu M, BeemKumar N, Amith Kishore P (2018) Experimental investigation on the influence of titanium dioxide nanofluid on emission pattern of biodiesel in a diesel engine. Atmos Pollut Res 9(1):47–52. https://doi.org/10.1016/j.apr.2017.06.003