International Journal of Ambient Energy

ISSN: 0143-0750 (Print) 2162-8246 (Online) Journal homepage: https://www.tandfonline.com/loi/taen20

Experimental investigation of performance and emissions characteristics on single-cylinder direct-injection diesel engine with PSZ coating using radish biodiesel

Pallavi Paturu & I. Vinoth kanna

To cite this article: Pallavi Paturu & I. Vinoth kanna (2020) Experimental investigation of performance and emissions characteristics on single-cylinder direct-injection diesel engine with PSZ coating using radish biodiesel, International Journal of Ambient Energy, 41:7, 744-753, DOI: 10.1080/01430750.2018.1492455

To link to this article: https://doi.org/10.1080/01430750.2018.1492455

Published online: 06 Jul 2018.

INTERNATIONAL JOURNAL OF AMBIENT ENERGY
2020, VOL. 41, NO. 7, 744–753
https://doi.org/10.1080/01430750.2018.1492455

Experimental investigation of performance and emissions characteristics on single-cylinder direct-injection diesel engine with PSZ coating using radish biodiesel

Pallavi Paturu and I. Vinoth kanna

Department of Mechanical Engineering, Vel Tech Rangarajan Dr Sagunthala R&D Institute of Science and Technology, Chennai, India

ABSTRACT

It has been determined that world oil production is likely to level off very shortly and that alternative fuels will have to meet the demands of an increasing energy crisis. The crude oil price is continuing to increase; at the same time the need of energy is also increasing rapidly. So there is an urgent need to switch to some other fuels which could replace petrol and diesel in order to produce energy. An eco-friendly alternative is required to fulfil the growing demand. This project highlights our work on alternate fuels and the importance of choosing radish seed as one such alternative. The aim of this study is the experimental investigation of performance and emissions on a single-cylinder direct-injection diesel engine with a coating. Diesel, B25, B50, B75 and B100 are used as fuels. The engine cylinder head, valves and piston crown are coated with 100 micron of nickel-chrome-aluminium bond coat and 450 micron of partially stabilised zirconia by the atmospheric plasma spray method [Ravikumar and Senthilkumar (2013). "Reduction of NOx Emission on NiCrAl-Titanium Oxide Coated Direct Injection Diesel Engine Fuelled with Radish (*Raphanus sativus*) Biodiesel." *Journal of Renewable and Sustainable Energy* 5 (6): 063121]. Further, by using radish biodiesel and its blends, the emission and performance characteristics are checked and a suitable blend is selected.

ARTICLE HISTORY
Received 22 May 2018
Accepted 14 June 2018

KEYWORDS
Biodiesel; PSZ; radish biodiesel; emission and performance

1. Introduction

Specialists on inward burning motors have constantly focussed efforts towards motor execution upgrade and emanation control. Diesel motors which are utilised in different segments like transportation, railroads and agribusiness have high work proficiency, sturdiness and unwavering quality of use. In the coming decades, the eco-accommodating and fundamental biofuels will fill in as a substitute for traditional oil fuel which will be in tremendous shortage (Ravikumar and Senthilkumar 2013). Biodiesel is superior to any other substitute of diesel in view of some of its physical properties like sulphur content, streak point, aerometric substance and biodegradability. However, high thickness and low predictability of the vegetable oils causes poor atomisation, inadequate ignition and fouling because of their carbon intensity; such shortcomings are mitigated by preparing biodiesel from vegetable oil utilising the transesterification process (Vinoth Kanna, Vasudevan, and Subramani 2018).

Indeed, even in diesel motors over 60% of warmth vitality is squandered through fumes, gas and coolants. Warm effectiveness could be expanded by diminishing warmth dismissal to the coolant. In this exertion, the ignition chamber dividers are protected by earthenware coatings. The ideal covering thickness for better warm efficiency will be the scope of 0.25–0.5 µm. Testing was done on a supercharged DI diesel motor with PSZ covering thickness of 0.5–1 µm; in their investigation protecting the cylinder crown with a thinly (0.5 µm) covered engine gives better motor execution and lessened emanations. Biodiesel can be utilised as a more effective fuel in the low warmth dismissal motors, in view of the high temperature of the warm obstruction covered burning chamber. Corn oil biodiesel was used as a fuel in a covered motor, and it was found that the decline in CO, NO_x and SFC alongside an expansion in fume and gas temperature was in contrasted with standard motor. The performance parameter improvement of a turbocharged diesel motor covered with yttria-stabilised zirconia (YSZ) utilising sunflower oil methyl ester was explored. The writing survey delineates that much work has not been centred around radish oil as a biodiesel.

The main focus of the present investigation is to produce biodiesel from radish oil as a fuel; also to evaluate the performance and emission characteristics of radish biodiesel in a blendwith diesel (B25) in a standard and coated single-cylinder diesel engine and to compare the result with diesel (Ravikumar and Senthilkumar 2013).

As oil costs have risen quickly in the previous seven years, options for oil-based fills have been looked into broadly. In diesel fuel substitutes, it has been observed that vegetable oil methyl esters (biodiesel) is an appropriate fuel substitute for diesel. The real harvest utilised for biodiesel creation in the United States is soybean. Different harvests utilised are, but not restricted to, shelled nut, sunflower and canola. Barring canola, every one of these yields is a warm season edit initially developed for its utilisation as a sustenance trim. This raises an issue if conventional oilseed crops are to be utilised for biodiesel generation; for instance, developing oilseed crops for fuel utilisation in the warm season, Georgia's fundamental income-developing season, will contend with Georgia's traditional cash crops (Puhan et al. 2005).

CONTACT I. Vinoth kanna vinothkanna.research@gmail.com

On the off chance that an oilseed harvest could be developed in the cool season, it would not contend with customary monetary yields, and homestead pay could be kept up without bargaining fuel creation on the ranch. This undertaking has gone for the assessment of cool season oilseed crops for potential biodiesel creation in Georgia. Fuel quality needs to be investigated and fuel execution tests have led to set up crops for additionally inquiry on edit rotation and generation; this proposition shows another harvest for biodiesel creation in Georgia, which has not yet been assessed for quality and execution as a fuel. This harvest would likewise give extra economic and agronomic advantages.

1.1. Radish seeds

The seeds of the *Raphanus sativus* species can be pressed to extract seed oil. Wild radish seeds contain up to 48% oil content, and while not suitable for human consumption, the oil is a potential source of biofuel. The oilseed radish grows well in cool climates.

A comprehensive model has been developed for diesel engines and coated engines and the experimental results have been compared. The performance was compared to that of an uncoated diesel engine and it was found that there is a decrease in CO, NO_x and SFC along with an increase of 11.3% in exhaust gas temperature (EGT) for all biodiesel blends in a coated engine. The performance parameter enhancement of a turbocharged diesel engine coated with YSZ (Y2O3ZrO2) and NiCrAl using sunflower oil methyl ester was found by C. Hasimoglu et al. (Figure 1).

Obviously, most of the analysts have been concentrating on transesterification forms of various sorts of vegetable oils (Jatropha, Cottonseed, Sunflower, Pongamia, Canola, Madhuca Indica, corn and so on) for production of biodiesel and have tried utilising uncoated and covered diesel motors; a couple of specialists utilised vegetable oils as a sole fuel for a diesel motor (Ravikumar and Senthilkumar 2013). None utilised radish seed oil as a fuel for partially stabilised zirconia (PSZ) as a covering material for the diesel motor. The primary reason for this work is to create biodiesel from radish seed oil by the transesterification process as a fuel, and then to use it in blends with diesel (B25, B50, B75, B100) in an uncoated and mostly settled zirconia (PSZ)-covered single-chamber diesel motor, to contrast execution and fume outflows with those of diesel fuel (Vinoth Kanna 2018). This examination is to to endeavour to keep the earth poison-free and, furthermore, to decrease fuel cost by expanding radish development and use with our venture (Hazar and Ozturk 2010).

Figure 1. Radish seeds.

2. Methodology

2.1. Seed collection

The seeds were collected from co-operative societies and Agricultural University, Coimbatore, India.

2.2. Drying seeds

The seeds are well dried and de-moisturised naturally under sunlight (Figure 2).

2.3. Crushing

The dried seeds were crushed using a standard grinding machine (Figure 3).

2.4. Oil extraction

- The oil was extracted from the crushed radish seeds (Figure 4).
- Extraction of oil from the radish seeds with the help of a mechanical crusher.

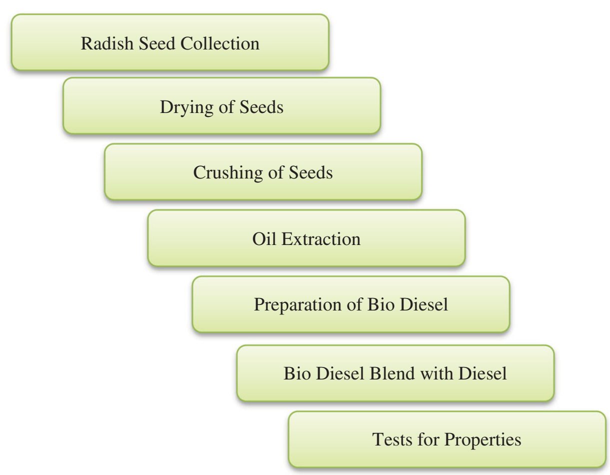

Figure 2. Flowchart.

Figure 3. Crushing of seeds.

Figure 4. Oil extraction.

2.5. Preparation of biodiesel

Using the transesterification process, biodiesel was prepared from the raw oil from the radish seeds.

2.6. Biodiesel blends with diesel

The prepared biodiesel was blended with diesel to produce the following samples.

(1) Raw oil.
(2) B25 with 25% biodiesel and 75% diesel.
(3) B50 with 50% biodiesel and 50% diesel.
(4) B75 with 75% biodiesel and 25% diesel.
(5) B100 with 100% biodiesel and 0% diesel.
(6) Pure diesel (Figure 5).

Figure 5. Biodiesel blends with diesel.

2.7. Test for properties

Properties of radish seed oil methyl ester and its diesel blends have been evaluated using standard tests; the thermo-physical properties of radish oil methyl ester and its mix with unadulterated diesel have been assessed. Table 1 reports the estimations of unadulterated diesel (B0) and a mix of 25% radish seed biodiesel with unadulterated diesel by volume (B25) (Ravikumar and Senthilkumar 2013). Table 1, presents particularly gravity, corrosiveness, kinematic consistency, streak point, fire point and cloud point increments as the methyl ester content in the biodiesel–diesel blends is increased (Karthikeyan and Srithar 2011).

Particularly, the critical increment in the fire point demonstrates that the unpredictability of the blend having increased biodiesel substance will diminish. It is additionally observed that the blaze point and fire point of the biodiesel mix increase in different volumetric extents. In this manner, the mixes of fuel are not difficult to store and are safe for transportation in contrast with B0 (unadulterated diesel) (Vinoth Kanna, Devaraj, and Subramani, 2018). The gross calorific esteem diminishes as the biodiesel in the blend increments. This is because of the oxygen content in the fuel and it requires more fuel to be singed for a given warmth discharge.

2.8. Experimental procedure

Experiments have been conducted on a four stroke, Kirloskar, TV 1 direct-injection diesel engine, which develops a power output of 5.2 kW at 1500 rpm, connected with water-cooled eddy current dynamometer.

Table 2. Specification details of the diesel engine (Ravikumar and Senthilkumar, 2013).

Name of the description	Details/value
Make	Kirloskar TV – I
Type	Vertical single-cylinder, DI diesel engine
Bore x Stroke	87.5 mm × 110 mm
Compression ratio	17.5:1
Speed	1500 rpm
Rated brake power	5.2 kW
Cooling system	Water-cooled
Nozzle-opening pressure	220 bar (rated)
Static injection timing	23° bTDC (rated) at full load
Coating material	PSZ
Thickness	450 microns

Table 1. Properties of biodiesel blends (Basha, Gopal, and Jayaraj 2009).

Sl. no.	Name of the properties	ASTM code	B0	B25	B50	B75	B100
1	Kinematic viscosity at 40°C in cSt	D2217	2.6	3.42	5.70	6.60	51.9
2	Gross calorific value in kJ/kg	D4809	45,600	44,000	43,768	42,938	41,987
3	Flash point in °C	–	65	76	96	117	211
4	Fire point in °C	–	70	81	101	122	223
5	Cloud point in °C	–	−15	4	8	11	13
6	Specific gravity	D445	0.82	0.8416	0.854	0.8702	0.9167
7	Acidity	–	0.065	0.066	0.071	0.081	0.47
8	Cetane number	–	46	51.6	51.7	51.8	52.4

The specifications of the engine are presented in Table 2. The standard static injection timing of 23° bTDC and nozzle-opening pressure of 220 bar (Vijaya Kumar and Sundareswaran 2010) are used for the entire experiments at full load condition of the engine. An AVL 444 digital di-gas analyser is used for the measurement of exhaust emission of HC, CO_2 and NO_x. The smoke level is measured using a standard AVL 437 smoke meter (Ravikumar and Senthilkumar 2013).

3. Production of radish biodiesel

From the radish seed, oil is extracted by means of mechanical extraction and biodiesel is produced. It can be produced by the transesterification process. It is a method which is used to produce biodiesel from radish oil using methanol as the reagent and KOH as the catalyst. Twenty per cent of methanol mixed with 1.54% of KOH by volume is prepared as the base solvent. This is mixed thoroughly and added to 1000 ml of raw radish oil at 60°C with a stirring rate of 35 rpm for 15–20 min for separating the residues of the biodiesel. The final solution can be separated from the glycerol by a separating funnel (Ravikumar and Senthilkumar 2013). This final solution may have some soap content which may be removed by bubble washing by adding 50% of water to the final solution, which is derived from the base reaction process. This solution may be heated up to 100°C for removing the water content which is available in the solution. The biodiesel (mixture of alkyl ester) is the end product of the process. After washing of the biodiesel, the excess methanol, if any, is evaporated by heating it to about 70°C (boiling point of the methanol) for a few minutes. This process is called as de-methanolisation (Devaraj et al. 2017)

The raw materials required are plant seeds to extract oils, methanol and sodium hydroxide as the catalyst. There are different methods to make biodiesel. The following are the various methodologies for biodiesel preparation (Ravikumar and Senthilkumar 2013).

- Catalysts.
- Supercritical carbon dioxide.
- Ultrasonic reactor method.
- Pyrolysis.
- Thermal depolymerisation.
- Hydrotreating/hydroprocessing.
- Super critical.
- Transesterification.

3.1. Catalysts

Catalysts are the chemicals used to provoke a reaction in the feedstock, turning it from oil to biodiesel.

Most home brewers and commercial producers use a mixture of lye (sodium hydroxide) or caustic potash (potassium hydroxide), and alcohol (usually methanol, but sometimes ethanol), called Methoxide or Methylate, to be mixed with the heated oil. Different types of modern catalysts are used for biodiesel production.

3.2. Supercritical carbon dioxide

Scientists at the Yale School of Forestry and Environment have discovered a 'one-pot' method for making biodiesel from algae that combines lipid extraction and conversion of that lipid into biodiesel, using supercritical CO_2.

Similar approaches have been proposed for using supercritical methanol and ethanol, but the use of supercritical carbon dioxide requires lower temperatures, making it easier to work with and less energy-intensive.

Another advantage is that the supercritical carbon dioxide, which acts as a solvent for oil, can be tuned to extract only specific components from algae oils, saving time and resources.

3.3. Ultrasonic reactor method

In the ultrasonic reactor method, the ultrasonic waves cause the reaction mixture to produce and collapse bubbles constantly. This cavitation provides simultaneously the mixing and heating required to carry out the transesterification process. Thus, using an ultrasonic reactor for biodiesel production drastically reduces the reaction time, reaction temperatures and energy input.

Hence, the process of transesterification can run inline rather than using the time-consuming batch processing. Industrial scale ultrasonic devices allow for the industrial-scale processing of several thousand barrels per day.

3.4. Pyrolysis

It is not technically considered a biodiesel process, but by burning biomass (dead trees for instance) without oxygen (a process called pyrolysis), it gives a 'bio-oil' which can be blended with diesel.

3.5. Thermal depolymerisation

Thermal depolymerisation is one of the most exciting processes of biodiesel production, in that virtually anything can be used as the feedstock, including plastic bottles, medical waste and tires. The process is similar to pyrolysis, except that steam is somehow part of the process (this is called hydrous pyrolysis). This process is said to mimic the natural geological processes thought to be involved in the production of fossil fuels.

3.6. Hydrotreating/hydroprocessing

Thermal depolymerisation creates 'renewable' diesel and hydrotreating creates 'green' diesel or 'Hydrogenation-Derived Renewable Diesel'. Hydrotreating involves hydrogen, as well as some specialised and expensive catalysts. It is said to be chemically equivalent to petro-diesel and has a lower cloud point than biodiesel, which means it can be used in a broader range of temperatures.

3.7. Super critical

In the supercritical state, the oil and methanol are in a single phase, and reaction occurs spontaneously and rapidly. The process can tolerate water in the feedstock; free fatty acids are converted to methyl esters instead of soap, so a wide variety of feedstock' can be used. Also the catalyst removal step is eliminated. High temperatures and pressures are required, but energy costs of production are similar or less than catalytic production routes.

3.8. Transesterification

Animal and plant fats and oils are made out of triglycerides which are esters containing three free unsaturated fats and the trihydric liquor, glycerol. In the transesterification procedure, the liquor is deprotonated with a base to make it a more grounded nucleophile (Woods and Oda 1982). Ordinarily, ethanol or methanols are utilised. As can be seen, the response has no different contributions than the triglyceride and the liquor. Under typical conditions, this response will go before, either exceedingly gradually or not under any condition, so warmth, and also impetuses (corrosive as well as base) are utilised to speed the response. Note that the corrosive or base is not devoured by the transesterification response (Figure 6).

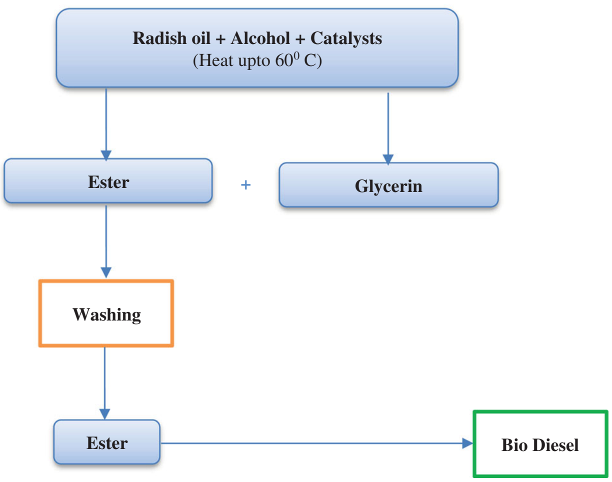

Figure 6. Transesterification process.

Figure 7. Photographic view of the biodiesel reactor (stirring and heating the raw oil, methanol, catalysts at 60°C).

Figure 8. Biodiesel separation.

Figure 7 represents the stirring furnace, which will mix the raw oil, catalyst and the KOH at a temperature of 60°C–70°C. This process is required to reduce the density of the oil (Jun et al. 1997) (Figure 8).

4. Results

4.1. Fuel consumption (kg/h) vs. brake power

Figure 9 shows variation of fuel consumption with respect to brake power for a PSZ-coated engine for diesel, B25, B50, B75 and B100 at 1500 rpm. From the graph, it could be seen that there is an increasing trend observed with respect to increasing brake power. The fuel consumption is decreased from B100 to diesel. In the different blends of biodiesel, B25 gives the least fuel consumption. There is only a minute difference in fuel consumption for diesel and B25. The percentage increase in fuel consumption for B25 compared to diesel for low brake power is 5.5% and at the full load it is 5.80%. The graph below explains about the fuel consumption with respect to brake power (Cortes et al. 2005).

4.2. Specific fuel consumption (kg/kW-h) vs. brake power

Figure 10 shows variation of specific fuel consumption with respect to brake power for the PSZ-coated engine for diesel, B25, B50, B75 and B100 at 1500 rpm. From the graph, it could be seen that there is a decreasing trend observed with respect to increasing brake power. The largest SFC is for B100 and the least SFC for diesel fuel. The percentage increase in specific fuel consumption at different brake power varies from 9.2% to 12.5%. When B25 is used as a fuel in a coated engine, the percentage increase in SFC compared to diesel is only 5.67%. SFC in B25 operation is higher when compared to that of diesel for a coated engine; this is due to the lower calorific value and higher viscosity of biodiesel (Kurchatkin, Gorshkalev, and Blagin 2017)

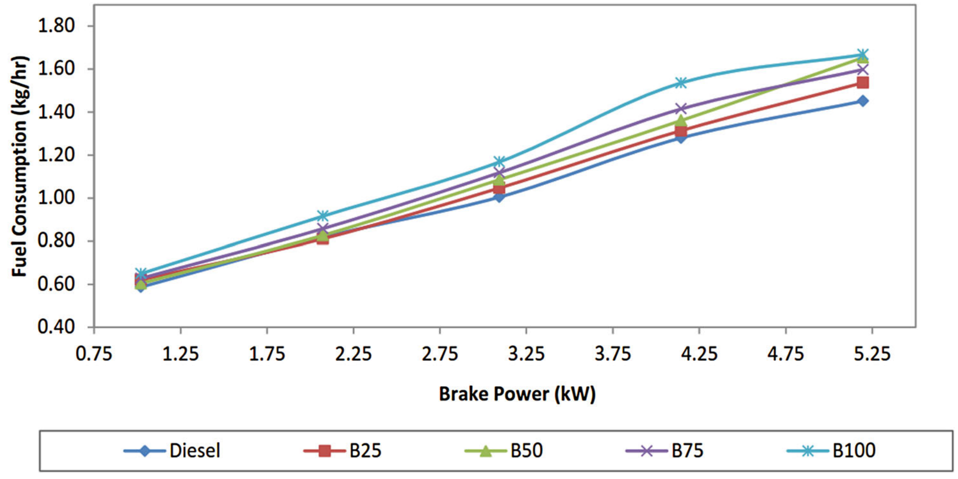

Figure 9. Fuel consumption (kg/h) vs. brake power.

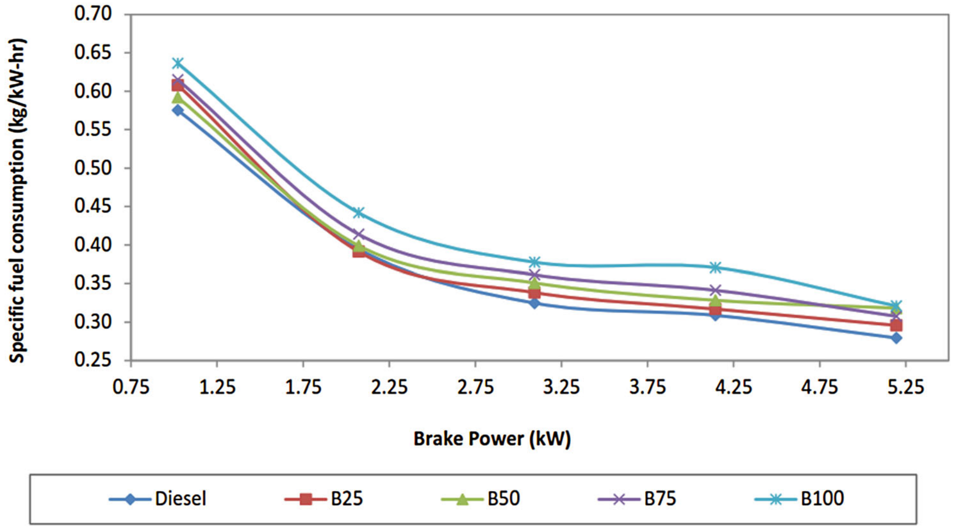

Figure 10. Specific fuel consumption (kg/kW-h) vs. brake power.

4.3. Brake thermal efficiency (%) vs. brake power

Figure 11 shows variation of brake thermal efficiency (BTE) with respect to different brake power for a PSZ-coated engine for diesel, B25, B50, B75 and B100 at 1500 rpm. From the graph, it could be seen that there is an increasing trend observed with respect to increasing brake power. The coated engine with B25 gives better BTE when compared with other blends. The percentage increase in BTE for B25 compared to diesel at low brake power is 3% and at full load is 2.95%. The thermal resistance on the wall will not allow the heat energy to the coolant. This could be the reason for increase in BTE at higher load. Similar findings have been observed by other researchers (Yerrennagoudaru and Manjunatha 2017).

4.4. EGT (°C) vs. brake power

Figure 12 shows the variation of EGT with respect to brake power for a PSZ-coated engine for diesel, B25, B50, B75 and B100 at 1500 rpm. From the graph, it could be seen that there is an increasing trend observed with respect to increasing brake power. EGT is the temperature of the exhaust gases as they leave the cylinders of a reciprocating engine. The greater or excessive EGT may cause melting of the cylinder material. The graph below represents the EGT and the brake power. At higher brake power the EGT is increased, with diesel and B25 having almost the same EGT, which is greater as compared to that of B100. B100 has the least EGT. The percentage decrease in the difference of EGT for B25 compared to diesel at high brake power is 0.95%.

4.5. Smoke density (HSU) vs. brake power

Figure 13 shows the variation of smoke density with respect to brake power for a PSZ-coated engine at different brake power for diesel, B25, B50, B75 and B100 at 1500 rpm. From the graph, it could be seen that there is an increasing trend observed with respect to increasing brake power. A higher smoke density value of 51 HSU at full load was obtained for B25. B100 has the greatest smoke density among the blends. This can be attributed to poor mixture formation due to high viscosity, short ignition delay and poor volatility of B25 (Yerrennagoudaru and Manjunatha 2017). Diesel has the highest smoke density at high load. Low heat rejection engines would produce less smoke and particulates than standard engines for reasons such as higher-temperature gases and higher temperature combustion chamber wall. Investigation by A.C. Alkidas ['On the performance and emission of an

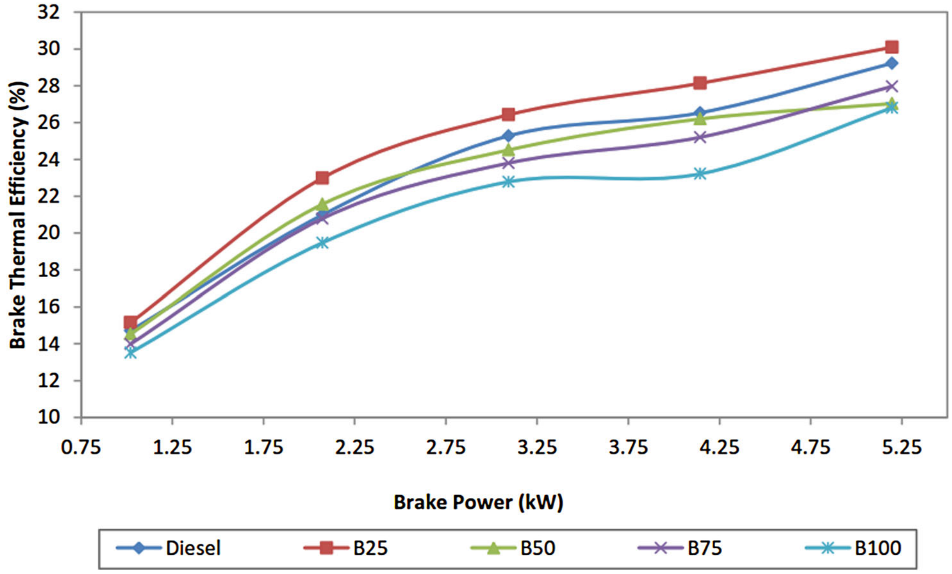

Figure 11. BTE (%) vs. brake power.

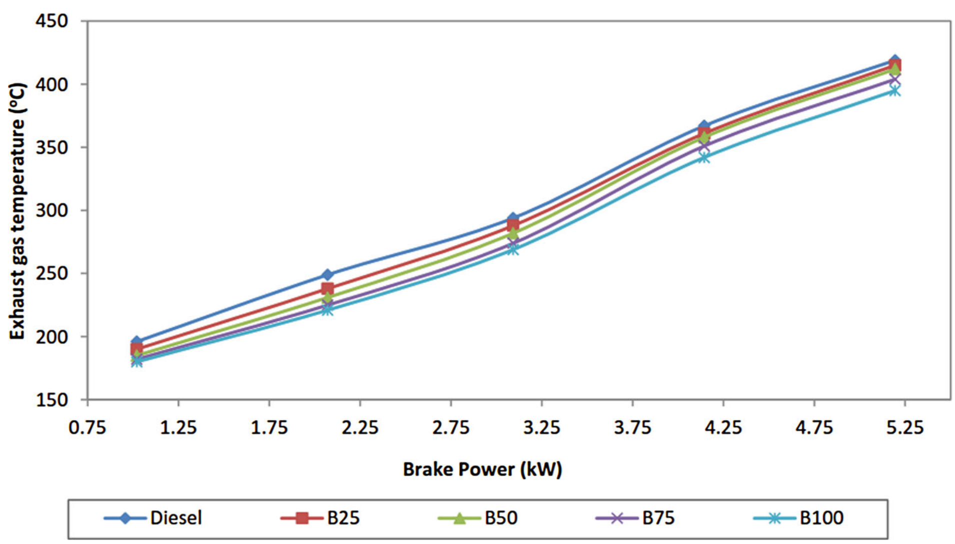

Figure 12. EGT (°C) vs. brake power.

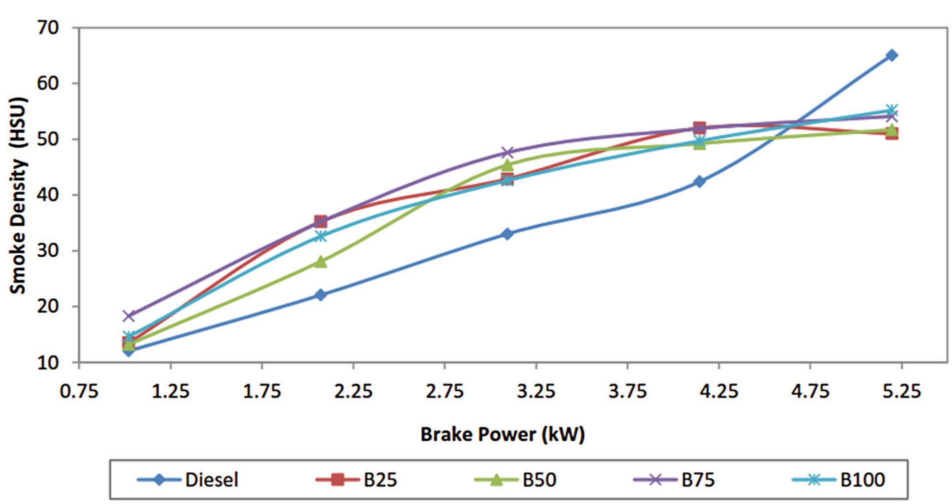

Figure 13. Smoke density (HSU) vs. brake power.

uncooled heavy duty single cylinder diesel engine'] has shown a reduced level of smoke from the LHR engine.

4.6. Oxides of nitrogen (ppm) vs. brake power

Figure 14 shows variation of oxides of nitrogen with respect to brake power for a PSZ-coated engine at different brake power for B25, B50, B75, B100 and pure diesel at 1500 rpm. From the graph, it could be seen that there is an increasing trend observed with respect to increasing brake power. NO_x, coming mostly from the nitrogen present in air coming into the engine, is generated due to high combustion temperature. NO_x emissions for biodiesel operation is less compared to diesel at variations of brake power for the coated engine.

From the figure it is observed that NO_x emission increases with increase in brake power; NO_x emissions are sensitive to oxygen content, adiabatic flame temperature and spray characteristics. It is well known that sulphur, aromatics and nitrogen content of vegetable-based fuels are very small. The spray properties depend on droplet size, droplet momentum and degree of mixing with air and penetration rate, evaporation rate and radiant heat transfer rate. The change in any of those properties may change the NO_x production. From these results for B25, NO_x emission is lower than for diesel at full load condition. B100 has the least NO_x emission. The percentage decrease in NO_x for B25 compared to diesel at full load is 10.88%. At a certain brake power of 3 kW there is an increase in NO_x for B25 compared to diesel of about 5.76%.

4.7. Carbon monoxide (% by volume) vs. brake power

Figure 15 shows variation of carbon monoxide with respect to brake power for a PSZ-coated engine at different brake power for B25, B50, B75, B100 and pure diesel at 1500 rpm. From the graph, it could be seen that there is constant CO emission for all blends at a certain low brake power.

Carbon monoxide emission depends on many parameters such as the air/fuel ratio and the engine temperature. CO is

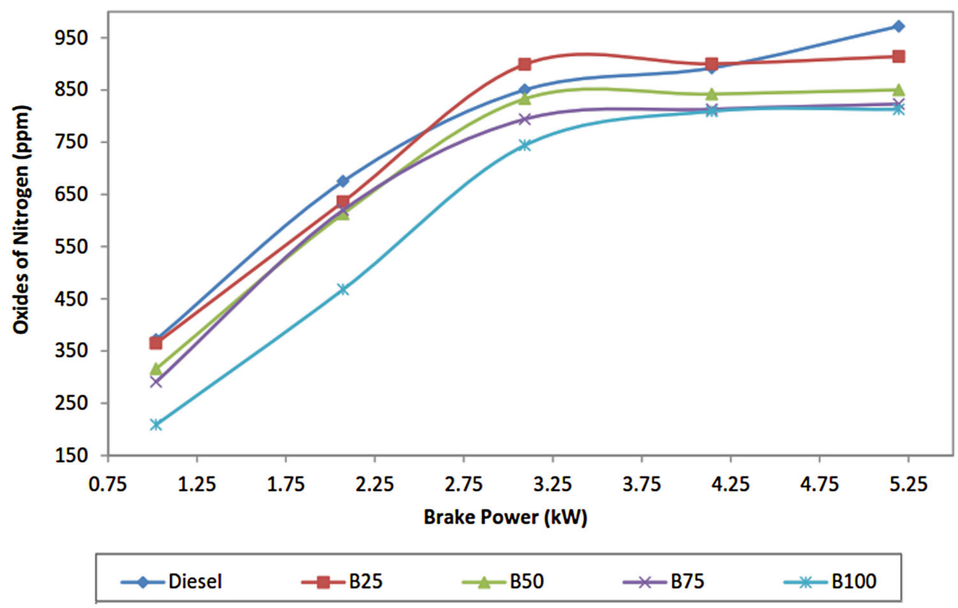

Figure 14. Oxides of nitrogen (ppm) vs. brake power.

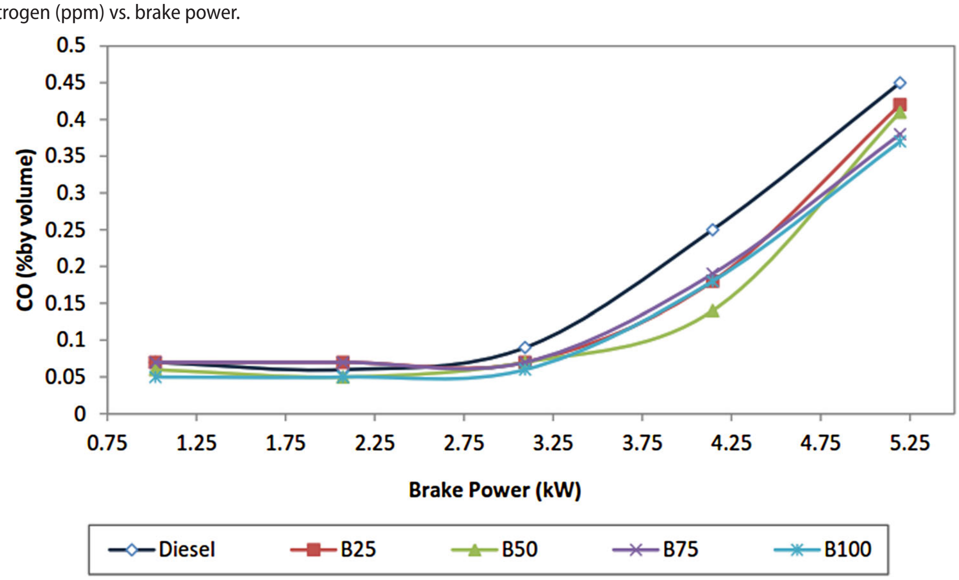

Figure 15. Carbon monoxide (% by volume) vs. brake power.

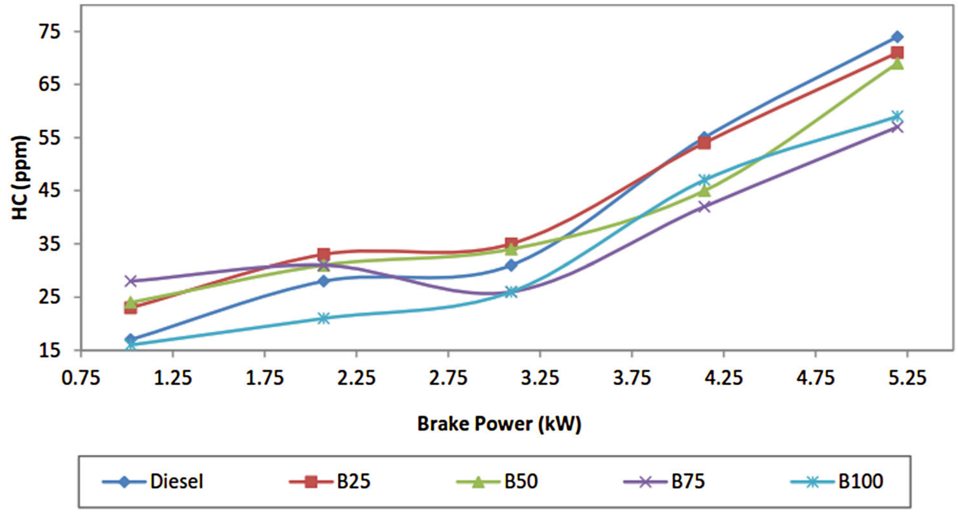

Figure 16. Hydrocarbon (ppm) vs. brake power.

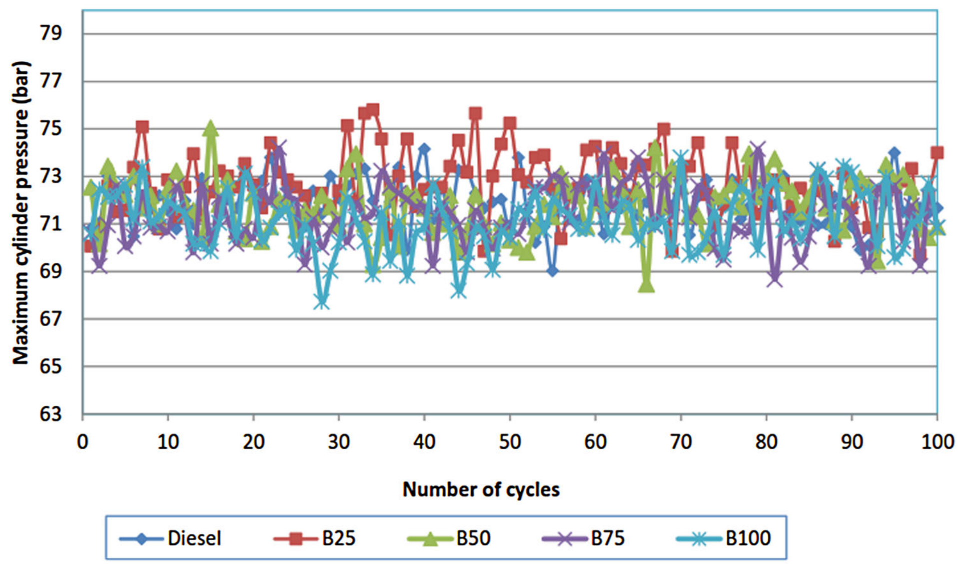

Figure 17. Combustion graph for maximum cylinder pressure vs. number of cycles.

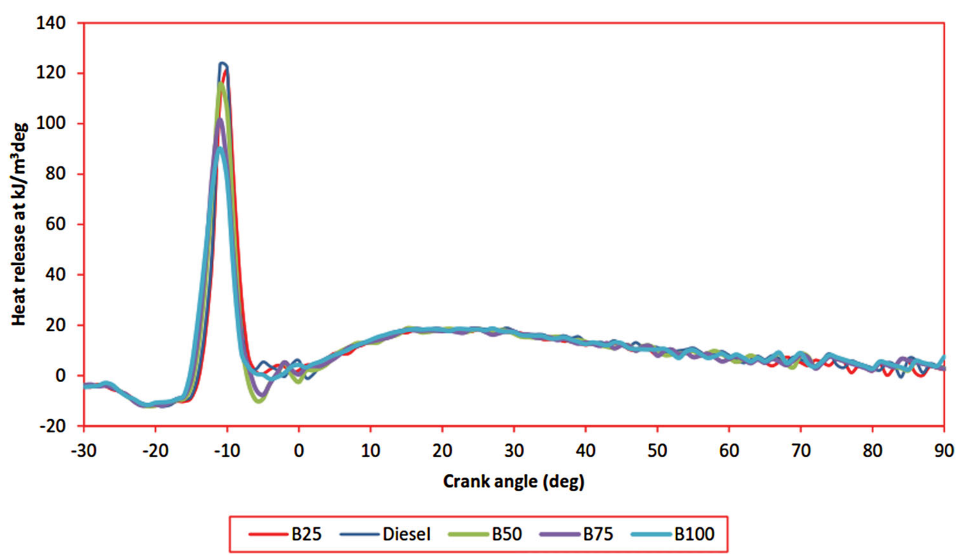

Figure 18. Heat release at 100% of load with various blends of fuel.

formed by the incomplete combustion of fuel. Compared to diesel, biodiesel emits lower CO emission in the coated engine. This may be due to the fact that the oxygen amount in the biodiesel is higher than that of diesel (Ravikumar and Senthilkumar 2013). The coated engine gave a decreasing trend in CO emission for all test fuels at different brake load. Diesel shows the largest CO emission, and B100 shows the lowest CO emission due to increase in oxygen content. The percentage decrease in carbon monoxide of the coated engine for B25 compared to diesel is 9.7% for the full load condition.

4.8. Hydrocarbon (ppm) vs. brake power

Figure 16 shows variation of hydrocarbons with respect to different brake power for the PSZ-coated engine for diesel, B25, B50, B75, B100 at 1500 rpm. From the graph, it could be seen that there is an increasing trend observed with respect to increasing brake power.

The rate of increment in hydrocarbons of the covered motor for B25 contrasted with that for diesel is 2.6%, and for the full load condition, the decrease in rate is 4.5%. From these discoveries, it could be seen that the B100 gives a low measure of hydrocarbons. This might be because of the higher cetane number of B100. This could be seen from the properties table. A regular motor gives higher measure of hydrocarbons when contrasted with the covered motor. This might be, because of higher temperatures, the motor will have an adequate measure of oxygen, which blends with hydrocarbon emanations. Ultimately, HC will part into H and C, which blends with O_2, accordingly lessening HC discharges. Comparative discoveries have been found by different scientists (Ravikumar and Senthilkumar 2013).

4.9. Combustion graph for maximum cylinder pressure vs. number of cycles

Figure 17 shows the variation of the maximum cylinder pressure with respect to the number of cycles for diesel, B25, B50, B75 and B100 at 1500 rpm. From the graph, it could be seen that B25 gives the maximum cylinder pressure of 75.813(bar) at a crank angle of 35. The variation in different blends is shown in the graph.

4.10. Heat release at 100% of load with various blends of fuel

Figure 18 shows the variation of heat release with respect to the crank angle for diesel, B25, B50, B75 and B100 at 1500 rpm.

From the graph, it could be seen that diesel gives the maximum heat release of 123 kJ/m^3 at a crank angle of −100. The B25 gives the maximum heat release of 120 kJ/m^3 at a crank angle of −110. The variation in different blends is shown in the graph (Ravikumar and Senthilkumar 2013).

5. Conclusion

This study focuses on the combined effects of the PSZ-coated direct-injection diesel engine using radish biodiesel. In this experimental study, the piston crown surface, valves and cylinder head of a diesel engine were coated with ceramic materials of PSZ by the atmospheric plasma spray coating method. From the performance characteristics it is observed that diesel fuel provides good combustion characteristics and the biodiesel blends such as B100 and B75 give good emission characteristics.

By using the B25 blend along with a thermal barrier coating, the engine efficiency, specific fuel consumption and emissions of CO, smoke density, HC and NO_x were reduced. From the experimental results, it is inferred that B25 in the PSZ-coated mode has better performance and emission characteristics with using a single-cylinder direct-injection diesel engine.

Disclosure statement

No potential conflict of interest was reported by the authors.

ORCID

I. Vinoth kanna http://orcid.org/0000-0001-8194-8781

References

Basha, Syed Amear, K. Raja Gopal, and S. Jayaraj. 2009. “A Review on Biodiesel Production, Combustion, Emissions and Performance.” *Renewable and Sustainable Energy* 13: 1628–1634.

Cortes, D. A., A. A. Nogiwa, J. M. Almanza, and S. Ortega. 2005. “Biomimetic Apatite Coating on Mg-PSZ/Al2O3 Composites. Effect of the Immersion Method.” *Materials Letters* 59 (11): 1352–1355.

Devaraj, A., I. Vinoth kanna, K. Manikandan, and Jishuchandran 2017. “Impact of Engine Emissions From HCCI Engine, An Overview.” *International Journal of Mechanical and Production Engineering Research and Development* 7 (6): 501–506.

Hazar, Hanbey, and Ugur Ozturk. 2010. “The Effect of Al_2O_3- TiO_2 Coating in a Diesel Engine on Performance and Emission of Corn oil Methyl Ester.” *Renewable Energy* 35: 2211–2216.

Jun, L., D. Changsong, W. Dianlong, and H. Xinguo. 1997. “Electroforming of Nickel and Partially Stabilized Zirconia (Ni + PSZ) Gradient Coating.” *Surface and Coatings Technology* 91 (1–2): 131–135.

Karthikeyan, B., and K. Srithar. 2011. “Performance Characteristics of a Glow Plug Assisted Low Heat Rejection Diesel Engine Using Ethanol.” *Applied Energy* 88: 323–329.

Kurchatkin, I. V., A. A. Gorshkalev, and E. V. Blagin. 2017. “Methods of the Working Processes Modelling of an Internal Combustion Engine by an ANSYS IC Engine Module.” *Journal of Physics: Conference Series* 803: 012085.

Puhan, S., N. Vedaraman, V. Boppana, B. Ram, G. Sankaranarayanan, and K. Jeychandran. 2005. “Mahua Oil (Madhuca Indica Seed Oil) Methyl Ester as Bio-Diesel Preparation and Emission Characteristics.” *Biomass and Bioenergy* 28: 87–93.

Ravikumar, V., and D. Senthilkumar. 2013. “Reduction of NOx Emission on NiCrAl-Titanium Oxide Coated Direct Injection Diesel Engine Fuelled with Radish (*Raphanus sativus*) Biodiesel.” *Journal of Renewable and Sustainable Energy* 5 (6): 063121.

Vijaya Kumar, K. R., and V. Sundareswaran. 2010. “Performance, Combustion and Emission Characteristics of PZT Loaded Cyanate Modified Epoxy Coated Combustion Chamber in Diesel Engine.” *International Journal of Engineering Science and Technology* 2 (7): 2876–2885.

Vinoth Kanna, I. 2018. “Solar Research – A Review and Recommendations for the Most Important Supplier of Energy for the Earth with Solar Systems.” *International Journal of Ambient Energy*, 1–11.

Vinoth Kanna, I., A. Devaraj, and K. Subramani. 2018. “Bio Diesel Production by Using Jatropha: the Fuel for Future.” *International Journal of Ambient Energy*, 1–7.

Vinoth Kanna, I., A. Vasudevan, and K. Subramani. 2018. “Internal Combustion Engine Efficiency Enhancer by Using Hydrogen.” *International Journal of Ambient Energy*, 1–4.

Woods, M. E., and I. Oda. 1982. “PSZ Ceramics for Adiabatic Engine Components.” SAE Technical Paper Series, February.

Yerrennagoudaru, H., and K. Manjunatha. 2017. “Combustion Analysis of Modified Inverted ‘M’ Type Piston for Diesel Engine with Platinum Coating and Without Coating by Using CFD.” *Materials Today: Proceedings* 4 (2): 2333–2340.