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Performance and emission analysis of tamanu oil–diesel blends in CI engine

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ABSTRACT
Bio-energises are ended up being great substitutes for the current oil powers. Biodiesel can be separated from vegetable oils and waste fats. Trans-esterification is essentially portrayed as the concoction breaking of oil utilising liquor to frame liquor esters and glycerol. This method includes a three-stage process, corrosive, basic esterification and washing in view of fast fourier analysis content. At that point Tamanu oil methyl ester has been mixed with diesel fuel in different extents to check the execution and discharge attributes of a solitary chamber four-stroke steady speed diesel motor. Diesel and Tamanu oil methyl ester (B10, B20, B30, B40) fuel mixes are utilised for directing the execution and outflow as far as 25% load increases from no heap to full load. Among the mixes B20 and B30 have demonstrated a superior execution. All mixes indicate diminishment in HC, NO_x with an increment in stack. This is because of higher cetane number, calorific esteem and oxygen content. Exploratory examinations demonstrate that mixing of Tamanu oil methyl esters up to 30% as diesel fuel can be utilised with no equipment adjustment in diesel motor and it decreases the unsafe outflows.

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KEYWORDS
Biodiesel; diesel engine; emission; tamanu oil; trans-esterification

1. Introduction

Exhausting mineral oil saves and expanding the expense of the oil-based goods request an escalated look for new elective powers. Of late, there has been a significant push to create and acquaint elective sustainable powers with supplant traditional oil-based fills (Babu and Mamilla 2012). Our economy and lifestyle rely on the use of fossil resources for the transportation fuels and materials; however, there has been rising concern over their cost, sustained availability and impact on global warming and pollution (Devaraj, Vinoth Kanna, and Manikandan 2017). This has led to a search for technologies that generate fuels and materials from renewable carbon sources, such as plant biomass (Parthasarathy et al. 2013). Depending on the component of the biomass used as feedstock and the technology employed to transform components into the desired product, at least three general platforms have been envisioned: the sugar platforms, sugar and oil platforms, Oil with bio-ethanol and biodiesel. The sugar and oil platforms are the best established today (Ayyasamy, Balamurugan, and Duraisamy 2018), with bioethanol and biodiesel being the examples of their commercial products, respectively (Paturu and Vinoth Kanna 2018). Bioethanol is produced through microbial fermentation of sugar derived from corn, sugarcane or sugar beet (Vinoth Kanna and Pinky 2018). Biodiesel is produced by the trans-esterification of vegetable oils with alcohols to produce esters (Devaraj, Yuvarajan, and Vinoth Kanna 2018). Given the increasing demand for biofuels (Vinoth Kanna and Paturu 2018), there is an urgent need to investigate new and more efficient alternatives for their production. For example, the conversion of lignocelluloses biomass to ethanol and the use of oil accumulating algae in the production of biodiesel (Duraisamy, Kulendaran, and Ayyasamy 2018), synthesis gas (Nagappan and Vinoth Kanna 2018) and oil (Duraisamy, Kulendaran, and Ayyasamy 2018; Le Coz 2004) are being investigated. These approaches are very promising and will provide abundant nonfood feedstock for the production of biofuels with environmental benefits and large net energy gains. However, an outstanding issue in both current and future biofuel production platforms is an economic viability (Miraculas and Bose 2014).

1.1. *Biodiesel as an alternate substitute for diesel*

Biodiesel alludes to a vegetable oil or creature fat-based diesel fuel comprising long-chain alkyl (methyl, propyl or ethyl) esters. Biodiesel is commonly made by synthetically responding lipids (e.g. vegetable oil and creature fat) with liquor delivering unsaturated fat esters. Biodiesel is intended to be utilised as a part of standard diesel motors and is in this way particular from the vegetable and waste oils used to fuel changed over diesel motors. Biodiesel can be utilised alone or mixed with petrodiesel. Biodiesel can likewise be utilised as a low-carbon contrasting option to warming oil (Vinoth Kanna, Vasudevan, and Subramani 2018). The esters of vegetable oils are prevalently known as biodiesel. It is the way toward responding triglyceride with a liquor in nearness of an impetus to create glycerol and unsaturated fat esters are created from triglyceride. In India, endeavours are being made for utilising non-consumable and under-abused oils for the generation of esters (Barsic and Humke 1981). There have been numerous reports demonstrating that huge emanation diminishments are accomplished with these mixes. A few investigations have demonstrated that diesel and biodiesel mixes diminish smoke obscurity, particulates,

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Table 1. Properties of oils.

Properties	Calorific value (KJ/Kg)
Diesel	44,500
Tamanu oil	41,450

Table 2. Engine specification table.

Engine specification table	
Designation	Single-cylinder, four-stroke, water-cooled, diesel engine, kirloskar
Bore × stroke	87.5 × 110mm
Compression ratio	17.5
Capacity	661cc
Rated power	5.2 kW
Overall size	1.90 × 1.0 × 1.40 m

unconsumed hydrocarbons, carbon dioxide, carbon monoxide and nitrous monoxide outflows (Van Gerpen 2005).

Vegetable oils, as an elective fuel for diesel motor, offer leverage due to its practically identical fuel properties with diesel fuel. The different palatable vegetable oils like tamanu oil, sunflower oil, cotton seed oil and palm oil have been tried effectively in the diesel motor (Vinoth Kanna 2018). In any case, as India still imports enormous amounts of eatable oils, the utilisation of palatable oils for diesel motor fuel is not feasible (Ramaraju and Ashok Kumar 2009). Be that as it may, non-palatable vegetable oil species could be utilised as elective fuel for diesel motor. Vegetable oil has warming qualities practically identical to those of diesel fuel; however; their high consistency and low instability are unfit to consume totally (Sadasivam and Manickam 2004). The substitute method to make utilisation of vegetable oil conceivable in the current diesel motor is to esterify it to create biodiesel. Trans-esterification is a procedure for creating a response between a triglyceride and liquor within the sight of an impetus to deliver glycerol and ester (biodiesel). Trans-esterification makes the consistency come down. Two kinds of oils for the generation of biodiesel from plants are Edible oil and Non-Edible oil (Monyem and Van Gerpen 2001).

2. Extraction of biodiesel methodology

Oil from dried and peeled tamanu seed is extracted by an engine-driven screw press. However, it must be noted that oil extracted by mechanical presses needs further treatment of filtering process and degumming.

2.1. Experimental set-up for biodiesel production

The set-up (Figure 1) used in the acid and alkali esterification consists of two-way round bottom flask to carry out the reaction, a magnetic stirrer with heater for continuous heating and stirring, a water-cooled condenser to restrict the evaporation of methanol during the heating process carried out in the two-way round bottom flask (Xue, Grift, and Hansen 2011). The two-way round bottom flask is partially immersed into the bowl containing water in order to constantly distribute the heat. Outside water supply is given to the condenser to ceaselessly cool the dissipated methanol from oil (Figure 2).

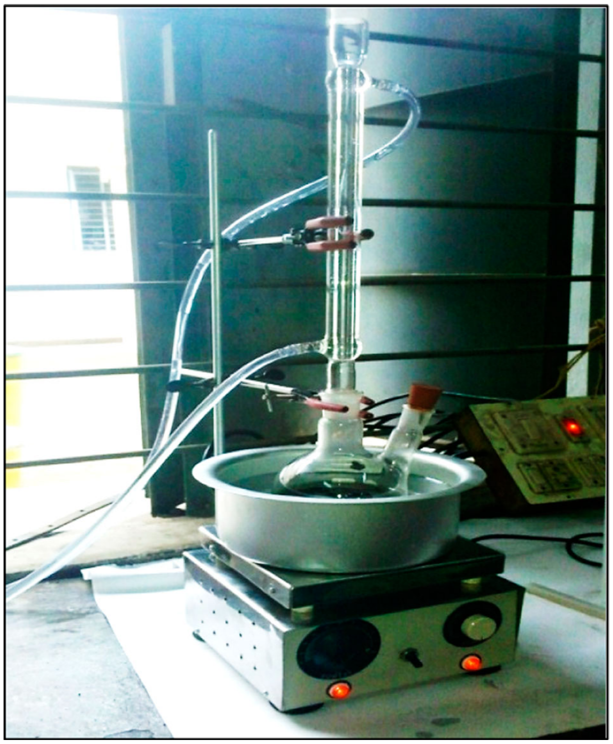

Figure 1. Trans-esterification set-up.

2.2. Trans-esterification

Trans-esterification of a triglyceride commonly comprises a progression of back to back reversible responses. The triglyceride is changed stepwise into a diglyceride, a glyceride finally as a glycerol, with the expulsion of an alkyl in each progression. The free unsaturated fat substance is 19.6% by the Gas Chromatography test. Trans-Esterification can be done in two ways, one-stage strategy and two-stage strategy in view of the fast fourier analysis (FFA) content.

2.3. Two-step method

Since the level of FFA is over 3%, the Trans-esterification process is by the two-stage strategy. The high level of FFA content makes troubles in the basic Trans-esterification process because of the cleanser arrangement. Along these lines, two phases of system are received here (Raj, Kumar, and Kandasamy 2012). High FFA oil was changed over to triglycerides in corrosive esterification process with methanol utilising anhydrous H_2SO_4 (corrosive impetus). The oil is warmed at 50–55°C of every a standard carafe. Methanol in the required amount is taken and the estimated amount of anhydrous H_2SO_4 is broken up in it. The blend is persistently mixed at steady speed keeping the temperature consistent at 60°C for 2 h to maintain a strategic distance from methanol misfortune. The blend in the wake of warming and mixing for the required time is exchanged to an isolating pipe and kept for settling. On settling, the abundance methanol shapes as the best layer and diglyceride stay as the base layer. The best layer is evacuated and diglyceride is gathered. The base layer is utilised for the antacid Trans-esterification (Vinoth Kanna, Devaraj, and Subramani 2018).

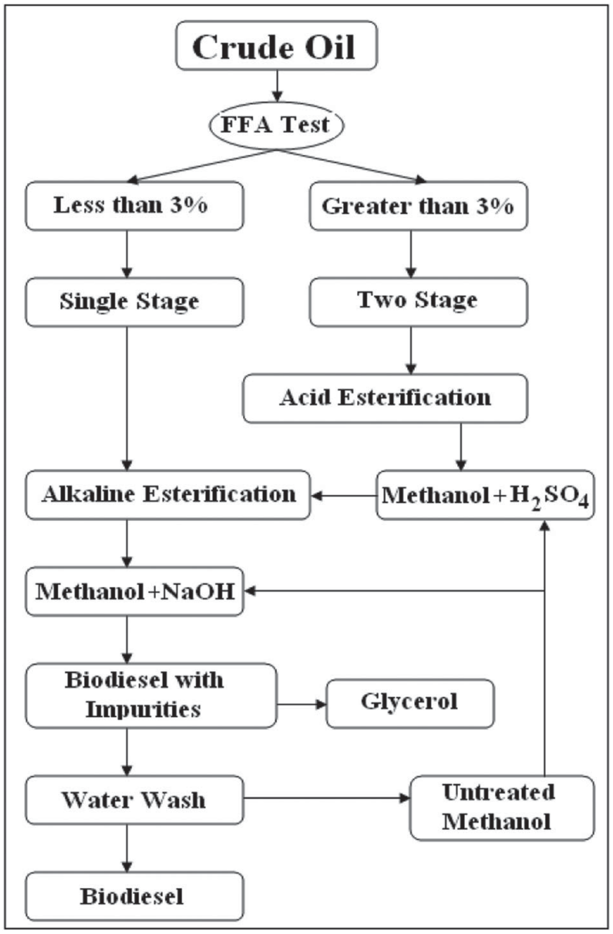

Figure 2. Trans-esterification chart.

At the second level, the isolated oil from the isolating channel needs to experience Trans-esterification. Methoxide (methanol + sodium hydroxide) is included with the above ester and warmed to 60°C. A similar temperature is kept up for 1 h with non-stop blending, and after that, it experiences normal cooling. After the response, the glycerol is isolated from the methyl esters. Glycerol settled in the isolating pipe is expelled and the remaining item is moved to the next stage for water wash.

2.4. Water wash

The upper layer of alkali Trans-esterification product is removed and treated for the water wash to remove the impurities (like traces of glycerol, unused methanol, soap particles, etc.) from the biodiesel (Figure 3).

Yield obtained	
Dried fruit	2.5 Kg
Crude oil obtained	1.25 L
Methanol added	0.8 L
Biodiesel obtained	1 L
Untreated methanol	0.6 L
Glycerol	0.2 L
Yield	80% Approx.

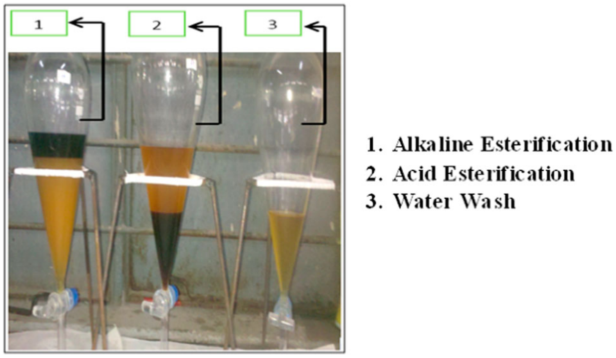

Figure 3. Setup for removing the impurities from biodiesel.

2.5. Properties of tamanu oil blends with diesel

A bomb calorimeter is used to measure the calorific value of various test fuels. The kinematic viscosities of the different blends of tamanu oil and diesel fuels were determined by using a Redwood viscometer at room temperature. Pensky Marten's flash point apparatus was used to determine flash and fire points.

Properties of Diesel and Tamanu oil

Properties	Flash Point (°C)	Fire Point (°C)	Density (kg/m^3)	Kinematic Viscosity (cSt)
Diesel	65	84	0.86	3.06
Tamanu oil	146	160	0.905	4.21
B10	72	96	0.865	3.12
B20	80	104	0.868	3.34
B30	86	118	0.873	3.57
B40	95	130	0.877	3.76

3. Experimental set-up for testing biofuel on engine

Utilising esterified tamanu oil in the pressure start diesel motor at an appraised speed of 1,500 rpm, the execution investigation is completed. In each test, volumetric effectiveness particular fuel utilisation, wind current rate, temperature of motor cooling water and fume gas emanations, for example, carbon monoxide (CO), hydrocarbon (HC), nitrogen oxides (NO_X), carbon dioxide (CO_2) and oxygen (O_2) are estimated with instrumentation given on the motor. At each working condition, the execution attributes, ignition qualities and fumes' emanation levels are performed. The execution parameters were computed from the major relations between these estimations while changing the heap on the motor from 0% to 100% in rough strides of 25%: Chamber, four-stroke diesel, water-cooled, control 5.2 kW at 1500 rpm, stroke 110 mm, bore 87.5 mm, 661 cc and pressure proportion of 17.5. It is coupled with Mechanical loading type. The test rig is provided with Piezo sensor to measure pressure of the engine cylinder online and the same procedure is repeated for other loads. Properties of oils and Engine specifications are shown in Tables 1 and 2 respectively.

3.1. Flue gas analyzer kid

The schematic diagram for the flue gas analyzer is drawn in Figure 4. The Gas analyzer kid comprises a test, hand set remote

Figure 4. Engine set-up.

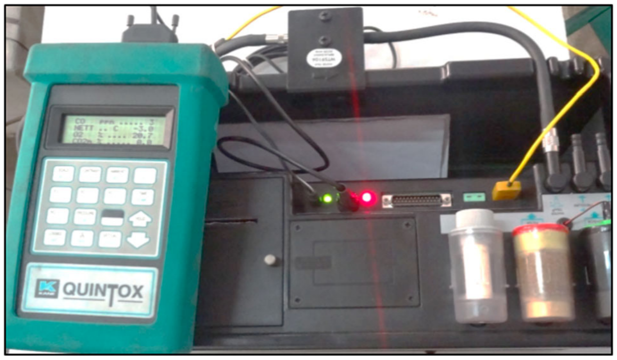

Figure 5. Flue gas analyzer.

association and an analyzer. While running the Diesel Engine, with the assistance of an analyzer kid the emanation level for Biodiesel mixes and Diesel fuel can be estimated (Figure 5).

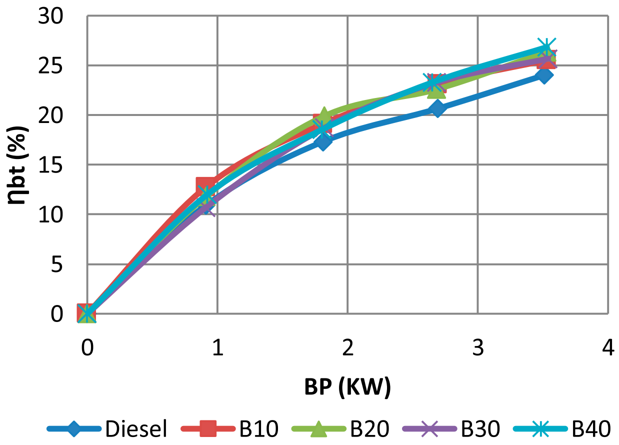

Figure 6. Brake power vs brake thermal efficiency.

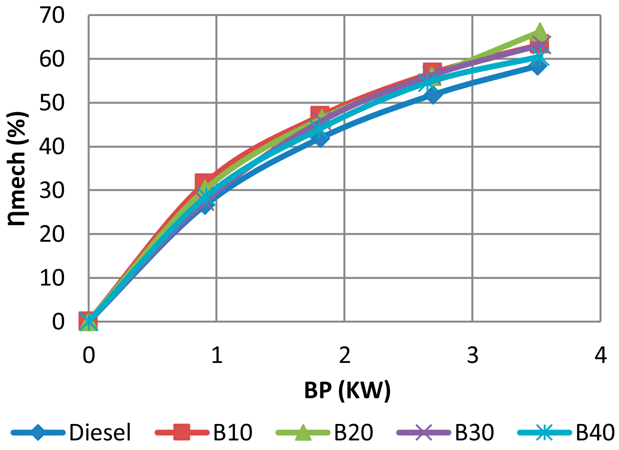

Figure 7. Brake power vs mechanical efficiency.

4. Result and discussion

4.1. Performance characteristic curves

Performance curves have been drawn for various parameters like η_{bt}, η_{mech}, SFC, etc. as mentioned above. For the convenience of easy understanding biodiesel with diesel, Diesel, B10, B20, B30 and B40 have been noted in all charts.

4.1.1. Brake thermal efficiency

Brake Thermal Efficiency (BTF) is characterised as the brake energy of a warmth motor as a component of the warm contribution from the fuel. It is utilised to assess how well a motor changes over the warmth from a fuel to mechanical vitality. It is seen from chart that the BTE of all mixes is continually incremented in view of the heap condition and B40 has higher brake warm effectiveness (Figure 6).

4.1.2. Mechanical efficiency

Mechanical efficiency measures the viability of a machine in changing the vitality and power that is contributed to the gadget into a yield power and development. It is seen in the diagram that B10 has higher productivity at various loads, yet at the full-load condition B20 has a higher effectiveness than the B10. Diesel fuel has smidgen slack in the mechanical effectiveness contrasted with Biodiesel mixes. This demonstrates the biodiesel lubricity has decreased the grating misfortunes (Figure 7).

4.1.3. Specific fuel consumption (SFC)

Particular Fuel Consumption (SFC) is a measure of the fuel productivity of a pole responding motor. It is the rate of fuel utilisation isolated by the power created. From the chart, B30 has a higher fuel utilisation at bring down load; however, as contrasted that of diesel, biodiesel mixes have brought down specific fuel utilisation. Among the mix B10 is most reduced at all heaps which is regularly the ideal for any diesel motor. Subsequently, SFC perspective B10 might be points of interest. This is a direct result of the joined impacts of higher warming quality and the lower fuel stream rate because of high thickness of the mixes. Higher extents of tamanu oil in the mixes expand the consistency which thus expanded the particular fuel utilisation because of poor atomisation of fuel (Figure 8).

4.1.4. Fuel consumption

Fuel consumption has increased in all load condition for diesel fuel. Among all other blends, B10 has the lower fuel consumption rate. Among every single other mix, B10 has the lower fuel utilisation rate. This is because of the quality of oxygen content

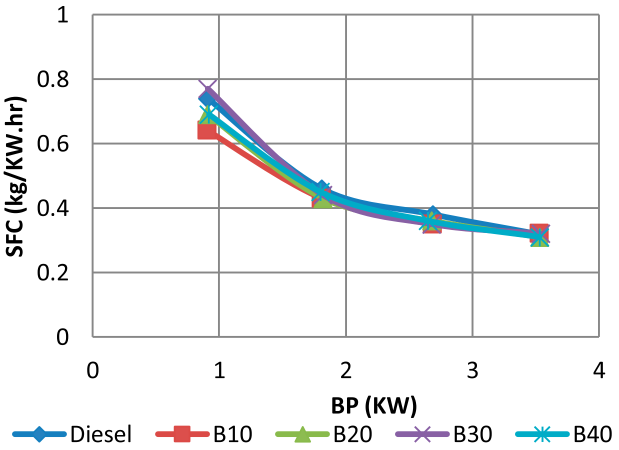

Figure 8. Brake power vs specific fuel consumption.

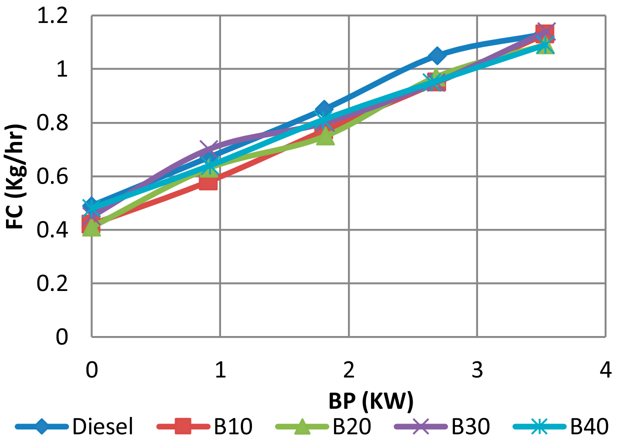

Figure 9. Brake power vs fuel consumption.

and the thickness in biodiesel. In this way, when the fuel mix proportion builds, the consistency of fuel additionally increments at the same time (Figure 9).

4.2. Emission characteristic charts

Emission characteristic charts have been drawn using the values obtained from the emission test. The variety in the volume of discharges, for example, CO, NO_x and HC is shown for the different burdens utilising the outflow trademark bends.

4.2.1. Carbon monoxide emission

Carbon monoxide (CO) emissions of tamanu oil blends in lower percentages B10, B20 are little bit higher than petrol diesel than the higher percentage blends, as plotted in the graph (Figure 10).

Lower CO outflow in the lower tamanu oil mixes is most likely because of higher oxygen accessibility in the fuel. B10, B20 has brought down CO discharges when contrasted with oil diesel at full load. In any case, the outcomes with higher mixes are distinctive with higher CO outflows at higher burdens. Higher consistency, despicable splash design with higher mix rate bringing about inadequate ignition may have expanded the CO emanations.

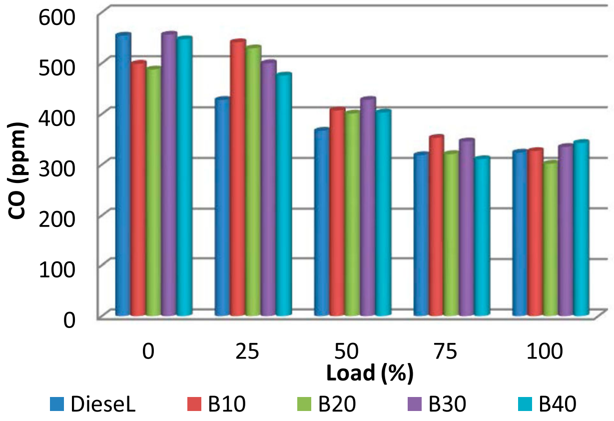

Figure 10. Load vs carbon monoxide.

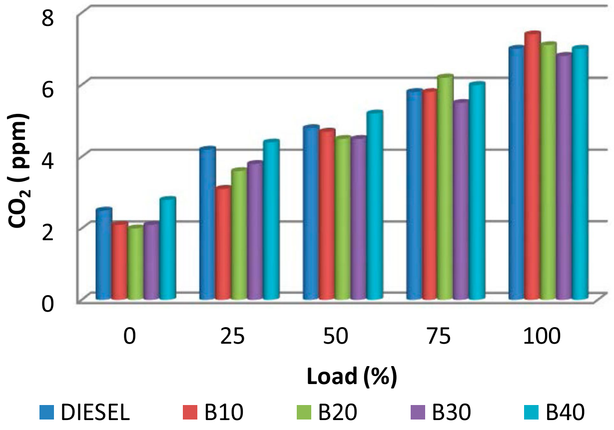

Figure 11. Load vs carbon dioxide.

4.2.2. CO_2 emission

The graph shows the emission levels of CO_2 for various blends and diesel. The test estimation uncovers that the CO_2 discharge for all mixes expect B40 is less when contrasted with diesel at all heaps. The rising pattern of CO_2 outflow with stack is because of the higher fuel passage as the heap increments (Figure 11).

4.2.3. Unburnt hydrocarbons

Diminished unburnt hydrocarbon (UBHC) discharges plainly demonstrate that the burning in the motor takes homogeneously. From the chart it is certain that expanding the mix level of tamanu oil diminishes the UBHC outflows. All mixes have indicated to bring down UBHC emanations after around 75% load. This might be because of higher oxygen content and the higher cetane number. Physical properties of powers, for example, thickness and consistency, impact the hydrocarbon emanations. Among the mixes B30 has brought down UBHC outflows (Figure 12).

4.2.4. NO_x emission

NO_x outflow of different mixes against stack is shown in the chart that the CO_2 emanation for all mixes is less when contrasted with diesel at all heaps. This is presumably because of lower ignition temperature in the motor barrel with expanding burden and mix proportion. It is additionally watched that by expanding the rate

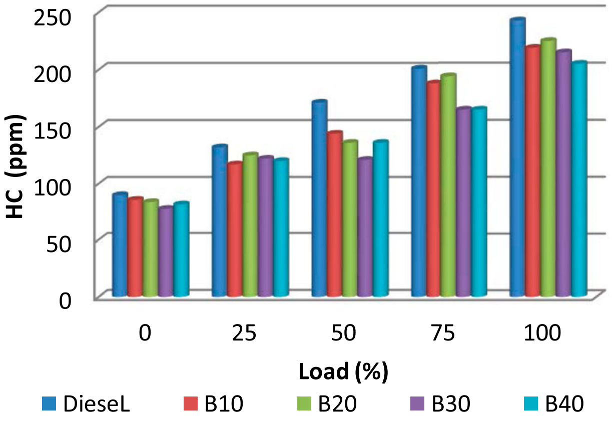

Figure 12. Load vs hydrocarbon.

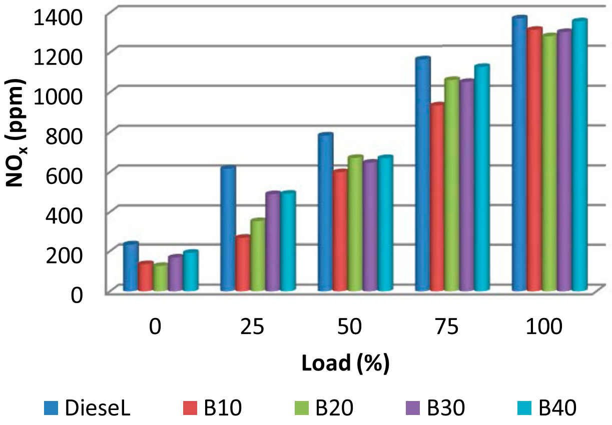

Figure 13. Load vs oxides of nitrogen.

tamanu mix there is a pattern of diminishment in NO_x outflows (Figure 13).

There is a diminishment of NO_x by 10% with tamanu oil mixes when contrasted with the petro-diesel at all heaps. As NO_x is 292 times more intense than carbon dioxide as a Greenhouse gas discharge its decrease carries more significance in the activity of a C.I. Motor. It is viewed that higher rate mixes are invaluable.

4.2.5. Exhaust gas temperature from engine

The chart demonstrates the variety of fumes gas temperature with stack for different mixes and diesel. The outcomes demonstrate that the fumes gas temperature increments with an increment in stack for mixes. At all heaps, diesel and biodiesel are found to have the other most minimal temperature and the temperatures for different mixes demonstrates an upward pattern with the expanding grouping of tamanu oil in the mixes. The biodiesel contains oxygen, which empowers the ignition procedure and henceforth the fumes gas temperatures are higher. Additionally, the motor being water cooled runs more sweltering which brings about higher fumes gas temperatures. However, among the mix B30 has the lower fume gas temperature than the diesel (Figure 14).

5. Conclusion

The following conclusions are drawn from the examination.

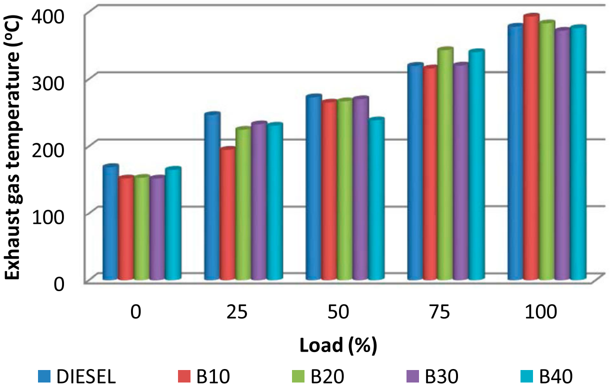

Figure 14. Load vs exhaust gas temperature.

The present investigation built up a two-phase esterification system to deliver biodiesel from tamanu oil. The main stage comprises esterification utilising anhydrous sulphuric corrosive as the impetus. This changes over the FFAs in the oil to methyl esters and along these lines diminishes the FFA substance of the oil. The item from this stage is subjected to trans-esterification in the second stage utilising pottasium hydroxide as impetus bringing about to tamanu biodiesel. The biodiesel has properties in concurrence with the biodiesel gauges and firmly coordinates with the oil diesel

The particular fuel utilisation is somewhat lower than that in diesel for B10, B20; however, nearer to diesel when increments the heap. Mixing of biofuel with diesel up to 30% decreases CO_2 emissions.

The fumes gas temperatures are higher but are almost equivalent to those of diesel, and furthermore they diminish the HC and NO_x emanations with an increment in stack because of the higher oxygen content in all tamanu oil methyl ester mixes.

Mechanical proficiency of the tamanu oil methyl ester increments for a similar power yield. Exploratory examinations demonstrate that mixing of tamanu methyl esters up to 30% with diesel for use in an unmodified diesel motor is practical and it lessens the unsafe emanations.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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