PERFORMANCE, EMISSION CHARACTERISTICS OF CI ENGINES FUELED WITH ANNONA SEED BIODIESEL BLENDS AND 1-PENTANOL AS AN ADDITIVE

by

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Fossil fuel is one of the predominant sources for automobiles are facing depletion across the world. This depletion put up a greater demand for the need of alternative fuel sources for automobiles. As a solution for this issue, many researchers formulated and synthesized biodiesel from the oil extract of plant seeds and bio waste materials. The present work involves the synthesis and extraction of methyl ester from the oils of Annona seed and blended with diesel along with 1-Pentanol as an additive. Three-blend mixture of biodiesel is prepared with methyl ester of 10%, 20%, and 30% of Annona seed oil with 10 ml of 1-Pentanol in it. The formulated biodiesel is evaluated for its performance using the Kirloskar Diesel engine under different loading conditions. The evaluation is carried out in terms of brake thermal efficiency, brake specific fuel consumption, and other parameters along with emission characteristic analysis of CO, NO_x, and CO_2, From the observed results, the biodiesel blend with 30% of Annona seed methyl ester showed better performance. However, the emission analysis over different gases showed biodiesel with 10% of Annona seed methyl ester showed reduced emission.

Key words*: Annona seed, 1-Pentanol, Diesel engine, brake thermal efficiency, brake specific fuel consumption, emission*

Introduction

The population across the world is in increasing trend and people sought to travel to various locations for their needs. Most of the transportation needs are satisfied through automobiles that are operated through the products of fossil fuels. Diesel is one of the common fossil fuels and it is being depleted due to its excessive consumption [1, 2]. The usage of diesel causes an adverse impact on the environment as its increases air pollution and results in ozone depletion. Several organizations established strict regulations and monitoring to control the adverse effect of emissions from diesel [3]. For overcoming the existing problems in diesel usage, the concept of biodiesel was developed and is used in the Diesel engine. The biodiesel can be either used in a pure form directly or blended at a certain proportion with the diesel in CI engine [4]. Most of the developed biodiesels are found to reduce emissions with-

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out impacting the performance of the existing CI engines [5]. The significant aspect of biodiesel is its high cetane number than pure diesel. The higher cetane number of biodiesel results in enhancing the combustion quality of engines with the reduction in ignition time [6, 7]. On the adverse side, the presence of oxygen can decrease the thermal efficiency of biofuels. Simultaneously, biofuels with high viscosity and density can instigate problems in injectors and injection units. The phenomenon of corruption and occlusion can occur during cold working environments [8]. The performance of the CI engine used with biodiesel often depends upon the fuel properties that include density and viscosity of the fuel, flash and cloud point, and heating value [9]. The performance of the Diesel engine is obtained at the optimum level when the blending composition is at a particular range [10]. Trans-esterification method is one of the common approaches employed to formulate biodiesel from vegetable oils or fats and seeds [11]. The biodiesel has to have better oxidation stability for it to be commercially viable source for the engines. Additionally, the amount of NO_x emission has to be minimized due to the strict regulations established for controlling the emission. Several types of research are conducted to increase the efficiency of biodiesel with controlled emission over the past years [12].

Senthil *et al.* [13] developed the biodiesel from the Sapota seed with a leaf extract that acts to be an anti-oxidant additive. The experimental set-up for investigating the performance of the extracted Methyl ester is carried out using the SCFSDE. The emission test is carried out and it was observed that the biodiesel with 20% of Sapota oil showed a decrease in nitrous oxide emission. Senthil *et al.* [14] formulated the biodiesel extracted from the Methyl esters of Annona seed oil along with the p-phenylenediamine added at a proportion of 0.010%-m. The emission analysis was carried out using the SCFSDE which showed that the emission of NO_x was reduced by 42%. Can *et al.* [15] produced the canola biodiesel and evaluated the performance at different loading conditions of the engine at a constant speed. The biodiesel blend is developed at four different proportions of canola ranges about 5-20%. The performance is investigated on performance metrics of BTE and BSFC along with the emission test. The investigation showed that both the BFSC and BTE values increased with a decrease in the emission of CO, smoke, and HC. There is an increase of CO_2 and NO_x emissions is also observed. Kshirsagar *et al.* [16] synthesized the biodiesel from calophylluminophyllum oil. The methyl ester is extracted from the oil and four different blends at a proportion of about 10-25%. The experiment is performed at different loading conditions, injection pressure, and timing. The performance analysis showed that both the BTE and BFSC increases along with the increase in the emission of CO_2 and NO_x. However, the emission of HC, CO, and oxygen decrease. Gharehghani *et al.* [17] formulated the biodiesel from the waste fish oil at various percentages that include 25%, 50%, 75%, and 100%. The experimentation is carried out using the engine at different engine loads with a constant operating speed. The investigation showed that an increase in BTE value is similar to the emission of nitrous oxide and carbon dioxide. The waste fish oil-based biodiesel showed a reduction in the emission of CO and HC.

Khandal *et al.* [18] developed the biodiesel using the Honge oil under the various operations of the engine that includes the variation in EGR, injection timing, and pressure. The experimentation with the aforementioned operating condition is carried out at a constant compression ratio and speed for the engine. The experiment showed that the engine showed increased performance on BTE and enhances the emission of NO_x. However, the emission of HC, smoke, and CO decreases. Dubey and Gupta [19] extracted the methyl esters from Jatropha oil and investigated their performance along with the emission characteristics. The biodiesel is developed with 50%, 70%, and 90% with the Jatropha oil under the operating condition of varying engine load at a constant speed. The BTE performance of the engine decreases with the developed biodiesel. The emission test showed that there is an increase in CO_2 emission and a decrease in the emission of NO_x, CO, smoke, and HC.

An extensive survey over the formulation of biodiesel is carried out commonly using the oil extracted from vegetables, fruits, or animal fats and most of them are edible in nature. While synthesizing biodiesel in large quantities with those oils may reduce their availability for edible consumption and its economic aspects need to be addressed. On considering these aspects, a plant that grows well in the dry coastal area of Ramnad district of Tamil Nadu *i.e.*, Annona is considered for formulating the biodiesel. These two plants are found largely across this region. The oils extracted from these two plants are non-edible in nature. Additionally, a smaller number of research is being carried out using the oils extracted from the seeds of those two plants. The major advantage of using the Annona seeds is its physical properties are equivalent to diesel. In the current research, the three different blends of B10, B20, and B30 are produced with 10%, 20%, and 30% of Annona seed oil along with 10 ml of 1-Pentanol mixed with diesel. The addition of Annona seed oil is limited to 30% based on the study of Sriram *et al*. [20] which revealed that biodiesel blends with 20% and 30% of Annona seed oil in diesel is an effective replacement for base diesel.

Extraction and transesterification of oils

The custard apple is a tree that belongs to the Annonaceae family and is a tropical fruit found across the world. The fruits are 80% pulpy and edible, whereas the seeds contribute about 20% of them. The seeds are the by-product of the edible fruit and are collected for formulating the biodiesel in the present research. The fruit along with its seeds is obtained and dried under the sun to remove its moisture. The custard apple oil is extracted using the normal hexane as solvent at 60 °C in a soxhlet extractor. The oil was separated from the hexane using a rotary vacuum evaporator, dried, and weighed for the determination of the oil yield.

The extracted custard oil has a fatty acid value of about 3.5 grams per gram and is treated with hydrochloric acid for neutralizing it. The custard apple oil is treated with NaOH-Methanol. The oil extracted from the seeds of the custard apple is heated to the temperature of 110 °C to remove the moisture and cooled to a temperature of 60 °C. The oil and methoxide are mixed at a 6:1 molar ratio within the spherical flask of 250 ml. The flask is provided with a magnetic stirrer/heater and a reflex condenser. The mixture is stirred for about 2 hours at 1100 rpm and kept idle for 8 hours. The glycerol and methyl esters are separated through the separating funnel. Using flash evaporation, the excess methanol is removed from the mixture at a temperature of 90 °C.

Experimental set-up and uncertainty analysis

Apart from the extraction of oils from the Annona seeds, the significant aspect of experimentation with the biodiesel is testing engine set-up. For the current work, the direct injection single-acting four-stroke cylinder is selected and the specification of the engine used in the proposed research work is given in tab 1. The selected engine has other provisions that include the interface for fuel and air-flow along with load and temperature measurements along with the engine and process indicators. The rotameter is employed for measuring the flow of the calorimeter and cooling water. A large number of test parameters can be measured manually in the experimental set-up. The signal covers ambient conditions to various temperatures, pressure, the mass-flow of air, fuel-flow and cooling water, the torque developed crank angle encoder and combustion pressure, *etc*. The uncertainty analysis of instruments used in this experiment is detailed in tab 2.

Table 1. Specification of engine used for experimentation

Make and model	KitrloskarmodelTV1
Engine type	Single cylinder four stroke direct injection
Bore × stroke	87.55 mm × 1500 rpm
Maximum power output	5.2 Kw at 1500 rpm
Displacement	661 cc
Compression ratio	17.5
Loading	Eddy current dynamometer, water cooling

Table 2. Uncertainty analysis for instruments used in the experiments

Instruments	Range	Accuracy	Uncertainty [%]
Gas Analyser (AVL 444N DI GAS ANALYSER)			
CO_2	0-20%	±0.01%	±0.1
CO	0-10%	±0.01%	±0.1
HC	0-20000 ppm	±10 ppm	±0.2
NO_x	0-5000 ppm	±10 ppm	±0.2
Smoke meter (AVL 437C smoke meter)	Smoke 0-100 opacity intensity in %	±1% full-scale readings	±1
Exhaust gas temperature indicator	0-950 °C	±1 °C	±0.1
Speed measuring unit	0-1500 rpm	±10 rpm	±0.1
Load indicator	0-100 kg	±0.1 kg	±0.15
Burette for fuel measurement	–	±0.1cc	±1
Original stopwatch	–	±0.6 seconds	±0.1
Manometer	–	±1 mm	±1

Inevitably, there will be some extent of inaccuracy and uncertainty in carrying out the experiments. Instrument configuration, stage and constraints, conditions, evaluation, examination, assessment, exploring technique, test process, and forecasting may all help reduce these kinds of errors and uncertainties. It is crucial to provide evidence that the experimental outcomes are reliable, consistent, and reliable. The uncertainty of emission is found to be higher at lower rpm and load conditions and the error percentage reduces at higher load conditions. The average error can be determined under nominal conditions. The total uncertainties can be calculated by adding the independent uncertainties and taking the square root of BSFC, power, air-fuel ratio (AFR), wet temperature, density of air, air-flow rate, BTE, brake power (BP), indicated power (IP), volumetric efficiency, exhaust gas temperature (EGT), CO, CO_2, HC, NO_x, and O_2 emission.

Total uncertainties = SQRT (uncertainty of BSFC)^2 + (uncertainty of AFR)^2 + (uncertainty of wet temperature)^2 + (uncertainty of density of air)^2 + (uncertainty of air-flow rate)^2 + (uncertainty of BTE)^2 + (uncertainty of BP)^2 + (uncertainty of IP)^2 + (uncertainty of volumetric efficiency)^2 + (uncertainty of EGT)^2 + (uncertainty of CO)^2 + (uncertainty of CO_2)^2 + (uncertainty of HC)^2 + (uncertainty of NO_x)^2 + (uncertainty of O_2)^2 + (uncertainty of stopwatch)^2 + (uncertainty of manometer)^2.

Total uncertainties = SQRT $(0.79)^2 + (0.88)^2 + (1.0)^2 + (0.95)^2 + (1.5)^2 + (1.0)^2 + (0.5)^2 + (1.5)^2 + (0.04)^2 + (1.05)^2 + (0.1)^2 + (0.1)^2 + (0.2)^2 + (0.2)^2 + (0.1)^2 + (0.1)^2 + (1.0)^2)$ = ±3.3%.

Result and analysis

This performance parameter for the engine is estimated under varying load conditions. The load is kept at 20%, 40%, 60%, 80%, and 100%. Along with the mentioned parameters, the exhaust gas temperature, smoke density, and the emission of gases from combustion are studied.

Smoke density

One of the most significant by-products of the combustion process is smoke. The density of smoke obtained from the combustion of the base diesel and Annona oil-based biodiesel is measured. From the smoke density analysis, it is evident that compared to the base diesel have lesser smoke density the Annona oil-based biodiesel. With the increase in engine load, the smoke density also increased. The smoke density was found to be maximum for the combustion of B30% biodiesel at full load condition of the engine with the value of 62 HSU and it is found minimum for the base diesel when the engine is operated at 20% load with the value of 12.8 HSU which is in conformity with the result provided in [21, 22]. This is due to the inbuilt oxygen presence in the biodiesel which helps in better and nearly complete combustion. The smoke density of the base diesel and biodiesel mixture is shown in fig. 1.

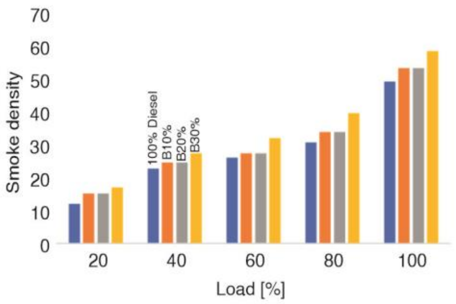

Figure 1. Comparison of Smoke Density

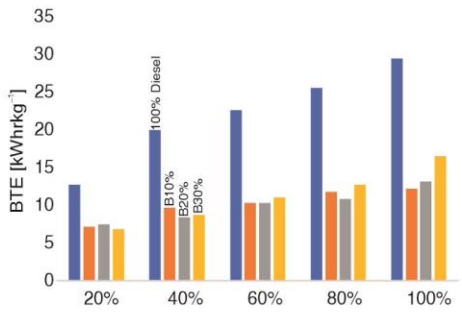

Figure 2. Comparison of BTE performance

Brake thermal efficiency

The estimation of BTE also reflects the amount of BP generation for the combustion fuel within the engine under observation. The BTE value is calculated for the three different mixtures of biodiesel and their values across varying load conditions are plotted in fig. 2. The BTE of the Annona-based biodiesel increases with an increase in engine load. From the obtained performance value, it is observed that under low loading conditions B10% and B20% biodiesel showed better performance on BTE values. This is due to AME's lower heating value, higher density, and increased viscosity which leads to poor atomization and fuel vaporization [21, 22].

Brake-specific fuel consumption

The variation in BSFC over the different loading conditions of the engine is calculated and the obtained values are plotted in fig. 3. From the plotted values, it was observed that the fuel consumption value for the Annona Oil-based biodiesel increased up to 36.09% of the engine at 100% loading. The fuel consumption performance of the formulated biodiesel is high at initial loading conditions for both B10% and B20% biodiesel mixtures which is similar to [21, 22]. This is due to complete combustion and also excess oxygen, high specific gravity, high viscosity, and lower calorific value of biodiesel. However, under 100% load conditions, the performance of B30% biodiesel is slightly higher compared to the base diesel. The fuel consumption performance of the biodiesel decreases with an increase in engine load conditions.

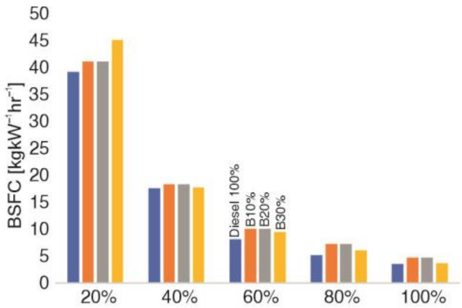

Figure 3. Comparison of BSFC performance

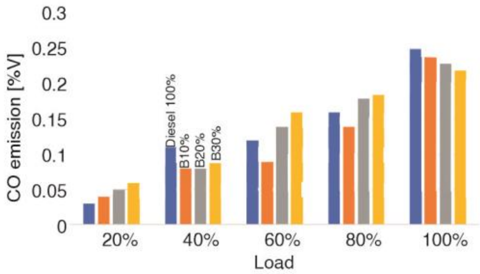

Figure 4. Comparison of CO emission

The CO emission

The CO emission after the combustion of both the biodiesel and base diesel is measured and the observed values are plotted in fig. 4. The emission of CO from the base diesel and formulated biodiesel increases with an increase in the loading condition of the engine. The CO emission test showed that B30% biodiesel emitted more CO in comparison with B10% and B20% biodiesel except for 100% engine loading conditions. The emission at 100% engine loading condition is 4%, 8%, and 12% for B10%, B20%, and B30%, respectively, which is less than that of the base biodiesel. This is due to more oxygen molecules present in the biodiesel, which leads to complete combustion which in turn helps in the reduction of CO [21, 22].

The CO_2 emission

The CO_2 gas emitted out of the engine combustion is measured and the obtained value over different loading conditions is plotted in fig. 5. The emission of CO_2 gas increased with an increase in loading conditions for base diesel. However, the Annona oil-based biodiesel showed fluctuation in the emission of CO_2. The biodiesel mixture of B10% and B20% oil showed lesser emission of CO_2 gas in comparison with base diesel and B30% biodiesel. In particular, B20% oil showed an emission of 2.90 which is the lowest value under 100% load on an engine. This phenomenon is due to the complete combustion of the oxygen molecule in biodiesel [21]. All the obtained value for the emission of CO_2 for the formulated biodiesel is less than that of the base diesel.

The NO_x emission

The emission of NO_x from the combustion of pure biodiesel and Annona oil-based biodiesel is observed from the test engine. The variation in the amount of NO_x emission corresponding to the various engine load is given in fig. 6. The emission analysis on NO_x showed that with an increase in engine load, the emission increases for both the pure diesel and developed biodiesel mixture. Among the biodiesel, there is a reduction in the emission of NO_x as the content of Annona oil is increased in diesel. The emission of NO_x is maximum at 100% engine load with the emission value of 1018 for pure diesel and a minimum of 195 for B30% biodiesel at 20% engine load due to the complete combustion oxygen molecule in biodiesel [21, 22].

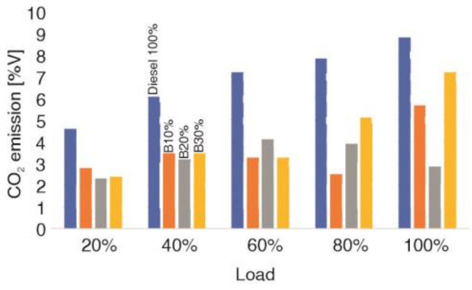

Figure 5. Comparison of CO_2 emission

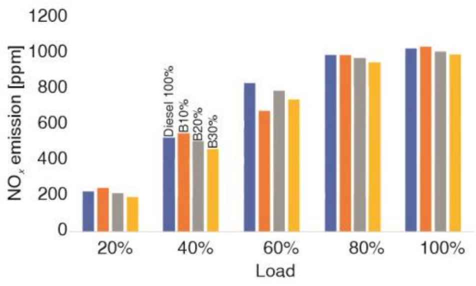

Figure 6. Comparison of Nitrous Oxide

Conclusion

The current research work involved the synthesis of biodiesel using the methyl ester extracted from the Annona Seed oils along with 1-Pentanol as an additive. The three different proportions of biodiesel were developed with varying percentages of methyl ester from Annona Seed oil at 10%, 20%, and 30%. The synthesized biodiesel mixture is tested for its performance using the test engine. From the analysis, the following inference is identified as follows.

- The smoke emission increased with the increase of Annona oil methyl ester in the biodiesel mixture. The biodiesel mixture with 30% Annona oil methyl ester showed higher smoke density at all engine loads.
- The BTE and BSFC performance analysis showed that the performance of 10% and 20% Annona oil methyl ester in diesel is better at low loading conditions of the engine and at full load, the B30% is better.
- The CO emission decreased with an increase in Annona oil methyl ester at full load condition of the engine.
- The emission of CO_2 is lesser for the synthesized biodiesel than the base diesel. The B20% showed better performance than the other two biodiesel mixtures.
- The emission of NO_x is lesser for the synthesized biodiesel than the base diesel. The B30% showed better performance than the other two biodiesel mixtures.

From the extensive analysis, it is observed that B30% biodiesel synthesized in this study has better performance than the other two mixtures. In the future, further analysis of other parameters like heat release rate, ignition delay, and in-cylinder pressure can be estimated to validate the performance of the synthesized biodiesel.

Nomenclature

AFR – air-fuel ratio
BTE – brake thermal efficiency
BSFC – brake-specific fuel consumption
B10% – Annona methyl ester 10%

B20% – Annona methyl ester 20%
B30% – Annona methyl ester 30%
BP – brake power
C – calorific value
CC – cubic centimeter
EGR – exhaust gas recirculation
EGT – exhaust gas temperature
HSU – Hartridge smoke unit
IP – indicated power
r – density
SCFSDE – single cylinder four stroke diesel engine
SOI – start of injection
KOH/gm – potassium hydroxide per gram
NaOH – sodium hydroxide
TFC – total fuel consumption
h – efficiency

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