Materials Today: Proceedings xxx (xxxx) xxx

Contents lists available at ScienceDirect

Materials Today: Proceedings

journal homepage: www.elsevier.com/locate/matpr

Evaluation of metal oxide nano particles in lemongrass biodiesel for engine performance, emission and combustion characteristics

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ARTICLE INFO

Article history:
Received 27 July 2020
Received in revised form 23 October 2020
Accepted 27 October 2020
Available online xxxx

Keywords:
Lemongrass Oil
Green Synthesis
ANOVA Table
Oldenlandia leaf
Nanoparticles

ABSTRACT

Physicochemical properties of lemongrass biodiesel and diesel engine parameters fueled with nanoparticles (Zinc Oxide, Titanium Oxide, and Alumina) added in diesel/biodiesel blended have been investigated, in which zinc oxide nanoparticles was green synthesized from ldenlandia leaf. The synthesized Zno Nps was characterized by Scanning Electron Microscope (SEM), X Ray Diffraction and FT-IR study. Each nanoparticles has own weightage of 50 ppm in 30% blend of lemongrass biodiesel/diesel. The performance, exhaust emission and combustion characteristics were performed for each lemongrass biodiesel nanoparticles blend using diesel engine and validation was carried out between each lemongrass biodiesel blends with diesel and ANOVA analysis was done to found out the dependency of parameters. It was concluded that characterization of ZnO, TiO_2 and Al_2O_3 nanoparticles such as XRD, SEM and FT-IR was conformed their behavior in anatase phase along with lemongrass oil also characterized by FT-IR. From ANOVA table, B3050ZnO has major significant dependence for brake thermal efficiency over 3%. It was concluded that lemongrass biodiesel with green synthesized zinc oxide nanoparticles has better performance, emission and combustion characteristics over 5% among other two nano-additives.

Selection and peer-review under responsibility of the scientific committee of the 3rd International Conference on Frontiers in Automobile & Mechanical Engineering.

1. Introduction

Fossil fuels are dipping around the world along with that price of fossil fuel increasing gradually, to overcome a huge demand, evolution of fuels are needed which is biodiesel. Biodiesel was extracted from various leafs, seeds such as jatropha, mauha, pongamia, lemongrass oil etc. [1–3]. Major drawback is NOx emission are huge as compared diesel due to huge content of oxygen contamination in biofuels [4]. To overcome emission, Nanoparticles are used. Due to Nano-size of the particles and its characteristics, sedimentation was not possible.

Emissions like CO and HC are reduced and smoke opacity and NOx was increased by using TiO_2 but brake thermal efficiency was increased by 3.1%. Doping of nanoparticles such as zinc oxide and titanium oxide will reduces emission mainly NOx. X-Ray diffraction was done for nanoparticles for identifying phase and percentage off crystallinity in along with that SEM and EDX was done to produce images of samples and to determine chemical components in a sample. By using, TiO_2 ignition delay period was reduced so brake specific fuel consumption was reduced [5]. Carbon monoxide varies by varying engine rotation and also by increasing catalytic cell, concentration of CO will reduces [6]. Doping of titanium dioxide and cerium acetate hydrate nanoparticles reduces NOx emission in which metallic nanoparticles acts as combustion catalyst of fuel for complete combustion. Nanoparticles such as MnO and CuO will increases performance marginally and reduces emission significantly but by using metallic nanoparticles NOx emissions were increased due to increase in oxygen rate and also density and viscosity of fuel gets increased which influence on atomization, air fuel mixing rate and spray angle [7]. Due to Nano-size, sedimentation, aggregation, clustering, flocculation and agglomeration are avoided [8]. Cerium Oxide is one of the rare earth metal with dual valance element which acts as oxygen buffering in biofuel and also it reduces harmful exhaust emission such as HC and NOx around 40 to 45% and 5 ppm to 35 ppm respectively which are the main cause for acid rain [9]. Incomplete combustion, air fuel ratio, fuel injection pressure injection timing and nature of the fuel are the main reasons for exhaust emission mainly carbon monoxide [10]. Zinc oxide nanoparticles provides catalytic effect and micro explosion of water molecules in which

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https://doi.org/10.1016/j.matpr.2020.10.796
2214-7853/
Selection and peer-review under responsibility of the scientific committee of the 3rd International Conference on Frontiers in Automobile & Mechanical Engineering.

by addition of 100 ppm, brake thermal efficiency was increased by 4.7% and NOx was reduced by 12.6%. Antioxidant such as ethanox reduces NOx by 500 ppm but emission such as hydrocarbon and carbon monoxide will increases, whereas manganese oxide will reduces emission such as carbon monoxide and oxides of nitrogen by 37% and 4%. Oxides of nitrogen was caused due to Zeldovich mechanism in which free nitrogen radicles reacts with oxygen present in fuels to form oxides of nitrogen. By using zinc oxide, zeldovich mechanism was disrupted [11]. Due to combustion of sulfur content fuels, harmful emission such as hydrocarbon, carbon monoxide was evolved at higher rates which leads to acid rain, to overcome this biodiesel was used which is free from sulfur content [12–14]. Oxides of nitrogen was dangerous gas which can influence acid rain can be reduced by using aluminum oxide nanoparticles which reduce ignition delay and normalize combusting timings [15]. The cylinder pressure, rate of heat release and cetane number was increased by adding zinc oxide nanoparticles in fuels where Cetane number influences angle of shift [16].

Nanoparticles size range of 20–40 nm has a great influence in emission such as NOx emission was reduced over 40% by adding zinc oxide into fuels [17]. Emissions such as NOx, smoke and hydrocarbon was decreased by increasing injection pressure and cylinder gas temperature. Cerium oxide nanoparticles had ability to increase injection pressure and cylinder gas temperature though which reduces emissions [18]. Brake power and brake thermal efficiency can be increased to 0.52% and 6.23% by adding aluminum oxide nanoparticles in fuels [19]. Oxides of nitrogen mainly (NOx) was non-ideal combustion which determines climatically change and global warming. Fuel properties such as cetane number, density, volatility will influence in formation of nitrogen oxide, which can be reduced by using ester oils [20]. Doping of nanoparticles such as zinc oxide and titanium oxide will reduce emission such as CO and HC drastically but NOx reduces to a lower percentage (7–29%) as increasing loads, increases brake power proportionally increases nitrogen oxide emission which can be reduced by catalytic converter [21]. Addition of copper oxide in fuels will reduces NOx emission around 9.8% and smoke around 12.8% but carbon monoxide and hydrocarbon increased to a moderate level than normal diesel [22]. Palm oil has cooling effect due to presence of water molecule which increases carbon monoxide emission and hydrocarbon but by adding zinc oxide nanoparticles, emission such as carbon monoxide hydrocarbon and nitrogen oxide was reduced [23]. As zinc oxide has the ability to reduce all emission such as hydrocarbon, carbon monoxide, nitrogen oxide and smoke, zinc oxide can be used as additives in fuels in the range of 50 ppm. In the same way zinc oxide can be green synthesized by aqueous extraction method and characterization was done by XRD, SEM and FT-IR study [24].

2. Materials and methodology

In these section, materials such as Lemongrass Oil, nanoparticle synthesis and its characterization and biodiesel blends with their methods discussed briefly along with the experimental setup and procedure.

2.1. Zinc oxide

Zinc Oxide nanoparticles was synthesized from oldenlandia leaf through aqueous extraction process. Preparation of Zn $(CH_3CO_{2)2}$ solution and sodium hydroxide for synthesis of zinc nanoparticles 4.38 g of zinc acetate dehydrated was dissolved in1000ml of double distillated water and stirrer the solution of 2hrs. 100 ml of distilled water with 4 g of sodium hydroxide was mixed and preparation of solution was done. 50 g of oldenlandia leaf is soaked with 250 ml of distilled water and grind with mixture, after fine mixing with the help filter paper leafs was removed. The solution of zinc acetate dehydrated and sodium hydroxide was mixed along with that leaf extracted solution was added by drop by drop and solution was stirred about 8hrs, yellow color appeared in the solution at room temperature and solution was centrifuged shown in Fig. 1. After centrifuged, supernatant and precipitate was separated, separated precipitate was collected to Petri plates and 5 ml of ethanol is mixed with that nanoparticle. The prepared nanoparticle zinc oxide was characterized by SEM, XRD and FT-IR. A drop of supernatant sample was taken by the micropipette and placed on SEM slide and then allowed to dry in room temperature. The SEM images of Zinc Oxide nanoparticle is shown in Fig. 3. The phase variety and particle size determined in X-ray diffraction studies with scanning range of 20–80 ° and bond angle 3°. The powder sample was taken for XRD analysis which was also placed on a glass slide for analysis. For FT-IR characterization, sample was mixed with solid KB run uniformly and properly which was compressed to settle down on a thin transparent film and this thin film was taken for analysis which was kept in chamber for analysis. Fig. 2. represents XRD for extracted zinc oxide nanoparticles in which, characteristics of extracted zinc oxide nanoparticle matches with anatase zinc oxide database JCPDS card no: 790207.

2.2. Titanium dioxide

Titanium dioxide which is also known as titania or titanium IV oxide or titanium white, titanium white was used as color pigment sourced from ilmenite, rutile and anatase. It has a huge application in the field of medical, automobile, automotive, painting, sunscreen and food coloring. Titanium dioxide was characterized with FT-IR and SEM for its own behavior. Fig. 4.(b) represents characterization of titanium oxide. Fig. 4. (a) represents titanium nanoparticles which was undergone for ball milling process to convert into nanoparticles and in which that processed nanoparticles was characterized by using FT-IR analysis, from analysis the peak was found at their respective wave number under transmittance. After characterization was successfully done, titanium dioxide nanoparticle was added as additive in lemongrass biodiesel blend in order to increase efficiency means of performance and to reduce emissions.

2.3. Aluminum oxide

Aluminum oxide was represented as Al_2O_3, with a chemical compound of aluminum and oxygen, most commonly occurring with several aluminum oxides and specified by aluminum III oxide also known as aloxide. It was significant to produce aluminum metal, abrasive owing to its hardness and refractory material to its melting point. Alumina oxide was characterized with FT-IR and SEM for its behavior. Fig. 5. (a) represents aluminum oxide nanoparticle and Fig. 5. (b) represents FT-IR of aluminum oxide nanoparticles.

2.4. Lemongrass biodiesel

Lemongrass oil was extracted from lemongrass also known as cymbopogon which is a genus of Asian, African, and Australian. Lemongrass oil was extracted by steam distillation method in which steam generated from external boiler was introduced into the chamber in which lemongrass gets heated and due to high temperature, lemongrass oil was extracted from lemongrass. The extracted lemon grass oil was blended with diesel as a percentage of 30 which means 30% lemongrass oil with 70% diesel, to produce lemongrass biodiesel (B30) along with that three Nano-additives such as zinc oxide (B30ZO), titanium oxide (B30TO) and alumina (B30AlO) are added at a weightage of 50 ppm through sonication

Fig. 1. (a) Oldenlandia leaf; (b) Oldenlandia leaf dilution; (c) Nano zinc oxide.

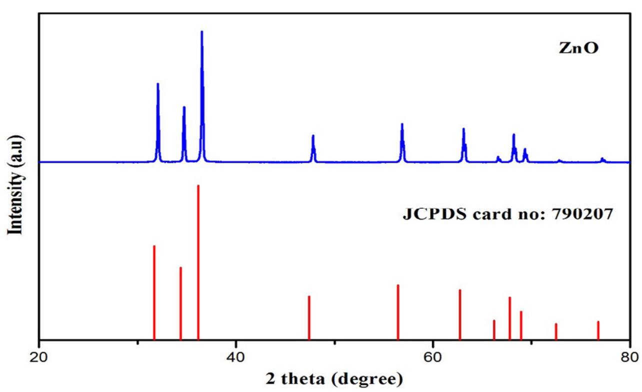


Fig. 2. XRD for extracted zinc oxide nanoparticles.

process by sonicator at high frequency of 25 MHz and after sonication lemongrass biodiesel was tested for fuel properties.

Fig. 6. (a) represents lemongrass oil which was extracted from lemongrass through steam distillation along with transesterification process and it was characterized by FT-IR in which highest peak was found on 2923 and 2855 cm-1 shown in Fig. 6. (b). From survey, highest peak could be found out in that wave number and properties of lemongrass biodiesel was described below in Table 1. In which both fire point and flash point was done by using PMMC METHOD.

2.5. Experimental setup

The engine on which the experiments are carried out is shown i.e. of the variable compression ratio compression ignition engine along with the online performance evaluation system is shown in Fig. 7. The various points in the flow line diagram of variable compression ratio compression ignition engine were given below in table 2.with full nomenclature.

3. Results and discussion

The present investigation concerns improvement in combustion, performance and emission characteristics of a single cylinder single cylinder, four stroke, and water cooled DI diesel engine with lemongrass oil and four types of nano particles namely: Green synthesised zinc oxide, titanium dioxide, and alumina have been investigated. The results of performance and emission parameters are based on the study of the combustion parameters, like ignition delay, cylinder pressure, rate of heat release and combustion duration are measured and presented in the following sections and finally analysis of variance was done to identify the variance of nanoparticles additives in performance characteristics such as brake power and brake thermal efficiency.

3.1. Performance of diesel engine using nano-additives

The experiments were conducted with diesel fuel, lemongrass biodiesel with various Nano-additives such as zinc oxide, titanium oxide and alumina. The results obtained from the experimental investigation of combustion and performance parameters for diesel engine are presented and discussed in this section. The results are compared with diesel fuel.

3.1.1. Brake thermal efficiency

Praveen et al, says that brake thermal efficiency is a brake power of a heat engine as a function of thermal input from the fuel.

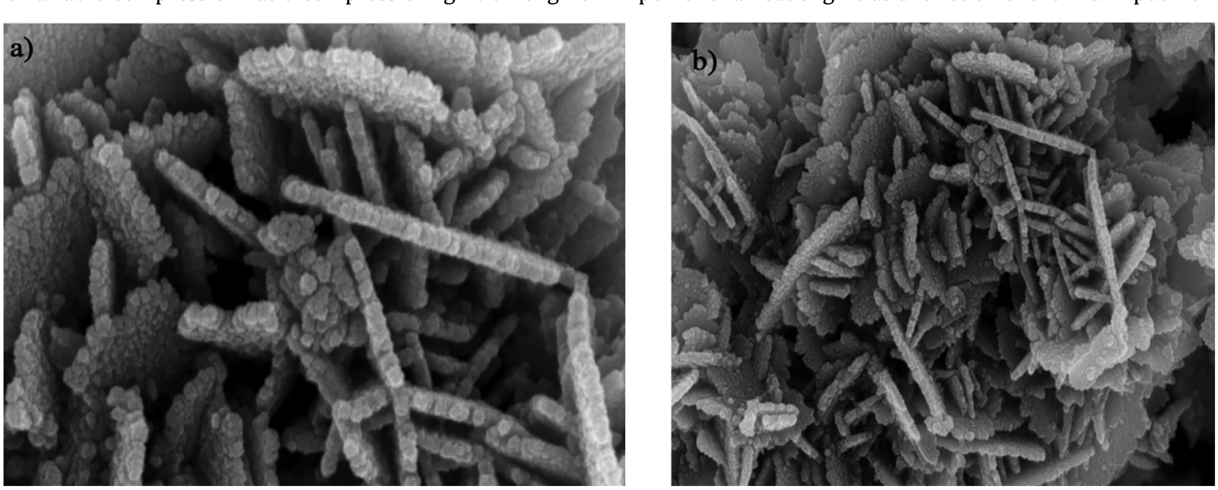


Fig. 3. (a) & (b) SEM images of extracted zinc oxide nanoparticles.

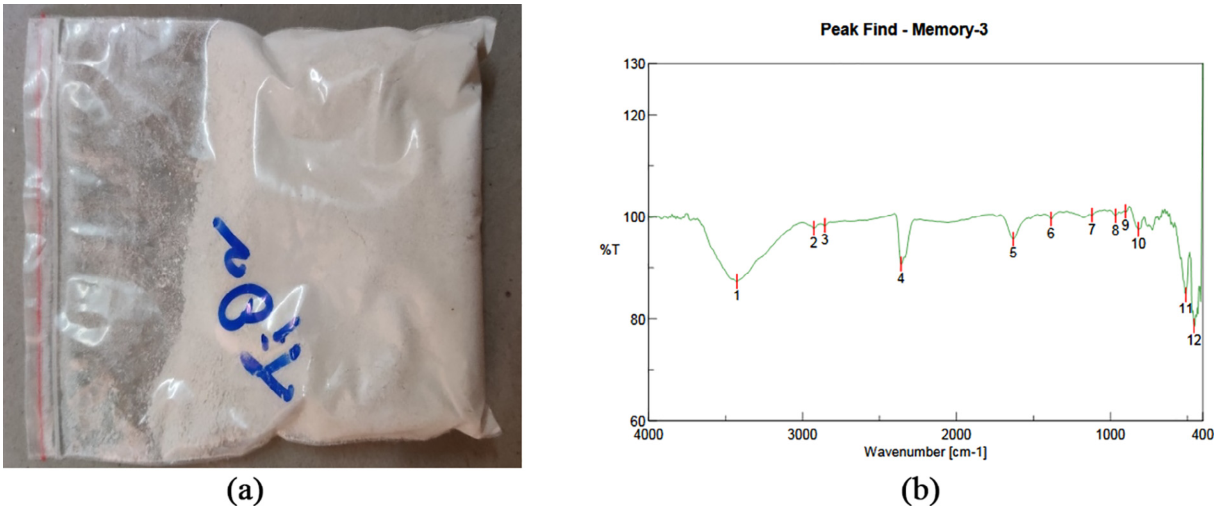


Fig. 4. (a) Titanium oxide nanoparticle; (b) FT-IR for titanium oxide.

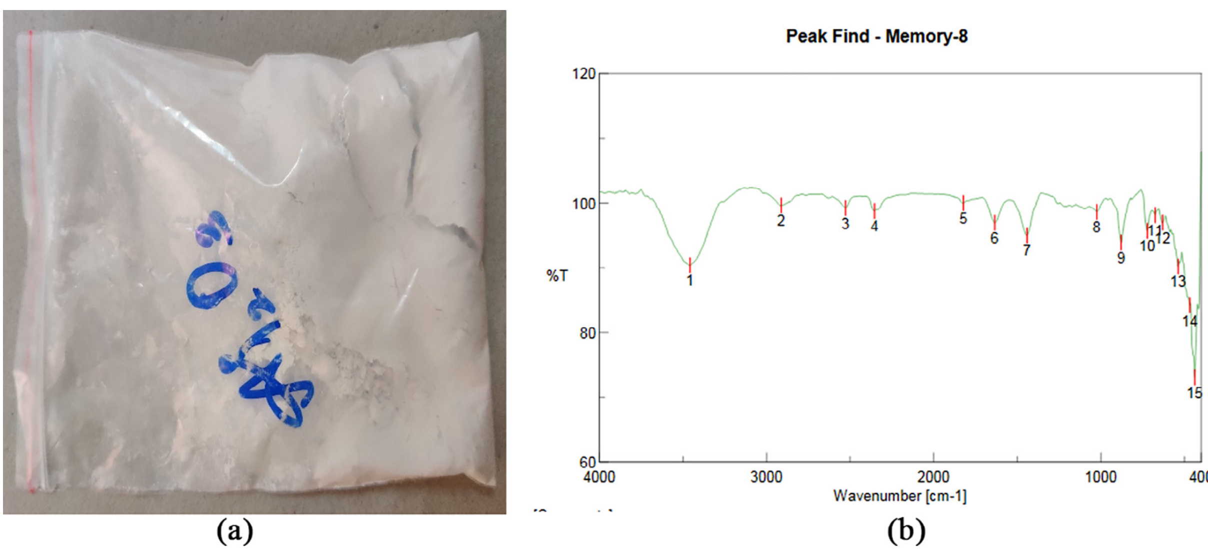


Fig. 5. (a) Aluminum oxide nanoparticle; (b) FT-IR for aluminum oxide powder.

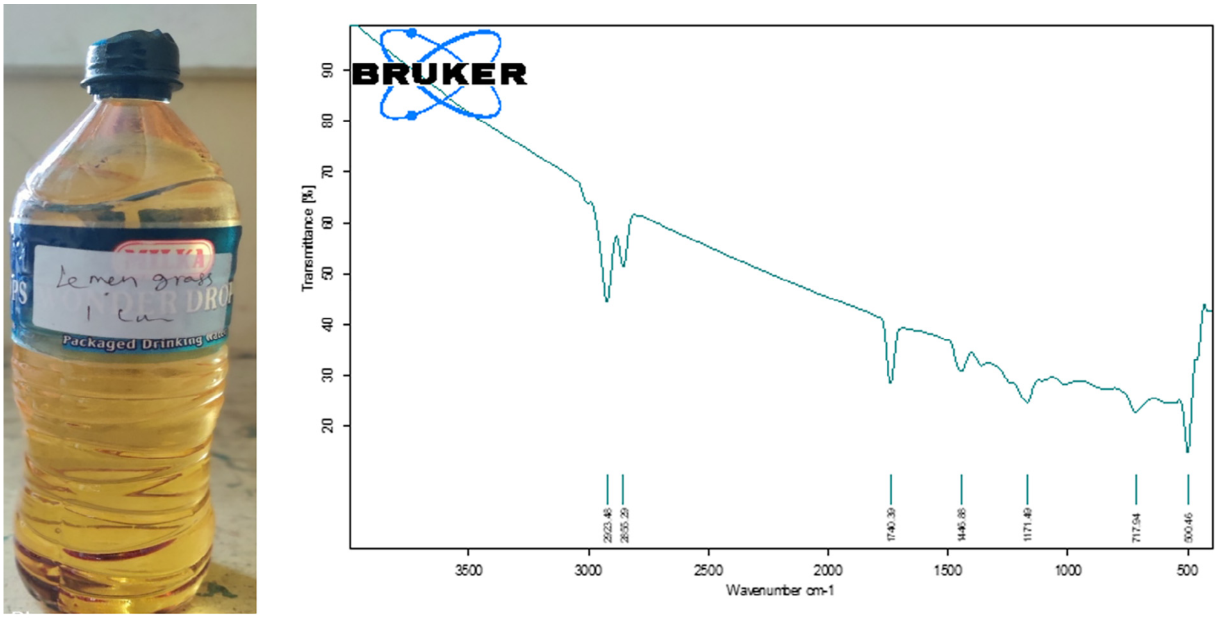
It is used to evaluate how well the engine converts heat from the fuel into mechanical energy. The brake thermal efficiency was measured and tabulated by using three types of lemongrass biodiesel blends as nano particles are different in each biodiesel as a variation factor of brake power. From the results obtained graph was drawn and compared between the various blends of biodiesel. Fig. 8, represents that brake thermal efficiency of Nano-additive fuels are higher than diesel with an average percentage of 3.121%, shows that by using lemongrass biodiesel with Nano-additives, diesel engine has a better brake thermal efficiency. In order to found out the effectives of each Nano-additives, results of each Nano-additive lemongrass biodiesel was compared and analyzed. From the analysis, green synthesized zinc oxide nanoparticles provide high brake thermal efficiency over 4.9% due to complete combustion of fuels [25].

3.1.2. Brake specific fuel consumption

Praveen et al., says that specific fuel consumption was used to define the amount of fuel consumed by a vehicle for each unit of power output. It is used to evaluate how much amount of fuel was consumed to produce one unit of power output, which determines effectiveness of the engine. The specific fuel consumption was measured and tabulated by using three types of lemongrass biodiesel blends as nano particles are different in each biodiesel as a variation factor of brake power. From the results obtained graph was drawn and compared between the various blends of biodiesel.Fig. 9, shows that fuel consumption for each loads in which fuel consumption for diesel has comparatively lower than lemongrass biodiesel with Nano-additives with varying load which varies brake power. Lemongrass biodiesel also has their major impact on specific fuel consumption but lesser than diesel about 10%. Comparison was carried out between Nano-additive fuels, among that green synthesised zinc oxide nano particles provides low brake specific fuel consumption over a percentage of 33.3 was reduced. Specific fuel consumption is mainly depends upon the fuel flow rate for the actual thrust level produced [26].

3.2. Exhaust emission of diesel engine using Nano-additive

The effects of five types of fuels in exhaust emission of diesel engine are discussed in the following section.



(a) (b)

Fig. 6. (a) Lemongrass oil; (b) FT-IR for lemongrass oil.

Table 1
Properties of lemongrass biodiesel.

Properties	Results
Acid Value	0.16 mg NaoH/g of oil
Density	0.820 g/cc
Kinematic Viscosity@40 °C	1.23 cSt
Flash Point by PPMC Method	56 °C
Fire Point by PPMC Method	63 °C
Moisture Content	0.001%
Calorific Value	8615.268Cal/g

3.2.1. Fractions of oxides of nitrogen

Fatemeh et al., says that the formation of oxides of nitrogen is mainly depends on varying loads. Mainly nitrogen oxide was formed due to Zeldovich mechanism which is a free nitrogen reacts with oxygen at higher temperature to form a nitrogen oxide due presence of high oxidation content in fuel. Due to high content of oxygen in fuel, NOx formation was high in biodiesel. In order to reduce NOx formation various additives was used such as zinc oxide, titanium oxide, and alumina to observe the convergence of NOx formation by varying loads.Fig. 10, represents fraction of

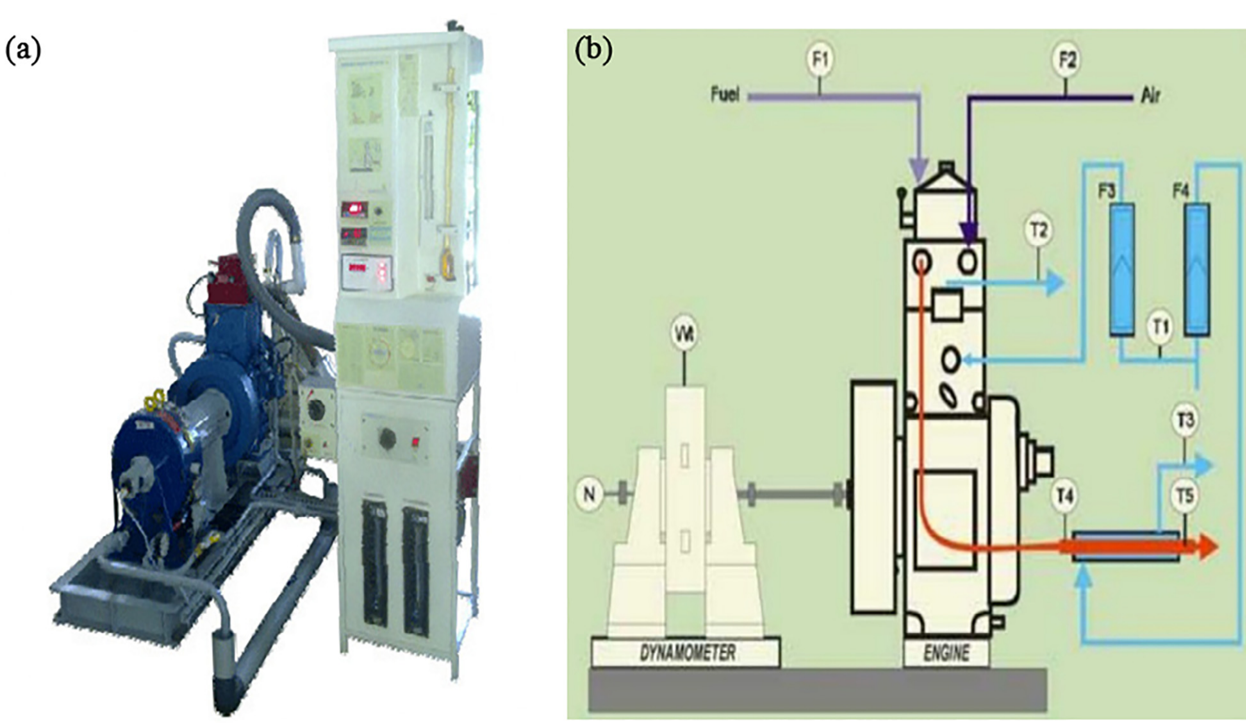


Fig. 7. (a) VCR CI engine; (b) Line diagram of VCR CI engine.

Table 2
Various points of VCR CI engine.

Points	Nomenclature
T1	Inlet temperature of water jacket in calorimeter and engine jacket
T2	Outlet temperature of water from engine jacket
T3	Outlet temperature of water from calorimeter
T4	Inlet temperature of exhaust gases into calorimeter
T5	Outlet temperature of exhaust gases from calorimeter
F1	Fuel supply to engine cylinder
F2	Air flow to engine cylinder
F3	Water flow to the engine jacket
F4	Water flow to calorimeter
N	Non-contact type speed sensor (Engine shaft speed)
W	Load sensor (Eddy current dynamometer)

NOx formation as varying load for four types of fuel as diesel and lemongrass biodiesel with Nano-additives. As load increasing, NOx formation was also increasing due to high fuel consumption in which high amount of oxygen content. By comparing between diesel and lemongrass biodiesel, lemongrass biodiesel has better effect because for higher loads NOx formation was much lesser than diesel over 33.8%. In among additives, green synthesised zinc oxide nanoparticles provide lesser formation of nitrogen oxide nearly 25% than other two nanoparticles.

3.2.2. Formation of carbon monoxide (CO)

Prabakaran et al., says that, the variation of carbon monoxide formation with varying loads for four types of fuel was measured and discussed below. The main reason for the formation carbon monoxide was improper air fuel ratio, temperature difference, delayed ignition period and low carbon activation. Due to this following reasons, fuel combustion doesn't takes place completely in which carbon monoxide was formed. In order to reduce CO formation various additives was used such as zinc oxide, titanium oxide, and alumina to observe the convergence of CO formation by varying loads. Fig. 11, represents fractions of carbon monoxide CO formation by varying loads for four different types of fuel. Carbon monoxide was continuously decreasing from zero load to full load. As compared with conventional diesel and lemongrass biodiesel additive fuel, lemongrass biodiesel with Nano-additive has a better impact to reduce carbon monoxide. Lemongrass biodiesel with Nano-additives has reduced 36% of carbon monoxide than diesel, because Nano-additives has the ability to reduce ignition delay, to increase carbon activation and to provide proper air–fuel ratio. So lemongrass biodiesel has better result of carbon monoxide formation than diesel. In among additives, green synthesised zinc oxide nano particles provide lesser formation of carbon monoxide nearly 61% than other two nano particles.

3.2.3. Formation of hydrocarbon (HC)

Dhana et al., says that the variation of hydrocarbon formation with varying loads for four types of fuel was measured and discussed below. The main reason for formation hydro carbon was improper fuel ratio, insufficient oxygen content in fuels. Due to insufficient oxygen, fuels undergoes an incomplete combustion in which a huge amount of carbon and hydrogen free radicals were get reacted among them to form hydro carbon emission in exhaust gas with improper combustion temperature.

Fig. 12, represents the formation of hydrocarbon as varying with load conditions. From results, hydrocarbon was gradually increasing as increasing load condition still reaching stable condition. Once reaching stable condition at half-load condition, formation of hydrocarbon was gradually decreasing. As comparing between diesel and lemongrass biodiesel with Nano-additives, lemongrass biodiesel with Nano-additives has a better impact too reduce hydrocarbon emission as 29% over diesel. Because Nano-additives will provide better air–fuel ratio and increases carbon activation for complete combustion. In addition to that, lemongrass biodiesel has rich amount of oxygen content due to these two following reasons, formation of hydrocarbon was reduced over 29% over diesel fuel. In among additives, green synthesised zinc oxide nano particles provide lesser formation of hydrocarbon nearly 32.5% than other two nanoparticles.

3.3. Analysis of variance (ANOVA)

In order to found out significant dependence on the response and factors which was influencing the process, ANOVA was used. Analysis of Variance table was drawn for brake specific fuel consumption with load as a varying factor.

3.3.1. Brake thermal efficiency

Brake thermal efficiency is a brake power of a heat engine as a function of thermal input from the fuel. It is used to evaluate how well the engine converts heat from the fuel into mechanical energy. The brake thermal efficiency was measured and tabulated by using three types of lemongrass biodiesel blends as nanoparticles are different in each biodiesel as a variation factor of brake power.

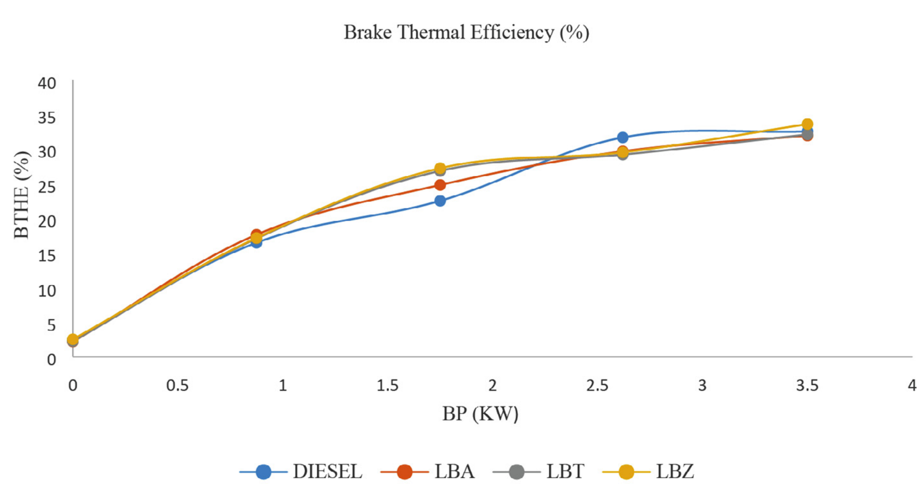


Fig. 8. Brake Thermal Efficiency.

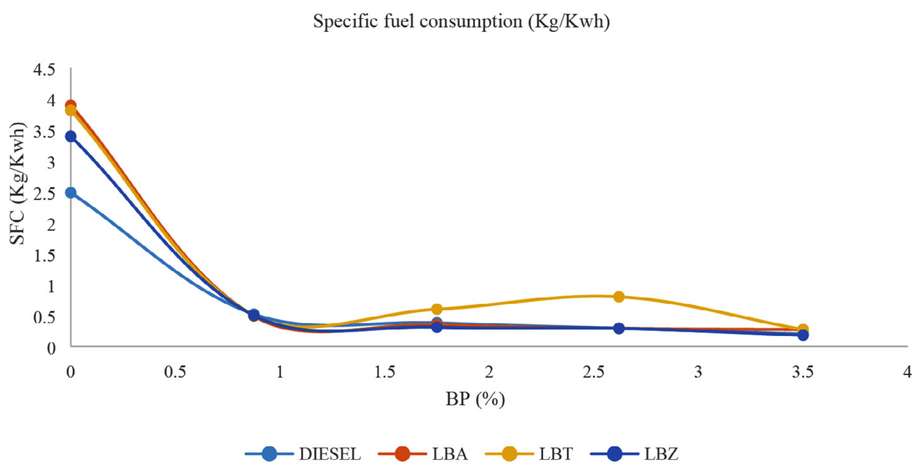


Fig. 9. Specific fuel consumption.

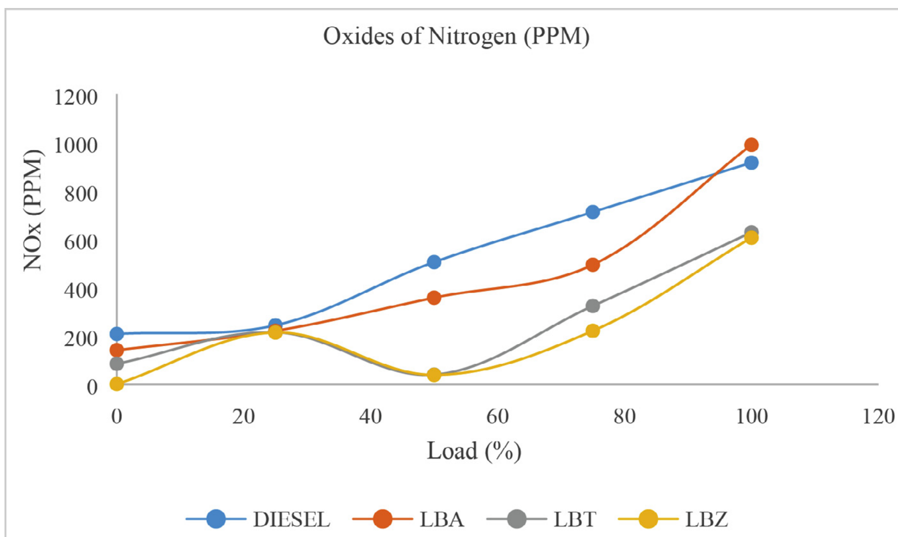


Fig. 10. Oxides of nitrogen.

Table.3, represents variation of load over diesel and lemongrass biodiesel with three different Nano-additives such as alumina, titanium dioxide and zinc oxide. For these table, ANOVA table was prepared to determine the dependence for brake thermal efficiency over load as considering factor.

From table.4, there is a significant dependence on fuels and load, in which each fuels as an individual significant dependence to respond brake thermal efficiency and also load has significant dependence. Among fuels, green synthesised zinc oxide Nano-additive has 3% more dependency then other all four type of fuels including diesel in which intimates that using lemongrass biodiesel with green synthesised Nano-additive has major impact of increasing brake thermal efficiency.

4. Conclusion

In this work in order to increase the performance and combustion of diesel engine with reduced exhaust emission, diesel engine was tested by various types of fuel such as diesel and lemongrass biodiesel. Lemongrass oil is blended as 30% over 100% and remaining 70% used as diesel which as 30%LOBD in addition to that three types of Nano-additives namely zinc oxide, titanium dioxide, and aluminum dioxide were added to increase performance and combustion characteristics and to decrease exhaust emission of diesel engine.

It was concluded that characterization of ZnO, TiO_2, and Al_2O_3 nanoparticles such as XRD, SEM and FT-IR was conformed their behavior in anatase phase along with lemongrass oil was also characterized with FT-IR. The brake thermal efficiency of B3050ZnO, was increased by 4.9% respectively over diesel fuel and brake specific fuel consumption of B3050TiO_2, B3050ZnO and B3050Al2O3 was increased by 1.3% over diesel. Emissions such as CO, NOx and HC was analyzed. Carbon monoxide emission for B3050TiO_2, B3050ZnO and B3050Al2O3 was decreased by 17%, 39% and 5% respectively. Nitrogen oxide emission for B3050TiO_2, and B3050ZnO, by 290PPM, and 310PPM and for B3050Al_2O_3 increased by 73PPM. Hydrocarbon emission for B3050TiO_2, B3050ZnO and B3050Al_2O_3 was decreased by3.3%, 32.5% and 1% respectively. From ANOVA table, B3050ZnO has major significant dependence for brake thermal efficiency over 3%. After validation among four types of fuel, B3050ZnO has a major impact in order to increase performance and combustion characteristics and to decrease exhaust gas emissions such as carbon monoxide, oxides

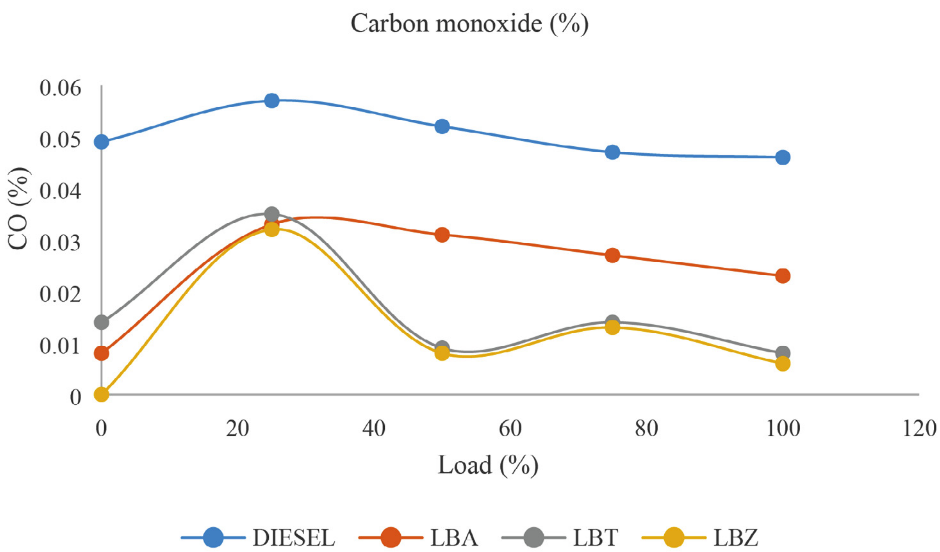


Fig. 11. Formation of carbon monoxide.

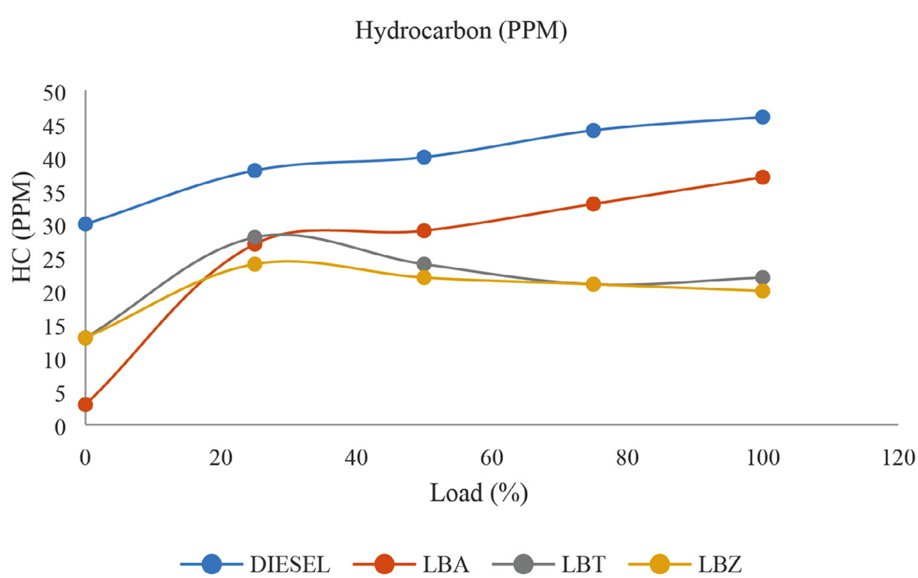


Fig. 12. Formation of hydrocarbon.

Table 3
Brake Thermal Efficiency.

Load/Fuels	Diesel	Alumina	Titanium Dioxide	Zinc Oxide
0%	2.45	2.2	2.25	2.53
25%	16.49	17.65	17.09	17.18
50%	22.75	24.84	26.88	27.26
75%	31.71	29.71	29.23	29.57
100%	32.59	31.98	32.14	30.64

Table 4
ANOVA Table for BTE.

Source of Variation	Sum of Squares	Degree of Freedom	Mean Sum of Squares	F RatioC/T
B/W Samples	16.46	3	4.15	3.635/3.49
B/W Loads	2357	4	589.25	390.49/3.26
Residual Error	18.11	12	1.509	
	2375.6	19		

of nitrogen and hydrocarbon. It was concluded that lemongrass biodiesel with green synthesized zinc oxide nanoparticles has better performance, emission and combustion characteristics over 5%.

CRediT authorship contribution statement

M. Sunil Kumar: Conceptualization, Investigation, Writing - original draft. **R. Rajasekar:** Methodology, Supervision. **S. Ganesan:** Investigation. **S.P. Venkatesan:** Supervision, Resources. **V. Praveen Kumar:** Resources.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The authors are grateful to Sathyabama Institute of Science and Technology for providing support in engine research Centre and also grateful to Mr. V Perumalsamy for adoring his work by his pleasant advices and motivation.

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