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Experimental investigation on SiO_2 nano particle as additives on performance and emission parameters of diesel engine fueled with castor oil blends

Charles Samuel Durai*, Narayanan Subramanian, Alwyn Joseph Duraisamy

Department of Mechanical Engineering, SNS College of Engineering, Coimbatore, Tamilnadu, India

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CORRESPONDING AUTHOR:

charlespm17@gmail.com
Tel: (+422) 2668604
Fax: (+422) 2668604

ABSTRACT

Introduction: Today, a lot of research work is carried out in the vegetable oil based fuels which are the blended renewable fuels derived from vegetable oils or the oxygenated fuels which could effect in reduced Carbonaceous emissions. This experimental study investigates the impact of Silicon dioxide (SiO_2) nanoparticles as additives on the performance and emission parameters of a diesel engine running on castor oil blends.
Materials and methods: Castor oil is a renewable source of biodiesel, but it has limitations such as lower calorific value and higher viscosity compared to conventional diesel. To overcome these limitations, SiO_2 nanoparticles were synthesized and characterized. Tests were conducted on a single-cylinder diesel engine under various load conditions using different fuel blends.
Results: Results shows that the addition of SiO_2 nanoparticles improved the engine's performance by increasing brake thermal efficiency by 25% and reducing specific fuel consumption by 9%. Carbon monoxide emissions (CO) were decreased by 25%, Hydro Carbon emissions (HC) decreased by 52% with SiO_2 nanoparticles while a marginal percentage of NO_x was also observed.
Conclusion: This study demonstrates the potential of SiO_2 nanoparticles as additives in enhancing the performance and reducing emissions of diesel engines using castor oil blends, contributing to the development of sustainable transportation.

Introduction

Diesel engines have been widely utilized in various sectors due to their robustness, high efficiency, and torque characteristics. They have found extensive applications in transportation, agriculture, industrial equipment, and power generation. However, the growing concerns about depleting fossil fuel reserves and environmental pollution have prompted the exploration of alternative fuels, such as biodiesel, which can be derived from renewable sources such as vegetable oils. Biodiesel, being a cleaner-burning fuel with reduced carbon dioxide emissions, has emerged as a promising substitute for conventional diesel fuel.

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The use of biodiesel as a blend with diesel fuel has gained significant attention as it offers several advantages, including reduced emissions of particulate matter, carbon monoxide, and sulphur compounds. It can be easily produced from various feedstocks, such as soybean oil, rapeseed oil, and palm oil, making it a versatile and sustainable fuel option. However, the performance and emission characteristics of biodiesel blends in diesel engines can be influenced by various factors, including fuel properties, combustion characteristics, and the presence of impurities.

To address the challenges associated with the use of biodiesel blends in diesel engines, researchers have explored the potential of incorporating nanoparticles as additives. Nanoparticles possess unique physical and chemical properties that can potentially enhance the combustion efficiency and emissions performance of biodiesel blends. The addition of nanoparticles can modify the fuel properties, improve atomization, and facilitate better air-fuel mixing, leading to improved combustion characteristics.

In recent years, there has been a growing body of research investigating the effects of nanoparticle additives on the performance and emission parameters of diesel engines fueled with biodiesel blends. These studies have focused on various nanoparticles, such as cerium oxide, titanium dioxide, and carbon nanotubes, to name a few. The findings have shown promising results in terms of improved combustion efficiency, reduced emissions of nitrogen oxides, carbon monoxide, and particulate matter.

Investigations carried out with cerebra maghas methyl ester blends as fuel in a single cylinder diesel engine exhibited marginal increase of brake thermal efficiency with reduced specific fuel consumption [1]. Experimental investigations conducted to analyze the effect of biodiesel-diesel-ethanol blends on diesel engine inferred that the blends of biodiesel-ethanol increases Brake specific fuel consumption marginally while augmentation of brake thermal efficiency were observed [2].

Investigations done to study the impact of waste cooking oil blends as an alternative fuel for diesel engine [3] showed that the energy conversion capacity of Diesel engine while running on waste cooking oil blends were found to be weaker with higher fuel consumption and lower thermal efficiency. CO and HC emissions reduced while NO_X increased. Experiments conducted with higher alcohol blend on diesel engine fuelled with Jatropha Methyl ester [4], the results indicated increased formation of oxides of nitrogen with Jatropha Methyl ester as fuel, whereas with lower alcohol blend, inclusion of 10 percent of alcohol, slightly decreased oxides of nitrogen.

Experiments conducted with Niger oil methyl ester blends on single cylinder diesel engine [5], show decrease of carbon monoxide and unburnt hydrocarbons with increase of biofuel composition.

Investigations on the effect of cerium oxide nanoparticles on physiochemical properties of pongamia methyl ester blends and its subsequent effect on diesel engine performance and emission parameters. The inferences show that the addition of cerium oxide nanoparticles enhanced the Calorific value of the blend [6].

To analyze the effects of punnai methyl ester blends on diesel engine, experiments were conducted with multiple blends of biodiesel with diesel. When the percentage of biodiesel in diesel increases thermal efficiency decreases. Presence of excess oxygen content in fuel showed the formation of increased oxides of nitrogen in diesel engine [7]. Experiments carried out to investigate the performance and emission of compression ignition engine fueled with biofuel blends, the simulation and experimental results indicate increase of Oxides of Nitrogen emissions with slight decrease of carbon monoxide [8].

From careful examination of above literature it is evident that handful of researches have been performed on the application of vegetable oils as fuel in diesel engines. However, on the emissions front it is required to balance between carbon based emissions and hydrocarbons. It was observed that if carbon based emissions (CO, HC) decreases, oxides of nitrogen would increase and vice-versa. This research work explores the significance of SiO_2¬ nanoparticles used as additive in castor oil based methyl ester (biodiesel) blend with diesel.

Materials and methods

Transesterification of castor oil

The preparation of castor oil methyl ester, commonly known as biodiesel, involves a chemical process called transesterification. Biodiesel production from castor oil begins with the selection of a suitable feedstock. Castor oil, derived from the seeds of the castor oil plant (Ricinus communis), is an ideal choice due to its high triglyceride content. Triglycerides are the main components of vegetable oils and serve as the raw material for biodiesel production.

Before transesterification, the castor oil undergoes a pre-treatment process. This step aims to remove impurities and moisture present in the oil, as they can affect the efficiency of the reaction and the quality of the final biodiesel product. Pre-treatment processes may include filtering to remove solid particles, degumming to remove phospholipids, and drying to eliminate water content.

The transesterification reaction is the key step in converting castor oil into biodiesel. It involves the reaction of castor oil with an alcohol, typically methanol, in the presence of a catalyst. The catalyst is used to speed up the reaction and improve its efficiency. Sodium hydroxide (NaOH) or potassium hydroxide (KOH) are commonly used as catalysts in the transesterification of castor oil. These alkaline catalysts are known as homogeneous catalysts [9].

The reaction mixture is prepared by combining castor oil, methanol, and Pottasium hydroxide is used as catalyst as the reaction takes place in a vessel. The ratio of castor oil to methanol in the mixture was set to 1:6. The reaction vessel is heated and agitated to maintain the appropriate temperature for the transesterification process, usually around 60°C. The agitation helps to improve the contact between the reactants and enhances the reaction kinetics. During transesterification, the triglycerides present in castor oil undergo a chemical reaction with methanol. The esterification of the triglycerides results in the formation of methyl esters, which are the main components of biodiesel. Simultaneously, glycerol, a byproduct of the reaction, is produced. The transesterification process facilitates the separation of methyl esters from glycerol, usually through a settling or centrifugation process. The resulting castor oil methyl ester, or biodiesel, can be used as a renewable and environmentally friendly alternative to conventional diesel fuel. It possesses similar properties to diesel fuel, making it compatible with existing diesel engines and infrastructure. Biodiesel exhibits lower emissions of particulate matter, carbon monoxide, and sulfur compounds compared to fossil diesel. Additionally, its production from renewable sources contributes to the reduction of greenhouse gas emissions and dependence on non-renewable fossil fuels.

Synthesis of SiO_2 nanoparticles

The first step is selecting a suitable precursor for the synthesis of silica nanoparticles. Commonly used precursors include Tetraethyl Ortho Silicate (TEOS). These precursors serve as a source of silicon for the formation of silica nanoparticles. The sol-gel method is a widely employed technique for synthesizing silica nanoparticles. For Sol Gel process the apparatus includes basic glassware like beakers and flasks, precision balances for precise measurements, magnetic stirrers for efficient mixing, and ovens for thorough drying and calcination. The ultrasonic bath facilitated the dispersion of nanoparticles within the sol-gel solution, ensuring homogeneity. Essential reagents and chemicals, including metal alkoxides, solvents, and acids, were carefully employed. In this method, the precursor (e.g., TEOS) is mixed with a solvent, usually ethanol or water, and a catalyst, such as ammonia or an acid, to initiate the hydrolysis and condensation reactions [10].

The precursor solution undergoes hydrolysis, which involves the reaction between the precursor and water molecules. During hydrolysis, the precursor breaks down, resulting in the formation of silanol groups (Si-OH) and alcohol molecules. This step is crucial for generating reactive sites necessary for the subsequent condensation reaction. Following hydrolysis, the silanol groups present in the solution begin to condense, leading to the formation of silica nanoparticles. This condensation reaction can be facilitated by adjusting the pH of the solution using a base or acid. The pH conditions influence the rate and extent of condensation and play a crucial role in controlling the size and morphology of the resulting nanoparticles. To enhance the stability and compatibility of the synthesized silica nanoparticles with castor oil methyl ester, surface modification can be performed. Surface modification involves coating the nanoparticles with organic molecules or polymers. This step improves the dispersibility of the nanoparticles and helps prevent their agglomeration or settling in the biodiesel fuel. Once the synthesis is complete, the synthesized silica nanoparticles need to be characterized to determine their size, morphology, and surface properties.

Blending and characterization

Initially 20% blend of castor oil methyl ester with 80% diesel by volume was prepared. After the preparation of 20% blend of Castor oil methyl ester Silica dioxide nanoparticle additive blend is prepared with 3 propositions (5 ppm, 10 ppm and 15 ppm). 20% blend of castor oil methyl ester is termed as B20 blend, while blends with 5 ppm, 10 ppm and 15 ppm along with B20 blend are termed as B20S5, B20S10 and B20S15 respectively. Calorific value is equivalent to amount of energy liberated when 1 kg of fuel is burnt. Calorific value was measured using an instrument called Bomb Calorimeter. With the increase in Concentration of SiO_2 nano particles the Calorific value increases as a result of improved thermal conductivity of nano particles [11]. The physiochemical properties of blends used in this investigation is given in Table 1 given below.

Table 1. Physiochemical properties of blends used

Property	Unit	B20	B20S5	B20S10	B20S15
Calorific value (kJ/kg)	kJ/kg	39600	40010	41250	41870
Flash point (^0C)	^0C	47	45	43	41
Cloud Point ((^0C)	^0C	-7	-6	-6	-5
Density (kg/m^3)	kg/m^3	870	877	883	888
Viscosity (cSt)	cSt	4.2	4.4	4.6	4.8

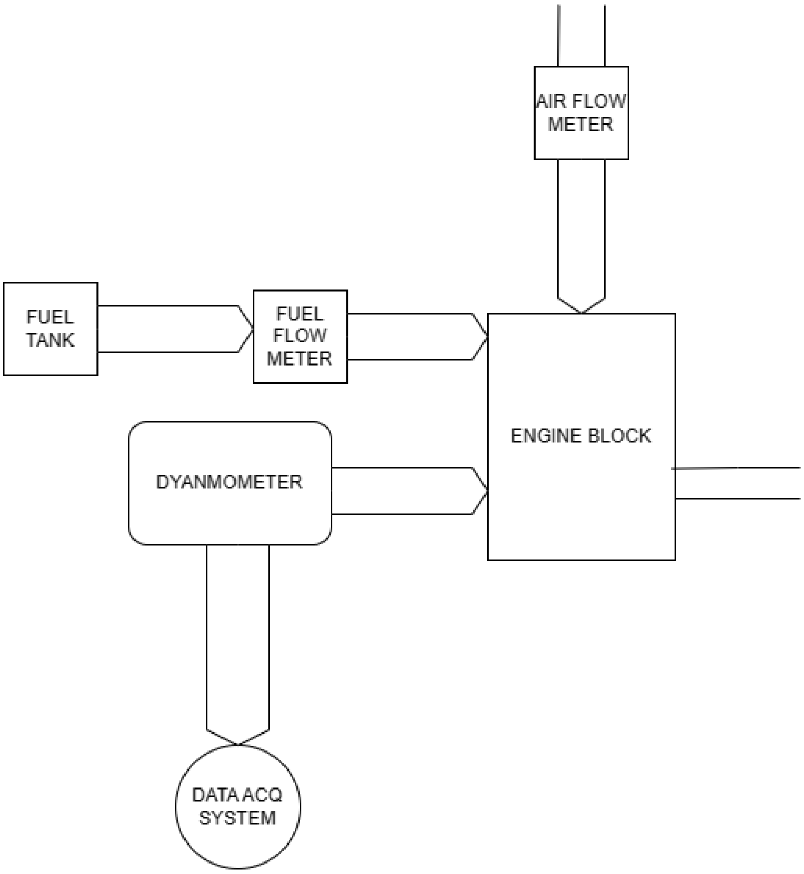

Fig. 1. Experimental layout

The experimental investigations are carried out in Kirloskar single cylinder diesel engine of rated power of 3.5 kW at 1500 rpm. Bore diameter is 87.5 mm and stroke length of 110 mm. The experiments were conducted at a compression ratio of 17. The test set up is coupled with Data acquisition system powered by engine soft software. The emissions were measured using AVL gas analyzer.

Results and discussions

Brake thermal efficiency

Brake thermal efficiency is representation of percentage of energy from fuel converted to power. As the calorific value of fuel rises with increase in the composition of nanoparticle, the brake thermal efficiency increases with increase of composition of nanoparticle. With increasing load the brake thermal efficiency increases as a result of increased in cylinder temperature [12]. Highest Brake Thermal Efficiency of 49% was observed with 20% blend of castor oil methyl ester (B20S15) with 15 ppm of SiO_2. Fig. 2 depicted below shows the variation of brake thermal efficiency with load and blends.

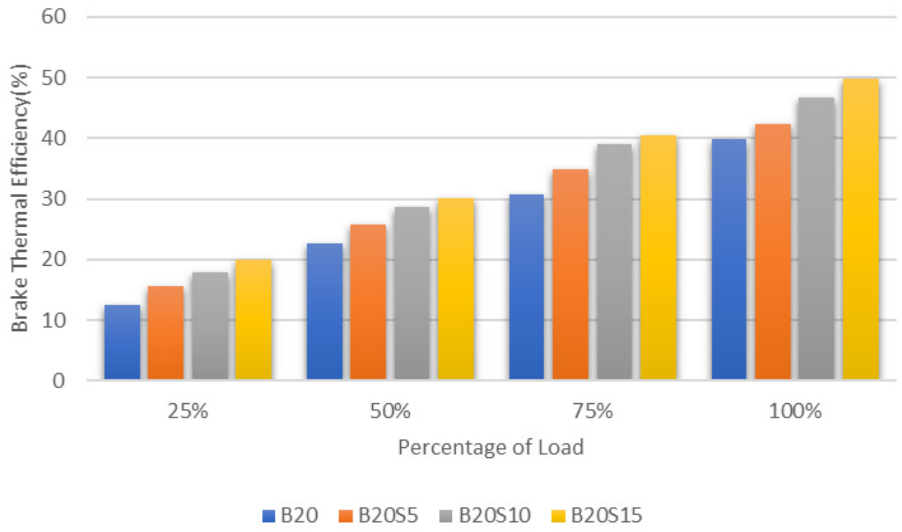

Fig. 2. Percentage of load vs brake thermal efficiency

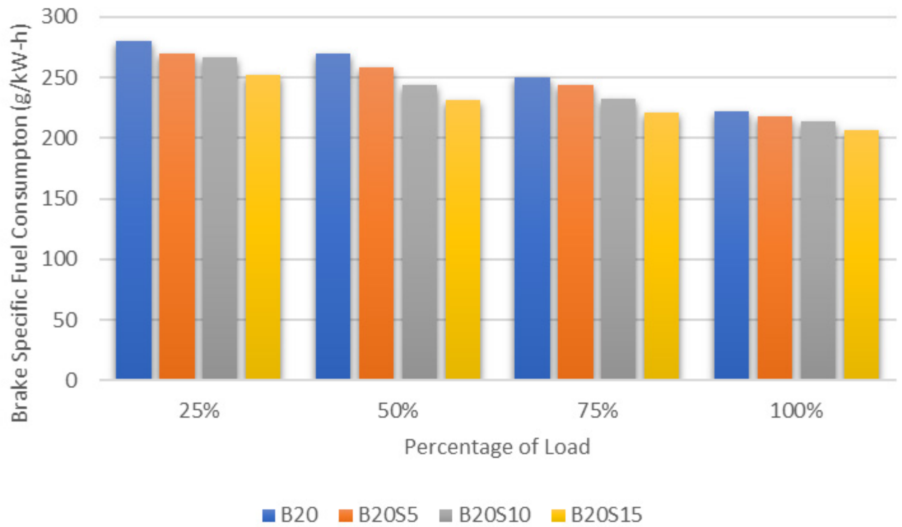

Fig. 3. Percentage of load vs brake specific fuel consumption

Brake specific fuel consumption

Brake specific fuel consumption is a measure of quantity of fuel consumed by the engine to deliver a brake power equivalent of 1 kW. Brake specific fuel consumption decreases with increasing load as result of better utilization of fuel by the engine [13]. Brake specific fuel consumption decreases with Increase in proportion of Silica dioxide nanoparticle as a result of superior calorific value [14]. The plot shown in Fig. 3 represents the variation of brake specific fuel consumption with load across all blends in this investigation. Lowest brake specific fuel consumption of 205 g/kW-h was observed with 20% blend of castor oil methyl ester (B20S15) with 15 ppm of SiO_2 nanoparticles.

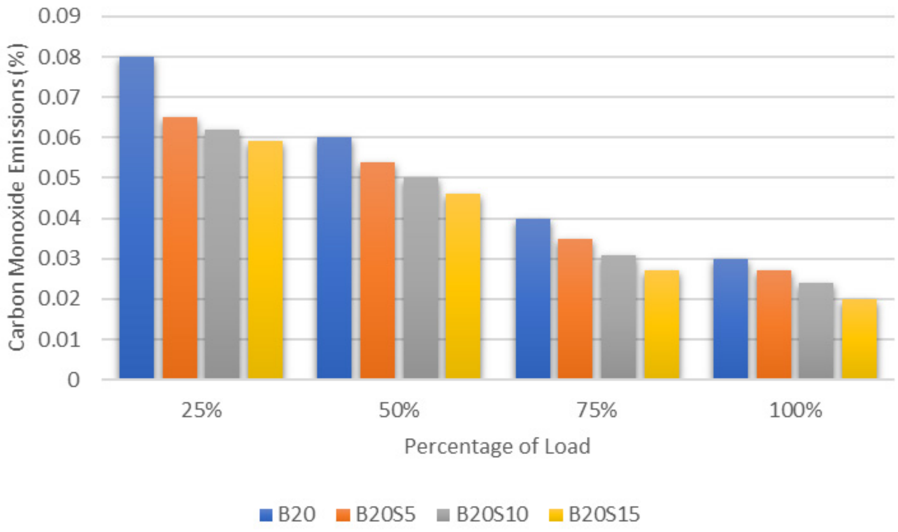

Fig. 4. Percentage of load vs carbon monoxide emissions

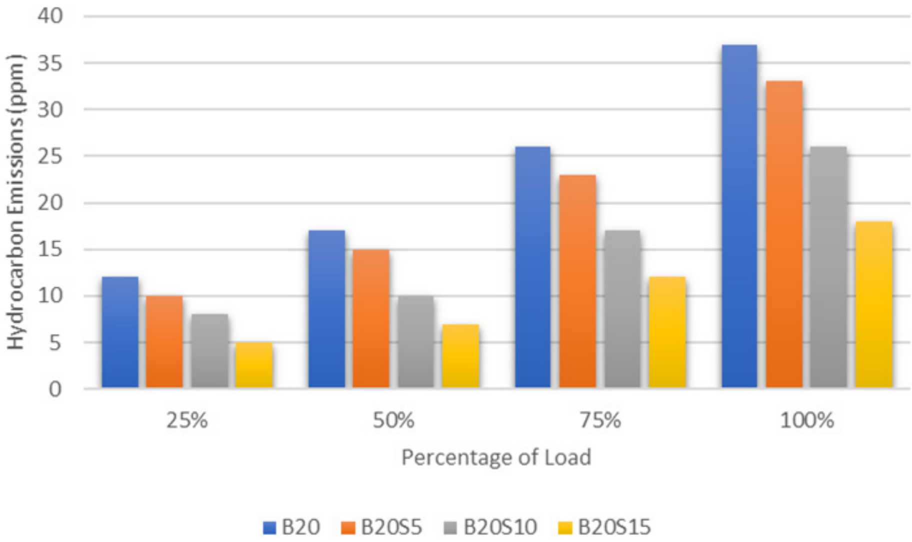

Fig. 5. Percentage of load vs hydrocarbon emissions

Fuels can be chemically characterized with hydrocarbons and fatty acids in methyl ester contains oxygen. Carbon monoxide emissions are formed as a result of incomplete combustion. As it can be inferred from Fig. 4 given below carbon monoxide emissions decreases with the augmentation of engine load [15]. Lowest carbon monoxide emission is observed with 20% blend of castor oil methyl ester (B20S15) with SiO_2 nanoparticles. Analyzing the physiochemical properties of blends used in this investigations, we could infer that calorific value of the fuel increases with the increase of composition of Nanoparticles, the combustion gets better as Nanoparticle composition augments [16] as depicted in figure given below.

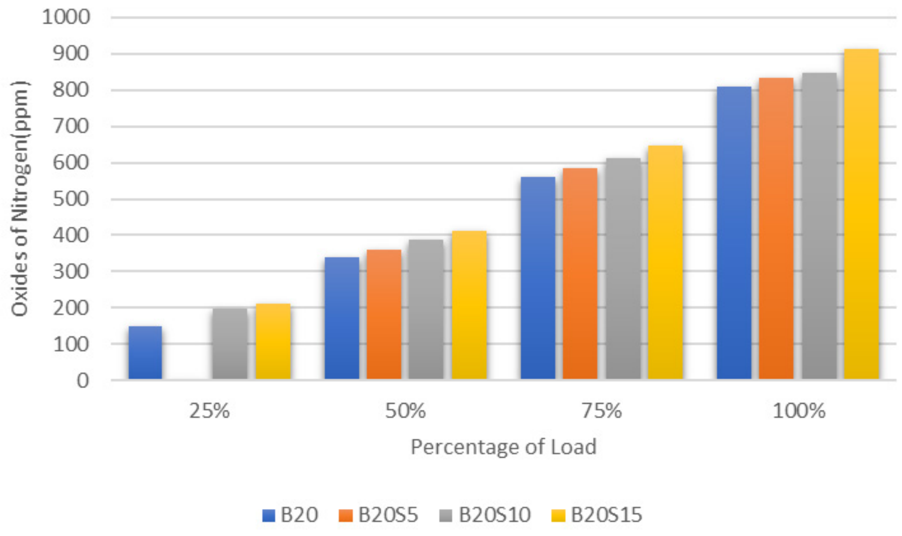

Fig. 6. Percentage of load vs oxides of nitrogen emissions

Hydrocarbon emissions

Hydrocarbon emissions are formed as a result of unburnt hydrogen and carbon chains present after the combustion process. As composition of nanoparticles increases hydrocarbon emissions decreases as the fuel is utilized more effectively as load increases [17]. Increased calorific value with the increase of composition of Nanoparticle composition would increase the possibility of complete combustion thus reducing the probability of formation of Hydrocarbon emissions [18]. Lowest Hydrocarbon emission of 5 ppm is observed at blend of B20S15 blend. Fig. 5 Depicted above graphically represents the variation of Hydrocarbon emissions with respect to percentage of load.

Oxides of nitrogen

The probability of formation of oxides of nitrogen increases with the increase in cylinder temperature. As the load increases the oxides of nitrogen increases as a result of higher combustion temperature [19]. Blends with SiO_2 nanoparticle has a superior calorific value as compared to clean B20 blend and calorific value augments with increase of nanoparticle percentage. With increased calorific value oxides of nitrogen increases with the increase of Additive percentage [20] as depicted in Fig. 6.

Conclusion

A compression ignition engines have wide applications such as generators, locomotives, agricultural equipment's, trucks, marine engines. Exploring the potential of vegetable oils in CI engines and reinstate their significance as fuel is the driving idea of this research work. The experimental investigation of diesel engine powered by castor oil methyl ester with a minor quantum of Nano additives were conducted and following inferences are made. The physiochemical properties of all blends are measured using designated American Society for Testing and Materials (ASTM) standard and the properties align with that of petroleum diesel. brake thermal efficiency rises with the augmentation of load and nanoparticle composition. Brake specific fuel consumption decreases with increase of load while it decreases with increase of nanoparticle composition. Carbon monoxide, hydrocarbon emissions decreases with augmentation of load and increase of nanoparticle composition. Oxides of nitrogen increase due to high in cylinder temperatures. The blend that contains 15% SiO_2 nanoparticles demonstrated superior performance and lower specific fuel consumption compared to all other tested blends. Talking about the emissions, CO and HC emissions are lowest for above blends while oxides of nitrogen increased due to higher in cylinder temperature and better combustion. The present work explores the utility of castor oil methyl ester blends along with Silicon Dioxide nano particles. The scope of further research extends to augmentation of castor oil methyl ester percentage with diesel and varying engine parameters such as nozzle hole configuration, injection pressure and Combustion chamber geometry. The implications of above engine configuration changes while running with blends of castor oil methyl ester blend may also be explored in future.

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Competing interests

The authors declare that they have no known financial or non-financial competing interests in any material discussed in this paper

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Ethical considerations

"Ethical issues (Including plagiarism, Informed Consent, misconduct, data fabrication and/ or falsification, double publication and/ or submission, redundancy, etc) have been completely ob-served by the authors."

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