Effect of Cerium Oxide Nanoparticles Additive Blended in Palm Oil Biodiesel as Alternative Fuel Used in Diesel Engine

Dr. T Srinivasa Rao¹, Dr. H Suresh Babu Rao²,*, S A K Jilani³ and Avinash Mutluri⁴

¹,²,³,⁴Department of Mechanical Engineering, Vasireddy Venkatadri Institute of Technology, Nambur, Peddakakani Mandal, Guntur District, 522508, Andhra Pradesh, India.
²Department of Mechanical Engineering, Chaitanya Bharathi Institute of Technology, Proddatur, India.

* Corresponding author email: hsbr110479@gmail.com

Abstract

In the present study, the effects of adding of cerium oxide (CeO₂) nanoparticle additive as a fuel additive to a palm oil biodiesel-diesel fuel blend on engine performance, and exhaust emissions were studied in a single cylinder four stroke diesel engine under different torque conditions. The test fuels used were fossil diesel fuels, B20 blend biodiesel (as 20% biodiesel and 80% diesel) with cerium oxide (CeO₂) nanoparticle additive (30ppm, 60ppm, 90ppm and 120ppm). The experimental results demonstrated that B20 blend biodiesel at 90ppm of CeO₂ nanoparticles additive found significant reduction emissions nitrogen oxide (NOX), carbon dioxide (CO), unburnt hydrocarbons (UBHC) and smoke. However, brake specific fuel consumption (BSFC) is decreased with significant from increased brake thermal efficiency (BTE) by doping of CeO₂ from 30ppm to 90ppm. B20 biodiesel blend with 90ppm of CeO₂ nanoparticles additive as optimum blend out of the test blends.

Key words: Biodiesel; Calophyllum inophyllum; Cerium oxide nanoparticle; Performance; Exhaust emissions.

1. Introduction

A diesel engine has higher brake thermal efficiency than a petrol engine. Also, they have an advantage of using lesser fossil fuel. Petroleum diesel plays a significant role in the transportation sector, the agricultural sector and industrial growth. However, the total petroleum reserves are depleting day by day due to indiscriminate extraction and lavish consumption [1, 45, 47]. Therefore, the researchers are suggested that biofuels are a viable alternative to diesel fuel in the diesel engine. Biodiesel can be prepared from various renewable feedstocks like vegetable oils - palm oil, sunflower oil, peanut oil etc., are edible oils and jatropha, calophyllum inophyllum, karanja, cotton seed, waste plastic oil, etc., are non-edible oils [3, 6, 8, 10, 44, 46]. The biodiesel properties are like rich oxygen content, higher kinematic viscosity, reduced smoke emission and diluted level of pollutants from engine exhaust (CO, HC and particulate matter). The biodiesel’s emission characteristics are better than petro-diesel fuel except for NOX emission [13]. To control NOX emissions from the C.I engines, various researchers have been described strategies like engine modification like EGR (Exhaust Gas Recirculation), increasing/decreasing injection timing, injection pressure and
adulteration of fuel [25, 27]. Among these fuel alterations with nanoparticles in biodiesel results in reducing the level of pollutants at the engine exhaust and eventually, increases engine performance. Nanoparticle blended with fuel shown better thermal properties, which is mainly due to the higher surface area to volume ratio of the nanoparticles also resulting in increased oxidation of HC and acting as an oxygen buffer against NOX [19].

Many researchers used different additives to biodiesel and found reduced emissions and increased performance [41, 42, 43]. Acetone blended with Palm biodiesel given a significant reduction in HC, NOX, CO and smoke emissions when compared to palm biodiesel [27, 29]. V Sajith et al., 2010 conducted experiments with cerium oxide as nanoparticle additive in Jatropha biodiesel (20ppm, 40ppm & 80ppm) had shown increased brake thermal efficiency by 1.5% and there is a significant reduction of NO by 30% and hydrocarbon emissions by 40%. Ajin et al., 2011 experimentally observed that the CeO₂ as a nano-additive in diesel improved the BTE by 5% and a reduction of HC and NOX emission by 45% and 30% respectively. From the various metal oxides copper, iron, cerium and cobalt have used as fuel additives. Among all nanoparticle’s additives, cerium oxide has exhibited a high catalytic activity due to its high surface-to-volume ratio, which improves the brake thermal efficiency and reduces the emission [15]. Selvan et al., 2009 experimentally investigated the effect of cerium oxide nanoparticle with diesel and biodiesel as fuel in diesel engine and observed the brake thermal efficiency was increased and a drastic reduction in HC and NOX emission. The performance and emission characteristics of the CI engines improves due to the doping of alumina nanoparticles in the biodiesel emulsion fuels, which leads to ignition delay and reduced peak pressure.

*About palm oil*

Oil palm, was growing wild and was a native to West Africa and nowadays it is an agricultural crop. Annually, Oil palm can produce 10 to 34 tons per hectare of oil palm fresh fruit bunches. Palm oil biodiesel has most widely recognized as a potential alternative fuel [2, 13].

Figure 1 shows the various biodiesel feedstock oil yield. Palm oil has shown a high productivity when it is compared to other oils. The palm oil productivity is about 5945 litres per hectare and which is about 14 times higher than soybean oil.

![Figure 1. Various biodiesel feedstock production oil yield [16.]](image-url)
2. Materials and Methods

Preparation of palm oil biodiesel

Different researchers have developed methods for biodiesel preparation from various feedstocks [14, 15, 16]. The following is the process for converting palm oil to biodiesel.

Palm oil is collected and is preheated to 60°C separately. A 0.5g of NaOH and methanol (9:1 methanol to oil ratio) are mixed properly to form Sodium methoxide. The preheated oil is slowly poured in Sodium methoxide, keeping the stirrer on. The mixture is allowed stir in a magnetic stirrer for 1 hour at 400 rpm maintaining 55°C reflux. Then the mixture is poured in separating funnel and left it undisturbed for 1 hour in a separating funnel and thus formed glycerin is removed which are formed at the bottom layer. The top layered oil is required one and it is separated to the next step.

Water washing has done to wash the soaps out of the biodiesel with warm water, 3 to 4 times. Add a small amount of dilute acetic acid in biodiesel before adding the water. Thus, the pH of the solution should be closer to neutral and take out any catalyst suspended in the biodiesel. The biodiesel is water washed gently with warm water at 50°C temperature to remove impurities for three to four times. Then the washed oil is heated above 100°C to remove water particles and excess methanol. Moreover, thus obtained product is the required palm oil biodiesel.

Characterization of Cerium Oxide nanoparticle

There are various methods to synthesis CeO$_2$ precipitation, hydrothermal, sol-gel method, microemulsion method and other methods [23-30]. Among the various preparation methods, microwave-assisted solution method is an inexpensive and simple method to prepare the nanoparticles. The synthesis of CeO$_2$ nanoparticles was done by method - Solvothermal technique [23].

The synthesis of CeO$_2$ nanoparticles has carried out by using Solvothermal technique. X-ray diffraction method (XRD) characteristic peaks corresponding to the (111), (200), (220), (311), (222), (400), (331) and (420) planes are located at 2θ = 28.6°, 33.1°, 47.5°, 56.4°, 59.1°, 69.4°, 76.7° and 79.1° respectively.

![Figure 2. XRD of synthesized cerium oxide nanoparticles.](image-url)
3. Experimental Setup

The experimental investigation was carried out and the properties of modified fuels are compared with diesel fuel. The properties were studied as the calorific value, viscosity, flash point and fire point. The standard ASTM procedures were used during experimentation. The performance tests were conducted on research engine (single cylinder four stroke diesel engine) using test fuels and also, the emission characteristics are studied by using exhaust gas emission analyzer.

A single cylinder, four stroke and water-cooled diesel engine was used to conduct the performance, emission and combustion test. An electrical generator used for loading the engine. AVL 444 N Di-Gas analyzer and AVL 437C Smoke meter were used for emission studies. The following Table 1 is the specifications of the engine:

| Table 1: Specifications of the diesel engine. |
|-----------------------------------------------|
| Type                                           |
| Single cylinder, four stroke, water cooled     |
| diesel engine                                 |
| Stroke                                        |
| 110mm                                         |
| Bore                                          |
| 88mm                                          |
| Rated output                                  |
| 5.2 kW                                        |
| Rated speed                                   |
| 1500 rpm                                      |
| Compression ratio                             |
| 17.5                                          |
| Loading device                                |
| Electric generator                            |

4. Results & Discussions

The findings of diesel engine performance, combustion, and emission characteristics for the diesel, biodiesel blend B20 and CeO₂ nanoparticle as additive to B20 (30ppm, 60ppm, 90ppm and 120ppm) test fuels are discussed in the subsequent sections.

Properties of fuels used

The properties of the above modified fuels along with diesel fuel are shown in Table 2. The various physicochemical properties of the above modified fuels were carried out and the thus obtained results are compared with the pure diesel (D100). The main objective of the investigation was to find the variations in the properties of the fuels also, the effect of the level of inclusion of CeO₂ nanoparticles added to the B20 biodiesel blend. The tested fuels were shown an increasing trend for the flash and fire points with the increase in dosing level, which indicates a continual decrease in the volatility of the test fuels with increases in the quantity of the CeO₂ nanoparticle additive [5, 8]. The CeO₂ nanoparticles additive to the modified fuels shown that the fluid layer resistance has increased and hence the kinematic viscosity [9] also.
Table 2 Properties of the modified fuels and Diesel.

|                        | D100 | B20  | B20+30ppm | B20+60ppm | B20+90ppm | B20+120ppm |
|------------------------|------|------|-----------|-----------|-----------|------------|
| Kinematic Viscosity @40°C in cSt | 2.5  | 3.29 | 3.32      | 3.38      | 3.53      | 3.98       |
| Flash point °C         | 45   | 52   | 56        | 64        | 72        | 74         |
| Fire point °C          | 56   | 59   | 63        | 72        | 79        | 81         |
| Density @15°C in kg/m³ | 834  | 852  | 857       | 860       | 863       | 866        |
| Calorific value in kJ/kg | 42,538 | 41,094 | 41,162    | 41,214    | 41,319    | 41,325     |

Performance and emissions of test fuels on diesel engine

Brake Thermal Efficiency (BTE)

The biodiesel’s BTE is less than diesel fuel [3] due to its lower calorific value. Figure 3 shows variations in the BTE with load for the palm oil biodiesel blends doped with CeO₂ nanoparticles and diesel fuel [41]. The result depicted that the BTE of the diesel engine continuously improved by the increased dosing levels of CeO₂ nanoparticles additive in B20 biodiesel blend. The enhancement in BTE for the CeO₂ nanoparticles additive in B20 biodiesel blend doped fuels from 30ppm to 120ppm is mainly due to the occurrence of better fuel combustion and the nanoparticles doping promoted the combustion in the engine [6, 43]. Above 90ppm dosing level of the CeO₂ nanoparticle increased, due to more agglomeration of particles, the catalytic action was lowered and lessens the BTE at 120ppm. The results depicted that the BTE of blend B20+90ppm of CeO₂ has highest efficiency in the modified blends of biodiesel but less than pure diesel i.e., D100 fuel at all loads.
Figure 3. Variation of brake thermal efficiency (BTE) for modified fuels and diesel.

Brake Specific Fuel Consumption (BSFC)

Due to lower calorific value of the biodiesel's, BSFC of the biodiesel is higher when compared to diesel fuel [3]. Figure 4 shows that the variations in BSFC with load for the palm oil biodiesel blends with CeO\(_2\) nanoparticles doped in biodiesel and diesel fuel. Due to increase in dose of CeO\(_2\) nanoparticles in biodiesel from 30ppm to 120ppm, favoured to enhance the combustion. Therefore, the BSFC decreased with the increased in the dosing levels of the particles, except for B20+120ppm, due to more agglomeration and lowered catalytic action. B20+90ppm blend shown the lower BSFC out of other biodiesel blends except for diesel.
Figure 4. Variation of brake specific fuel consumption (BSFC) for the modified fuels and diesel.

Unburned hydrocarbon (UBHC) emission

UBHC emission of biodiesel is lower than diesel fuel due to lower calorific value and incomplete combustion of fuel. Figure 5 illustrates variation in UBHC emission with load for the palm oil biodiesel blends doped with CeO₂ nanoparticles and diesel fuel. Due to CeO₂ nanoparticles additive doped in biodiesel blends from 30ppm to 120ppm increases the oxidation of hydrocarbon. Therefore, a complete combustion is promoted in the engine. For B20+120ppm, due to more agglomeration and lower catalytic action, the UBHC of B20+90ppm blend is lower than other modified fuels and diesel fuel. The chemical reactions during combustion are:

\[
\frac{(2x + y)CeO_2}{2} + \frac{CH}{x} \rightarrow \left[\frac{(2x+y)}{2}\right]Ce_2O_3 + \frac{x}{2}CO_2 + \frac{y}{2}H_2O \tag{1}
\]

\[
4CeO_2 + S_{saso} \rightarrow 2Ce_2O_3 + CO_2 \tag{2}
\]
Due to low calorific value and incomplete combustion, carbon monoxide emission of the biodiesel is less than diesel. Figure 6 shows the variation in CO emission with load for the palm oil biodiesel blends with CeO$_2$ nanoparticles doped and diesel fuel. The additive CeO$_2$ nanoparticles doped in biodiesels promoted better combustion, CO emissions from the diesel engine depends on the fuel properties, due to the ability of nanoparticles to convert CO to CO$_2$. Therefore, CO of B20+90ppm biodiesel blend is lower than other modified fuels (except B20+120ppm biodiesel blends) and diesel fuel.
Figure 6. Variation of carbon monoxide (CO) for the modified fuels and diesel.

Nitrogen oxides (NOX) emission

Figure 7 illustrates the variation in NOX emission with load for the palm oil biodiesel blends with CeO2 nanoparticles doped and diesel fuel. The CeO2 nanoparticles additive doped in biodiesel blends from 30ppm to 120ppm. The NOX emission has increased, in order to reduce it, CeO2 nanoparticles additive added to B20 biodiesel blend. Due to high thermal stability, oxidation of hydrocarbon forms Ce2O3 is formed equation (2) and again reduction of NO occur due to deoxidizing to CeO2. The chemical reaction during combustion is:

$$Ce_2O_3 + NO \rightarrow 2CeO_2 + \frac{1}{2}N_2$$

(3)

Therefore, due to the CeO2 nanoparticles additive to biodiesel blends, lower NOx emission occurs for the modified fuels doped up to 90ppm, and the NOx emission B20+90ppm biodiesel blend are lower than other modified fuels except for B20+120ppm biodiesel blend.
Figure 7. Variation of Oxides of Nitrogen (NO\textsubscript{x}) for the modified fuels and diesel.

Smoke Emissions

Figure 8 demonstrates the variation in smoke emission with load for the palm oil biodiesel blends with CeO\textsubscript{2} nanoparticles doped and diesel fuel. The CeO\textsubscript{2} nanoparticles additive doped in biodiesel blends from 30ppm to 120ppm, the decreased in smoke emission are detected due to higher surface area to volume ratio and improved combustion. Therefore, with increase in dosing of the nanoparticles, the smoke emission was reduced except for B20+120ppm. Hence, smoke emission of B20+90ppm blend is lower than other modified fuels and diesel fuel.
5. Conclusions

The outcome of the experimental investigation work was observed and the following effects on performance and emission of engine by CeO$_2$ nanoparticles doping in B20 palm oil biodiesel blends at 30ppm to 120ppm:

- A maximum increment of 1.23% in BTE and a maximum of 2.56% decrement in BSFC by CeO$_2$ nanoparticles doping in B20 biodiesel blend palm oil was found in B20+90ppm biodiesel blend at maximum load.
- A maximum reduction in unburned hydrocarbon and carbon monoxide emissions were observed by CeO$_2$ nanoparticles doping in palm oil B20 biodiesel blend is 19.7% and 15.4% respectively.
- Smoke and NOx emissions were reduced by CeO$_2$ nanoparticles doping in palm oil B20 biodiesel blend with maximum reduction of 4.6% and 5.9% respectively in biodiesel blend B20+90ppm.

Therefore, from the experimental investigation work concluded that B20+90ppm of palm oil biodiesel blend as best biodiesel blend of modified fuels and can be considered as an alternative fuel for the diesel engine.

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