MECHANICAL ENGINEERING | RESEARCH ARTICLE

Impact of alumina and cerium oxide nanoparticles on tailpipe emissions of waste cooking oil biodiesel fuelled CI engine

Pijakala Dinesha¹, Sooraj Mohan¹ and Shiva Kumar¹*

Abstract: Biofuels are one of the most sought-after renewable energy sources to overcome the current energy crisis in the world. Diesel blended with esters derived from oils has shown appreciable results for its use in compression ignition engines. In this work, B20 (20% biodiesel + 80% diesel by volume) fuel blend comprising 80% diesel and 20% biofuel extracted from waste cooking oil is used as a fuel. Two different metallic oxide nanoparticles (NPs), namely, cerium oxide (CeO₂) and aluminium oxide (Al₂O₃) each having size of 30 nm, are dispersed in B20 biodiesel blend and used to investigate their combined influence on engine combustion. Experiments are conducted to study the engine exhaust emissions of a single cylinder four-stroke diesel engine running at constant speed of 1,500 rpm with varying engine loads. Experiments are carried out with B20 fuel and adding mixtures of CeO₂ and Al₂O₃ nanoparticles in 50–30, 40–40 and 30–50 ppm, respectively, to B20 biodiesel blend. Responses recorded are the emissions of CO, HC, CO₂, NOx and smoke. The results reveal that, on adding the nanoparticles, the engine observed a smooth combustion with reduction in the exhaust emissions compared to neat B20 biodiesel operation. B20 blend with 50 ppm of CeO₂ and 30 ppm of Al₂O₃ nanoparticles showed lower exhaust emissions compared to other fuel blends. For the best fuel blend, CO, HC, NOx and smoke are reduced by 57.3%, 22.3%, 24.3% and 7.36%, respectively, compared to neat B20 operation.

Subjects: Renewable Energy; Energy & Fuels; Bio Energy

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PUBLIC INTEREST STATEMENT

In the present study combined influence of Al₂O₃ and CeO₂ nanoparticle in B20 biodiesel has been investigated on the emission characteristics of biodiesel fueled diesel engine run with blends of waste cooking oil ester. Nanoparticles combinations of CeO₂ and Al₂O₃ nanoparticles in 50-30, 40-40 and 30-50 ppm respectively used. NOx, CO HC and CO₂ emissions are measured for the nanoparticle blended fuel and are compared with the base line data of neatWCO operation. B20 blend with 50 ppm of CeO₂ and 30 ppm of Al₂O₃ nanoparticles showed lower exhaust emissions. It is concluded that optimum combination of Al₂O₃ and CeO₂ nanoparticles are useful for reduction in the exhaust emission from the diesel engines.
Keywords: Alumina; biodiesel; engine; combustion; emissions; nanoparticles

1. Introduction

Energy crisis and environmental pollution are the major issues resulting from industrialization and transportation sectors. In the transport sector, the major contribution of toxic pollutants to the environment is by diesel engine vehicles. Due to higher fuel economy and thermal performance, diesel engines are generally used in transport vehicles as public transport and goods carrier vehicles. Use of fossil-derived fuels in diesel engines increases the environmental pollution due to toxic exhaust gases such as carbon monoxide (CO), unburnt hydrocarbon (HC), oxides of nitrogen (NOx) and smoke. Also, the increased use of these fuels results in an energy crisis. Several studies have been reported by the researchers, which demonstrate the use of mineral diesel fuels in compression ignition engines and their ill effects to the environment (Geng et al., 2017). These issues can be effectively solved by using sustainable energy resources in engines. Sustainable energy resources are renewable and environment-friendly fuels. Biofuels are such kind of fuels which directly and indirectly help to minimize the environmental degradation. Use of biofuels in diesel engines is the most prominent method by which sustainable resources such as plant or animal-based oils are used to produce biodiesel. Though the biodiesel is eco-friendly and renewable in nature, its higher viscosity and lower calorific value limit the direct use in diesel engines. Biodiesel has higher viscosity, which causes poor penetration, atomization and mixing of fuel droplets, resulting in incomplete combustion. Lesser calorific value and higher viscosity of biodiesel fuel result in increased specific energy consumption, which in turn causes lower brake thermal efficiency.(Cheikh et al., 2016)

Several studies have been conducted all over the world (Kumar et al., 2019; Safieeddin Ardebeni et al., 2021, 2020; Uyumaz et al., 2020) and reported the influence of blending of biodiesel with mineral diesel on engine combustion and emissions. Some studies reported that the viscosity and volatility of biodiesel can be improved by adding oxygenated additives.(Ayhan et al., 2020) Use of these methods improves the thermal efficiency. The major disadvantage of biodiesel is its higher NOx emission. This may be due to the inbuilt oxygen content, which may take part in oxidation of nitrogen. Several methods are available and used to minimize NOx emissions of which exhaust gas recirculation (EGR), water emulsion and water injection are the simplest and most economical methods. The use of these methods in engines minimizes NOx emission and also deteriorates the engine efficiency with increase of other emissions.(Zhang et al., 2019)

1.1. Use of metallic nanoparticles (NPs) in biodiesel engine

Use of metallic NPs as a fuel additive is another novel method to reduce engine exhaust emissions without changing the engine performance. Thermal and chemical properties of NPs improve the combustion process in engines. Nano-sized particles in suspension form distribute the fuel droplets evenly throughout the combustion chamber. Figure 1 shows the atomization of NPs dispersed in biodiesel droplets in the combustion chamber. Superior thermal conductivity of NPs increases the heat transfer rate between these dispersed fuel droplets and also promotes rapid auto-ignition of the fuel droplets. Some of the NPs also act as a catalyst in fuel combustion and enhance the combustion rate by minimizing the unburnt reactants in the exhaust gas. There are several studies which revealed the use of different types of metallic oxide NPs as an additive to fuel blend.(Kumar, Dinesha, Bran et al., 2019; Saigeen & Sajith, 2013; Yaşar et al., 2019). Kumar et al. (Kumar, Dinesha, Bran et al., 2017) reported the use of 1% by volume of ferrofluid in B20 biodiesel resulted in maximum efficiency with reduced emissions.

1.2. Use of cerium oxide nanoparticles

Ceria is naturally available in +3 and +4 valance state. It is also known as cerium oxide or cerium dioxide with the general chemical formula CeO₂. Though it is available in two valance states, +4 valence state has a strong oxidizing tendency due to its non-trivalent nature. The structure of CeO₂ NPs is shown in Figure 2, and the general physicochemical properties are given in Table 1.
When CeO$_2$ is heated to high temperature, it liberates oxygen due to the ionic transformation from $+4$ to $+3$ valance state as shown in Eq. (1). (Mehrizi et al., 2018) Ionic transformation reaction is a low-energy reaction, and this encourages the use of cerium oxide as a combustion catalyst.

$$2\text{CeO}_2 \rightarrow \text{Ce}_2\text{O}_3 + 0.5\text{O}_2 \tag{1}$$

In biodiesel and HC combustion, CeO$_2$ plays a major role to achieve complete combustion by reducing HC and soot particles. The following chemical equations demonstrate these phenomena.

$$\left(2x + y\right)\text{C}_x\text{O}_y + \text{C}_n\text{H}_y \rightarrow \left[\frac{\left(2x + y\right)}{2}\right] \text{Ce}_2\text{O}_3 + \frac{x}{2}\text{CO}_2 + \frac{y}{2}\text{H}_2\text{O} \tag{2}$$

$$4\text{CeO}_2 + \text{C}_{\text{soot}} \rightarrow 2\text{Ce}_2\text{O}_3 + \text{CO}_2 \tag{3}$$

Another important advantage of CeO$_2$ is the reduction of NOx concentration. Ce$_2$O$_3$ formed during the combustion of fuel reacts with NOx and results in CeO$_2$ and nitrogen as shown Eq. (4).

$$\text{Ce}_2\text{O}_3 + \text{NO} \rightarrow 2\text{Ce}_2\text{O}_2 + \frac{1}{2}\text{N}_2 \tag{4}$$

Superior thermal conductivity of CeO$_2$ improves the heat transfer tendency. When the nanosized NPs dispersed in the fuel blend, promote the heat transfer rate between the fuel droplets. This reduces the delay period of the injected fuel and helps to undergo normal combustion without knocking. (Kumar et al., 2020)

The applications of CeO$_2$ NPs in biodiesel combustion have been studied by various researchers worldwide. Use of CeO$_2$ NPs reduces the engine emissions such as CO, HC, smoke and NOx emissions by a series of catalytic oxidation and reduction reactions with improved engine efficiency. (Sajeewan & Sajith, 2013; Xin et al., 2013) Kumar et al. (Kumar et al., 2020) reported that the use of CeO$_2$ NPs in B30 and B40 biodiesel blend improved performance with reduced emissions. Venkatesan et al. (Venkatesan et al., 2019) conducted experiments and tested the performance and emissions of a biodiesel fuelled engine. They used lemongrass biodiesel with 30 ppm CeO$_2$ NPs as additive. The test results showed 17.2% increase in BTE and a noticeable decrease in CO, HC and NOx emissions. Kumar et al. (M.V. Kumar et al., 2019) reported better engine performance and reduced emissions for B20 biodiesel blend with 150 ppm CeO$_2$ NPs combinations. Kapoor et al. (Kapoor et al., 2020) observed higher BTE and lower emissions for 100 ppm CeO$_2$ NPs-doped neem
oil and diethyl ether blend. The summary of literature related to CeO\textsubscript{2} NPs-doped fuel combustion is given in Table 2. The use of CeO\textsubscript{2} NPs-doped fuel combustion improves the engine efficiency with minimum exhaust emissions.

### 1.3. Use of alumina (Al\textsubscript{2}O\textsubscript{3}) nanoparticles

Alumina is a general name of aluminium oxide, which is a chemical compound having aluminium and oxygen. It is available naturally as α-Al\textsubscript{2}O\textsubscript{3}, which is in crystalline polymorphic phase. The chemical structure of Al\textsubscript{2}O\textsubscript{3} is shown in Figure 3, and the physicochemical properties are given in Table 3. Alumina has a very high thermal conductivity of 30 W m\textsuperscript{−1}K\textsuperscript{−1} and non-conductor of electricity. Al\textsubscript{2}O\textsubscript{3} in nanoparticle form is commonly used in heat exchangers to enhance heat transfer. It is also used as a fuel additive to improve the combustion. Due to its higher thermal conductivity, it enhances the rate of heat transfer between the fuel droplets. Several literature have been reported on the use of Al\textsubscript{2}O\textsubscript{3} NPs as the fuel additives in biodiesel fuel engine. (Hosseini et al., 2017; Prabu et al., 2019; Roy et al., 2020; Soudagar et al., 2020)

Researchers have tried using the nano-sized particles of Al\textsubscript{2}O\textsubscript{3} and analysed the engine combustion behaviour. Prabu et al. (Prabu et al., 2019) investigated the influence of Al\textsubscript{2}O\textsubscript{3} NPs on the performance and emissions of a diesel engine operated with aloe vera biodiesel blend. They observed minimum engine emissions with 3% reduction in brake thermal efficiency when compared to diesel. Soudagar et al. (Soudagar et al., 2020) conducted experiments in a diesel engine using honge methyl ester B20 blend with 20, 40 and 60 ppm of Al\textsubscript{2}O\textsubscript{3} NPs. The results showed

![Figure 2. Chemical structure of CeO\textsubscript{2}](image2)

![Figure 3. Chemical structure of Al\textsubscript{2}O\textsubscript{3}](image3)

| Table 1. Physicochemical properties of CeO\textsubscript{2} | Description |
|-----------------------------------------------------------|-------------|
| Chemical name                                             | Cerium oxide (CeO\textsubscript{2}) |
| particle size (average)                                    | 30 nm       |
| Molecular weight                                           | 172.115     |
| Appearance                                                | Pale yellow-white |
| Density                                                   | 7650 kg m\textsuperscript{−3} |
| Conductivity                                              | 12 W m\textsuperscript{−1}K\textsuperscript{−1} |
improved performance with reduced emissions of HC, CO and smoke for 40 ppm NPs-doped fuel blend. They reported increased NOx emissions for all combinations of NPs-doped fuel blends.

The major literature reported reveal that the use of Al₂O₃ NPs-doped biodiesel blends increases NOx emissions. Roy et al. (Roy et al., 2020) reported higher NOx emission for all combinations of biodiesel blends with 100 ppm NPs. Similarly, Hosseini et al. (Hosseini et al., 2017) observed increased NOx for 30, 60 and 90 ppm NPs with B5 and B20 WCO biodiesel blends. The use of Al₂O₃ NPs increases the combustion temperature which favours the condition for the NOx formation. Catalytic action of Al₂O₃ helps to minimize CO, HC and smoke emissions. But in most of the cases, it acts negatively on the control of NOx emission. A summary of the literature based on Al₂O₃ NP combustion is given in Table 4.

1.4. Motivation to the present study
From the thorough literature survey, it can be observed that the researchers have reported improved performance and reduced emissions for CeO₂ NPs-doped biodiesel combustion. CeO₂ acts as a catalyst in combustion and not only promotes complete combustion but also helps in the
reduction of all toxic pollutants including NOx. The major disadvantage of this NP is that it is rare-earth material and costs high. This limits the use of CeO\textsubscript{2} NPs in engine applications.

From Table 4, it is clear that the use of Al\textsubscript{2}O\textsubscript{3} NPs improves performance with reduced emission except NOx. Al\textsubscript{2}O\textsubscript{3} NPs enhances the combustions by atomization, dispersion and effective heat transfer between the fuel droplets. But there is no catalytic activity to reduce emissions. There is no positive impact of this NPs on NOx reduction. Though the Al\textsubscript{2}O\textsubscript{3} NPs are cheaper, they produce more NOx compared to neat fuel combustion without NPs. This limits the use of Al\textsubscript{2}O\textsubscript{3} NPs in engine applications. The disadvantages of CeO\textsubscript{2} and Al\textsubscript{2}O\textsubscript{3} NPs can be improved by mixing these NPs in different volume fractions. But studies related to the combined effect of two types of metallic NPs with biodiesel blends on the combustion and emission characteristics of a diesel engine are scanty. Hence an effort has been made in the present study to investigate the combined effect of CeO\textsubscript{2} and Al\textsubscript{2}O\textsubscript{3} NPs with B20 waste cooking oil biodiesel on the engine exhaust emission of a diesel engine. Literature (Kumar et al., 2019) shows that by using 80 ppm of cerium oxide nanoparticles with biodiesel would reduce the emissions to maximum extent. In addition to
cerium oxide NPs, Al2O3 NPs also added at different volume proportions to meet 80 ppm concentration to investigate the combined influence on engine emissions.
2. Materials and methods

2.1. Fuel blend preparation
Edible vegetable oil is widely used in frying and cooking purposes. Due to their repeated use may convert them into polycyclic aromatic HCs, dioxins, etc., which are toxic in nature and may cause severe health issues in human beings if consumed. Hence, value-added use of WCO includes soaps, lubricants and as a domestic fuel. The calorific value of WCO is at par with that of other vegetable oil-derived fuels. Properties of WCO biodiesel are comparatively similar to mineral diesel. Hence, it can be used as an alternative diesel engine fuel. The WCO biodiesel is procured from the local biofuel development centre. The WCO biodiesel is blended with diesel in a volume proportion of 20% biodiesel and 80% diesel. From the literature, it is revealed that B20 blend exhibits improved performance with lower emissions compared to other biodiesel blends. (Kumar, Dinesha, Bran et al., 2017) The physicochemical properties of the fuel blend have been determined as per ASTM standards and given in Table 5.

2.2. Experimental setup and experimentation
A set of experiments are conducted using a four-stroke single-cylinder diesel engine and are shown in Figure 4. Loading is applied by using eddy current dynamometer. Fuel consumption rate is measured using burette, and the time taken for the consumption of fuel is noted. Air is supplied to the engine inlet through orifice meter. Engine speed is maintained constant at 1,500 rpm, and the speed sensor is used to record the engine speed. First, the engine is run at no load condition for about 20 min and then loaded for 25%, 50%, 75% and 100% of full load condition. Experimental readings are recorded after 5 min of engine operation at the particular load condition. The engine exhaust emissions such as CO, HC, CO₂ and NOx are recorded by using AVL five gas analyser. AVL smoke meter is used to measure the smoke opacity. Engine exhaust emission parameters such as CO, HC, CO₂, NOx and smoke are noted and analysed for all test fuel variants, and the results are compared with baseline B20 operation. Two types of NPs, namely, CeO₂ and Al₂O₃ having 30 nm size, are selected and mixed with B20 biodiesel blend at different volume concentrations. Three types of fuel blends are prepared by combining these NPs at 40–40, 30–50 and 50–30 ppm of CeO₂ and Al₂O₃, respectively. The NPs are properly dispersed using 2% of Triton-X surfactant. These three fuel blends are prepared separately and used for the experimentation.

3. Results and discussion
A number of tests are performed in a diesel engine, and the exhaust emission characteristics are analysed at different load conditions. The engine exhaust emission parameters such as CO, HC, CO₂ and NOx are analysed and discussed. The results are compared with neat B20 operation.
Table 4. Summary of literature related to $\text{Al}_2\text{O}_3$ NPs-doped fuel combustion

| Reference                          | Fuel and NP combinations                                                                 | Outcomes                                                                                           |
|-----------------------------------|------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------|
| Soudagar et al. (Soudagar et al., 2020) | Hanoe methyl ester B20 with 20, 40 and 60 ppm $\text{Al}_2\text{O}_3$ NPs               | B20 with 40 ppm NPs showed higher BTE with reduced emissions of CO, HC and smoke. But 11. 27% increase in NOx. |
| Roy et al. (Roy et al., 2020)      | B10, B20 and B30 WCO biodiesel with 100 ppm $\text{Al}_2\text{O}_3$ NPs                  | Reduced emissions of CO, HC and smoke. Small increment in NOx emissions for NPs doped biodiesel blends. |
| Venkatesh et al. (Venkatesh & Prasanthi, 2020) | Coconut oil biodiesel with $\text{Al}_2\text{O}_3$ NPs                                  | Higher BTE and lower emissions.                                                                      |
| Ramesh et al. (Ramesh et al., 2018) | B20 poultry litter biodiesel with 30 mg/l $\text{Al}_2\text{O}_3$ NPs                   | Considerable reduction in CO, HC and NOx emissions.                                                  |
| El-Seesy et al. (El-Seesy et al., 2018) | B20 jojoba biodiesel with $\text{Al}_2\text{O}_3$ NPs at 10–50 ppm/l in step of 10 mg/l | Improved engine performance and reduced emissions for B20 with 30 mg/l NPs.                         |
| Kana et al. (Kana & Shojia, 2019)  | Waste Avocado biodiesel B20 with manganese doped 30, 60 and 90 ppm $\text{Al}_2\text{O}_3$ NPs | Improved performance and reduced emissions for B20 with 90 ppm NPs.                                |
| Anehupogu et al. (Anehupogu et al., 2018) | B20 biodiesel with 40 ppm $\text{Al}_2\text{O}_3$ NPs and 20% EGR                      | Better performance and emissions for B20 with 40 ppm NPs. There is no positive impact of EGR on the study. |
| Gurusala et al. (Gurusala & Selvan, 2015) | Waste chicken fat biodiesel with NPs B20 and B40 with 25 and 50 ppm $\text{Al}_2\text{O}_3$ NPs | Improved performance and reduced emissions except NOx.                                               |
| Venu (Venu, 2019)                  | Diesel, biodiesel and ethanol blend in proportion of 70 + 20 + 10 by volume with 10, 20 and 30 ppm NPs | Improved performance and reduced emissions for the fuel blend with 20 ppm NPs.                      |
| Sivakumar et al. (Sivakumar et al., 2018) | B25 biodiesel with 50 and 100 ppm $\text{Al}_2\text{O}_3$ NPs                          | Enhanced performance and reduced emissions for NP-doped fuel except NOx emission.                  |

3.1. CO emission

Figure 5 illustrates the variation of CO emission for various fuels at different loads. CO emission is minimum at part load conditions and reaches maximum value at full load condition. At full load, a large amount of fuel is injected into the combustion chamber, and a rich fuel-air mixture is formed. Lack of oxygen is available during the combustion, which causes CO formation instead of CO$_2$. Neat B20 biodiesel has higher viscosity, which causes poor atomization and dispersion of the injected fuel droplets. When NPs are added to the fuel blend, it improves the atomization and distribution of fuel due to increased heat transfer characteristics. (Akram et al., 2019; Kumar et al., 2020; Venkatesan et al., 2019) Compared to CeO$_2$, $\text{Al}_2\text{O}_3$ has higher thermal conductivity, which helps as a heat carrier between the fuel droplets. CeO$_2$ has more influence on combustion of fuel by reducing carbon activation temperature. The combined effect of these two types of metallic oxide NPs improves the combustion process and reduced CO emission is obtained. Among these NPs with added fuel variants, B20 with 30 ppm $\text{Al}_2\text{O}_3$ and 50 ppm CeO$_2$ produce minimum CO emissions.
3.2. HC emission
The variation of unburnt HC emission at different loads is depicted in Figure 6. HC emission also follows a similar trend of CO emission, that is, at part load conditions is lower HC emission and increases as the load is increased. This may be due to several reasons, such as poor atomization, distribution of fuel droplets, incomplete combustion due to lack of oxygen or wall quenching. Due to these reasons, neat B20 has higher HC emissions compared to other fuels. When NPs are added, the problems associated with HC emissions are solved and lower HC emission is obtained. (Kumar et al., 2020) Higher volume concentration of Al₂O₃ has no remarkable benefits on HC emissions. (Soudagar et al., 2020) The fuel blend B20 with 30 ppm Al₂O₃ and 50 ppm CeO₂ produces minimum HC emissions compared to other test fuel combinations.

3.3. Carbon dioxide (CO₂) emission
Emission of carbon dioxide is the indication of combustion nature of the fuel injected. The higher the CO₂ emission, the more complete combustion. Atomization, dispersion, mixing of fuel droplets and availability of oxygen decide the combustion of the injected fuel. B20 shows higher CO₂ emission, which may be due to its poor dispersion and uneven mixing of large-sized fuel droplets. Figure 7 shows the CO₂ emission characteristics of various fuels at different loads. When nanoparticles are added to B20 blend, they improve the fuel mixing and undergo uniform distribution throughout the combustion chamber. This

![Figure 9. Variation of smoke opacity for different nanoparticle combinations.](image)

| Property                  | Diesel | WCO neat biodiesel | B20 biodiesel |
|---------------------------|--------|--------------------|---------------|
| Density (kg m⁻³)          | 825    | 880                | 840           |
| Lower calorific value (MJ kg⁻¹) | 43.2   | 39.6               | 40.8          |
| Kinematic viscosity (mm² s⁻¹) | 3.85   | 5.3                | 4.09          |
| Cetane number             | 60.2 (Abed et al., 2018) | 63.63 (Abed et al., 2018) | 60.71 (Abed et al., 2018) |
| Flash point (°C)          | 55     | 135                | 65            |
reduced the tendency of CO formation. (Kana & Shaija, 2019; M.V. Kumar et al., 2019; Ramesh et al., 2018) The presence of Al2O3 improves the atomization and distribution of fuel droplets and increases the heat transfer between them. The presence of CeO2 NPs improves the combustion of carbon by catalytic oxidation process. CeO2 NPs reduce the carbon activation temperature and help the fuel droplets to undergo combustion at lower temperature. (Kumar et al., 2020) This results in increased formation of CO2. Higher volume concentration of Al2O3 has no significant effect on CO2 emissions. The fuel blend B20 with 30 ppm Al2O3 and 50 ppm CeO2 NPs produces maximum CO2 emissions compared to other test fuel combinations.

3.4. NOx emission

Figure 8 demonstrates the variation of NOx emission. The formation of NOx is due to many reasons, the important ones being (1) combustion temperature, (2) oxygen content and (3) residual time. If these factors are controlled, the performance of the engine will be effected. The most effective way to reduce NOx is by adding metallic nanoparticles to the fuel blend. The simultaneous oxidation and reduction reactions of CeO2 result in reduced NOx emissions. (Sajeenan & Sajith, 2013) This also improves the engine performance by releasing heat from HC and CO oxidation reaction. The presence of CeO2 in the fuel blend plays a major role in reducing NOx emissions. (Hawi et al., 2019) In this study, neat B20 has higher NOx emission compared to other fuel variants. When the CeO2 nanoparticle volume fraction is increased from 30 to 50 ppm, the remarkable reduction in NOx emission is achieved.

3.5. Smoke emission

Smoke characteristics for the tested fuel variants are shown in Figure 9. It is seen that, at lower load conditions, soot formation will be lower and increases rapidly near the full load conditions. Out of the different blends tested, for B20 blend with 50 ppm of CeO2 and 30 ppm of Al2O3 nanoparticles, smoke emission will be minimum and is 7.36% less than neat B20 operation. The catalytic action of CeO2 NPs, together with the better heat transfer characteristics shown by Al2O3 NPs, efficient combustion takes place. This is responsible for lower smoke emissions.

4. Conclusions

In this study, effect of Al2O3 and CeO2 nanoparticles on the engine exhaust emissions using B20 biodiesel blend was investigated. From the experimental studies, the following conclusions can be drawn.

A maximum reduction in engine exhaust emissions was obtained for B20 blend with 30 ppm Al2O3 and 50 ppm CeO2 nanoparticles. The use of 30 ppm Al2O3 and 50 ppm CeO2 simultaneously influences the combustion and reduces CO, HC and smoke emissions. The oxidation and reduction reaction due to catalytic action CeO2 reduces NOX emissions. The exhaust emissions are lower compared to other combinations of nanoparticles. For the best fuel blend, B20 blend with 50 ppm of CeO2 and 30 ppm of Al2O3 nanoparticles, CO, HC, NOX and smoke are reduced by 57.3%, 22.3%, 24.3% and 7.36%, respectively, compared to neat B20 operation.

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