Performance and Emission Characteristics of Cotton Seed Oil Biodiesel blend fuel with Nano additives in CI Engine

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ABSTRACT

Among petroleum products, diesel is a major fuel source, but environmental degradation and depletion of petroleum reserves are serious concerns worldwide. As a result, the search for an alternative to diesel is critical. Biodiesel-diesel blends are currently earning new interest in this regard. The performance of a CI engine with diesel, B20, B20+50ppm Al_2O_3, B20+50ppm CeO_2, and B20+50ppm Al_2O_3+50ppm CeO_2 fuels was investigated experimentally. For all test fuels, engine tests were; conducted to obtain comparative performance measures such as brake power (Pb), brake torque (Tb), and BSFC, and emissions such as CO, CO_2, HC, and oxygen concentration. From the experiment, the brake power of CI engine with B20+50ppmAl_2O_3, B20+50ppm CeO_2, and B20+50ppmAl_2O_3+50ppm CeO_2 significantly improved by 6.3%, 4.3%, 17.9% respectively. The engine brake torque was higher than diesel with fuels B20+50ppmAl_2O_3+50ppm CeO_2. Furthermore, the engine BSFC of B20 is higher than all the test fuels; however, the addition of nano-particles improved the BSFC of the engine. Moreover for B20, B20+50ppm Al_2O_3, B20+50ppm CeO_2, and B20+50ppm Al_2O_3+50ppm CeO_2 fuels CO emissions reduced by 6.7%, 11.2%, 9.7% and 23.2% and emissions of CO_2 reduced by 4.6%, 8.1%, 8.8% and 14.8% as compared with diesel fuel. Additionally, HC emissions from all cotton seed biodiesel blended fuels are lesser than diesel fuel. The experimental results showed that B20+50ppm Al_2O_3+50ppm CeO_2 test fuel has performance and emission improvements compared to all other test fuels.

Keywords: Biodiesel, Emission, Engine performance, Nanoparticle, Transesterification

INTRODUCTION

In recent years, most vehicles have been powered by petroleum fuel. The total amount of petroleum fuel is declining day by day around the world. Increasing petroleum fuel consumption has led researchers to look for alternative fuels (Dinesha et al., 2021). Biodiesel, which can be produced from any vegetable oil, can be used directly or mixed with diesel in a CI engine. Pure biodiesel can be used without additives or after mixing with diesel in various ratios (Sathiyamoorthi et al., 2016). The most common product of vegetable oils for fuel is methyl esters. Transesterification produces methyl esters by reacting methanol with oil using a catalyst. Triglycerides are a by-product of transesterification. KOH and NaOH are the most commonly used catalysts in the transesterification process (Babu P. S and Pandurangadu V, 2018). Biodiesel can be blended and used in many different concentrations, from which (20% biodiesel) B20 has a good balance of emissions and performance. Generally, B20 and lower-level blends can be used in current engines without modifications (Venkatesan et al., 2017). Adding metal and metal oxide nanoparticles to the fuel can improve combustion performance. Nanoparticles are added by weight percent or ppm. Metals such as Fe, Al, Mg, Mn, Ag, Au, Cu, B, Si, and metal oxides Al_2O_3, Co_3O_4, CeO_2, TiO_2, ZnO, and used as a fuel additive to improve physicochemical properties (Venkatesan et al., 2017).

Numerous researchers have studied how different additives in diesel or biodiesel-diesel mixes affect CI engine performance parameters. The most researched additives in recent years include alcohol, metals, metal oxide, ethanol, and diethyl ether (Prabu A and Anand R.B, 2016). Researchers utilized nanoparticles in diesel blend fuel in diesel engines. The nanoparticle concentration was varied at ratios ranging from 10–100 ppm to examine diesel engines operating at varying conditions of load as well as speed. The ideal nanoparticle proportion for optimal engine efficiency is determined to be about 50 ppm (Michael et al., 2021).

The addition of nanoparticles plays a major role in improving fuel properties, enhancing the performance of CI engines, and reducing exhaust emissions. Performance enhancement cannot be achieved with every amount of nanoparticle addition. Therefore, selecting an optimal range of nanoparticle addition is critical to getting good results on enhanced performance and reduced emission in a CI engine. Some nanoparticles give good results with every base fuel with which it is added, but in some cases, it fails to improve either performance or emissions. Therefore, selecting the nanoparticles based on the properties of the fuel to be improved will help to attain better results. Much research should be done in this area to select the suitable nano-metal additive based on the fuel. Most researchers have investigated the effect of single nano additives in CI engines. This experimental investigation was performed to investigate the effect of mixed (aluminum oxide and cerium oxide) nanoparticles in diesel-CSOME biodiesel blend fuel to observe diesel engines' performance and emission characteristics. Moreover, experimental tests were conducted on the performance and emissions characteristics of a Direct Injection diesel engine fuelled with diesel-biodiesel blends with and without nano-additives.

MATERIALS AND METHODS

The performance and emission parameters of the single-cylinder compression ignition engine were experimentally analyzed. Transesterification method can be used to modify biodiesel produced from cottonseed oil. CeO_2 and Al_2O_3 nanoparticles are added to the diesel-biodiesel blend with cottonseed oil which contains methyl ester. The process for producing biodiesel consists of five key steps: Preheating the oil, Alcohol catalyst mixing, Chemical reaction, separation, and Purification of the reaction products.

For the production of biodiesel, cottonseed oil was first prepared. Cottonseed oil should be measured, added to a beaker, and heated for 60 minutes at 60°C (Figure 1a). The catalyst (NaOH), which is used to produce biodiesel, must be mixed with the alcohol (methanol) before being added to the oil (Figure 1b). As shown in Figure 2(a), when a sodium methoxide solution is poured into heated cottonseed oil, transesterification takes place. Due to the need for high temperatures while mixing alcohol and oil, the chemical reaction was carried out at a high temperature of 60°C.

In contrast, the mixture was continuously stirred using a magnetic stirrer hot plate for 60 minutes. Decanter was used to separate the product (Figure 2b). Due to the difference in densities, the ester separates from the glycerol as soon as the stirring operation is stopped, resulting in two separate phases. Glycerol separation may leave traces of methanol, NaOH, and glycerol in the FAME mixture as impurities. The FAME should therefore be washed in warm water, neutralized, and dried after separation (Figure 3).

The preparation of a diesel-biodiesel mixture and nanoparticles made using an ultrasonic device. The fuels prepared for this experiment were diesel (B0), B20, B20 + 50ppm Al_2O_3, B20 + 50ppm CeO_2, and B20 + 50ppm Al_2O_3 + 50ppm CeO_2. Engine performance characteristics were measured experimentally using the experimental setup shown in Figure 4. Several important fuel properties were evaluated using the appropriate ASTM test methods. The test was conducted on TBMC3-02 computer-controlled diesel engine. Experiments were conducted with varying engine speeds. The engine used in this experiment was an air-cooled single-cylinder four-stroke diesel engine. The engine was computer controlled and started by software, an electric motor mounted in the TBM3-02 unit. The complete test stand consists of four main elements; an Asynchronous motor, an air-cooled diesel engine (TBMC3-02), a SCADA software control system, and an exhaust gas analyzer (TBMC_AGE).

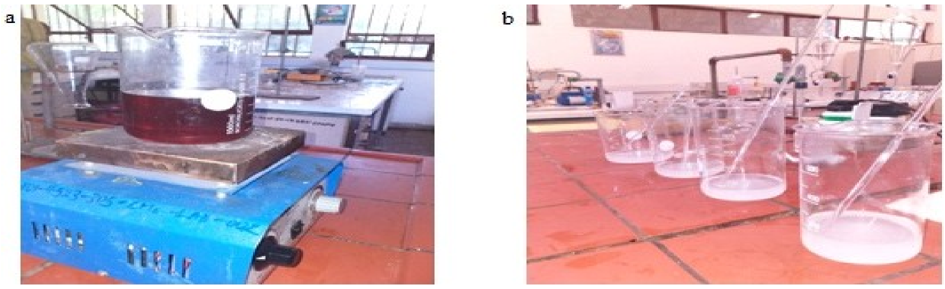

Figure 1. (a) Preheating of cotton seed oil; (b) Preparation of Sodium-Methoxide

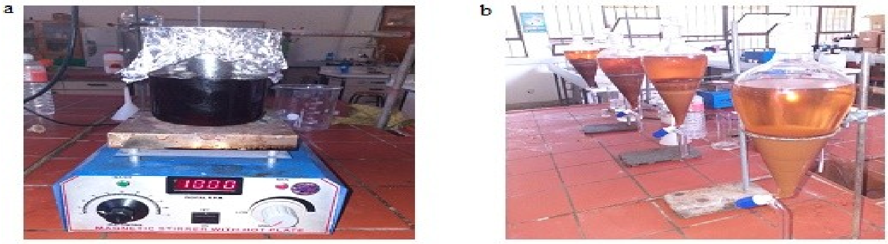

Figure 2. (a)Chemical reaction; (b) Separation of glycerol from COME

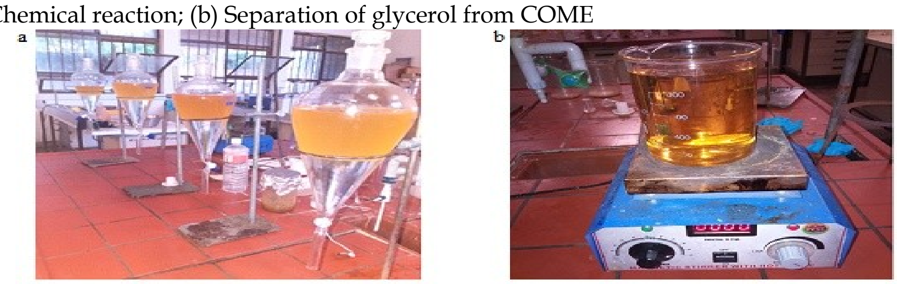

Figure 3. (a) Washing of COME; (b) Drying of cotton seed oil biodiesel

Table 1. Specification of nanoparticles

Item	Specification	
Manufacturer	NRL , USA	NRL, USA
Chemical Name	Alumina (Al_2O_3)	Cerium Oxide (CeO_2)
Purity	99.9%	Purity 99.9%
Average particle size	30-50 nm	20-30nm
Specific surface area (SSA)	130-140 m^2/g	40-45 m^2/g
Color	White	light yellow
Density	3.97 g/cm^3	6.5 g/cm^3

Experimental setup

The test was conducted on TBMC3-02 computer-controlled diesel engine. The engine used in this experiment was an air-cooled single-cylinder four-stroke diesel engine.

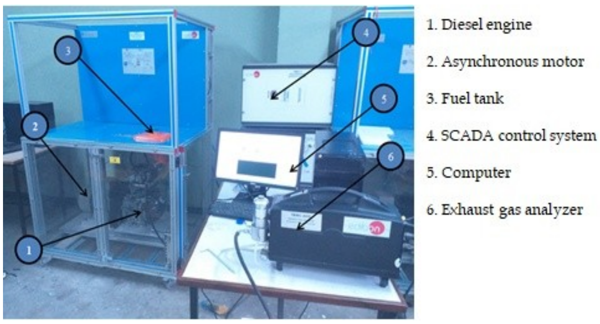

Figure 4.TBM3-02 test bench experimental setup

Table 2. Specification of the engine

Item	Specification
Engine Manufacture	Edison
Type of engine	Compression ignition
Fuel	Diesel
Number of cylinders	1
Number of strokes	4
Type of air intake	naturally-aspirated
Type of cooling	Air
Start	Computer-controlled / manual
Compression ratio	21:1
Maximum power	4.2HP/3.13kw @ 3600 rpm
Cylinder bore	69mm
Stroke	60mm

RESULTS AND DISCUSSION

Several tests were conducted to see how Al_2O_3 and CeO_2 nanoparticles affected the CI engine Performance and emissions. Diesel, B20, B20+50ppmAl_2O_3, B20+50ppm CeO_2, and B20+50ppmAl_2O_3+50ppm CeO_2 test fuels were evaluated for emissions and performance. Engine performance characteristics such as BP, BT, and BSFC were assessed, as well as CO, CO_2, O_2, and HC emissions.

Fuel characterization

Fuel properties were analyzed to know the fuel quality and suitability of the fuel used in the engine. The fuel properties were tested per the ASTM standards procedure (Table 3).

Performance characteristics

A TBMC3-02 computer-controlled test bench for single-cylinder, four-stroke diesel engines was used to evaluate the performance of test fuels. Engine performance was tested using diesel, B20, B20+50ppm Al2O3, B20+50ppm CeO2, and B20+50ppm Al2O3+50ppm CeO2. The tests made use of various engine speeds. At a range of engine speeds, brake power (Pb), brake torque (Tb), and brake-specific fuel consumption (BSFC) were measured.

Table 3. Properties of prepared fuels

Property	Test method	ASTM D6751 limits	Results				
			B100	B20	B20+ 50 ppm Al_2O_3	B20+ 50 ppm CeO_2	B20+50ppmAl_2O_3+50ppm CeO_2
Density@20°C (g/ml)	D4052	0.820 -0.890	0.8523	0.8435	0.8442	0.8445	0.8447
Kinematic viscosity @40°C (cst)	D562	1.9-6 mm^2/s	4.564	4.428	4.216	3.890	4.009
Flash Point (PMCC,°C)	D93	Min.60	181	89	87	86	85
Cloud point (°C)	D2500	Max.+5	+3	+1	-1	+2	+1
Total acidity(mgKOH/g) 0.0918	D974	-	0.0985	0.1007	0.0940	0.0910	0.1005

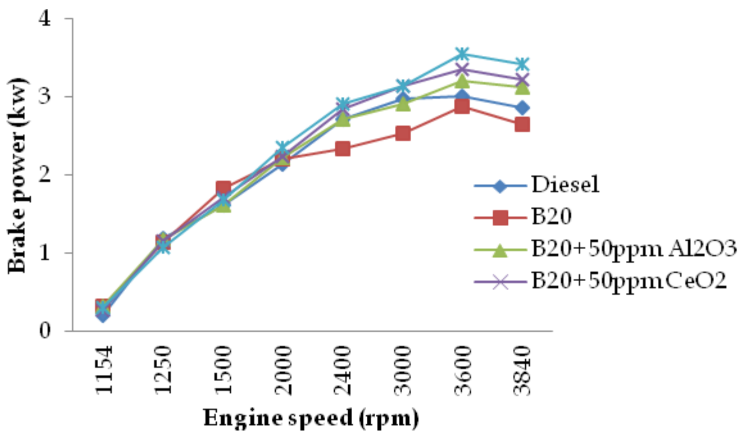

Figure 5. Brake power at different engine speeds

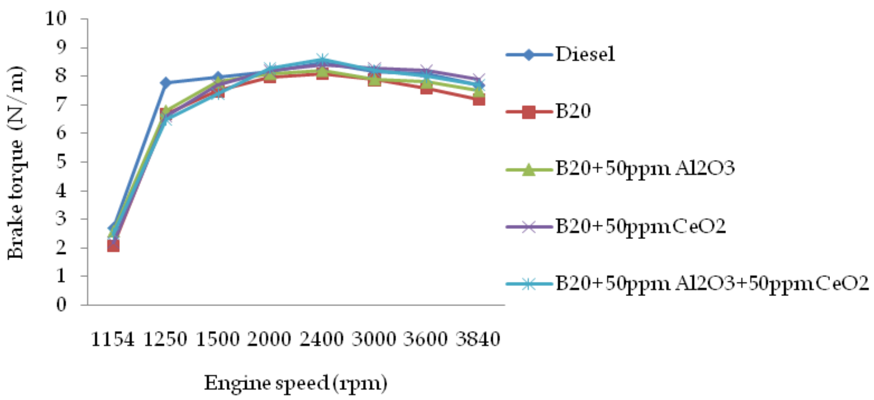

Figure 6.Variation of brake torque with Engine speed

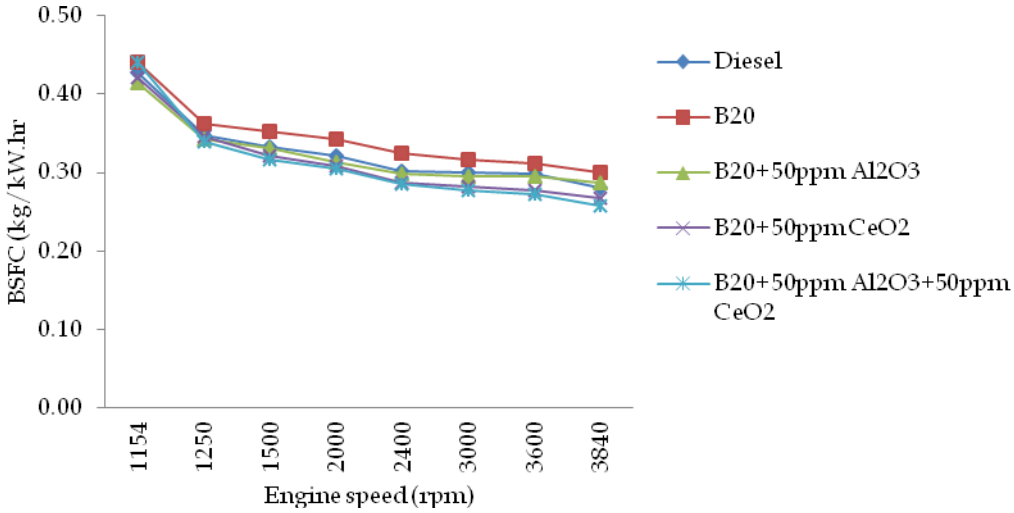

Figure 7.Variation of brake-specific fuel consumption concerning engine speed.

Figure 5 shows how to brake power changes for petrodiesel and different biodiesel at various engine speeds. From Figure 10 for all test fuel samples, braking power increases as engine speed rises until it reaches the maximum limiting engine speed of 3600rpm, at which point brake power begins to decline. At a 3600 rpm engine speed, the brake power values for diesel (B0), B20 B20+50ppm Al_2O_3, B20+50ppm CeO_2, and B20+50ppm Al_2O_3+50ppm CeO_2 were 3.01.kW, 2.89kW, 3.21kW, 3.35kW, and 3.56kWrespectively.The improvement in brake power of the test fuels with nanoparticles added fuels at 3600 rpm was 6.6%, 11.3%, and 18.3% for B20+50ppm Al_2O_3, B20+50ppm CeO_2, and B20+50ppm Al_2O_3+50ppm CeO_2, respectively. This is owing to nanoparticles' increased combustion energy by donating oxygen from its structure to the air-fuel mixture (Siddavatam N and Mohmad M.W, 2021). In comparison to other test fuels, the B20+50ppmAl_2O_3+50ppm CeO_2 test fuel has improved brake power due to the combined impact of CeO_2 and Al_2O_3 nanoparticles on the combustion property.

With all test fuels, torque rises with engine speed until it reaches its maximum (2400 rpm), then declines as engine speed rises (Figure 6). According to test results, it is adding nanoparticles to a diesel-biodiesel blended fuel improved engine torque output. This is because metallic nanoparticles promote total combustion, increased combustion energy, and, consequently, more torque (Michael et al., 2021).

The maximum recorded brake engine torque was 8.6 Nm at 2400 rpm, achieved by B20+50ppm Al_2O_3+50ppm CeO_2 test fuel. The highest engine braking torque was measured at this engine speed for all test fuels, and it was 8.5, 8.1, 8.2, and 8.4 N.m for B0, B20, B20+50ppm Al_2O_3, and B20 +50ppm CeO_2, respectively.

At various engine speeds, the experiment was conducted for petro diesel and several COME blend (B20, B20+50ppmAl_2O_3, B20+50ppm CeO_2, and B20+50ppmAl_2O_3+50ppm CeO_2) samples (Figure 7). The experiment revealed that when the engine speed is raised, the brake-specific fuel consumption reduces for all test fuel samples. B20 had the highest brake-specific fuel consumption among all the test fuels because COME has a lower calorific value and a more significant density (Nouri et al., 2021). However, the addition of nanoparticles improved, owing to the nano particle's increased surface area to volume ratio, favoring improved combustion (Mohammed et al., 2021). B20 + 50ppm Al_2O_3 + 50ppm CeO_2 fuel had the lowest specific fuel consumption among the test fuels.

Emission characteristics

The emission characteristics of B0, B20, B20+50ppm Al_2O_3, B20 +50ppm CeO_2, and B20+50ppm Al_2O_3+50ppm CeO_2 test fuels were determined under the engine steady state condition using an exhaust gas analyzer. Emissions such as CO, CO_2, HC, and O_2 are measured using an exhaust gas analyzer.

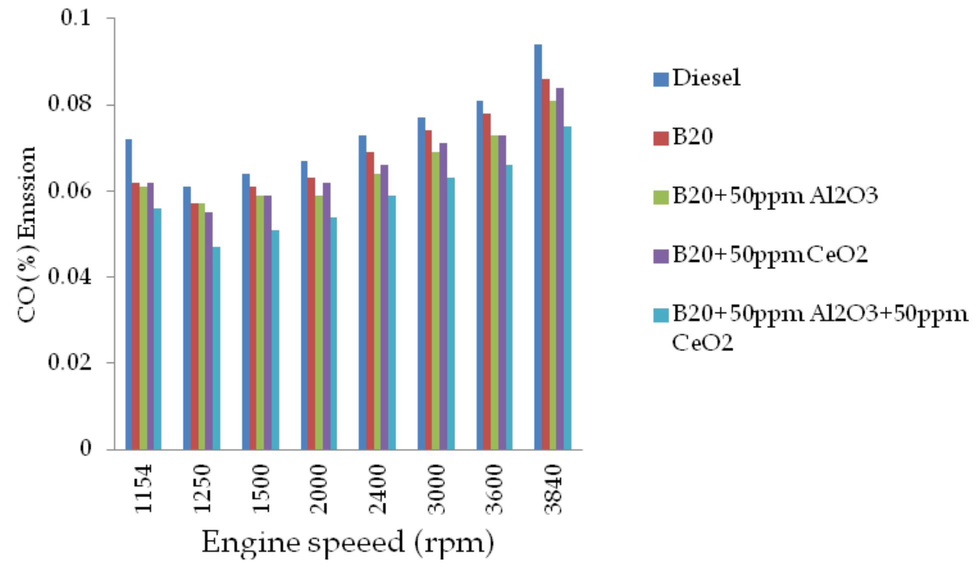

Figure 8. Carbon monoxide (CO) emissions at different engine speeds

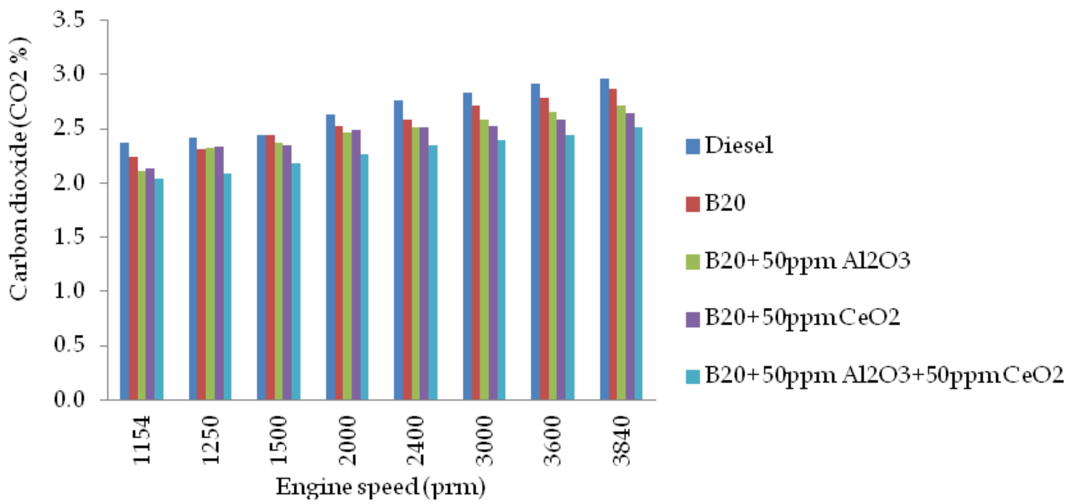

Figure 9. Variation of Carbon dioxide (CO_2 %) emissions with engine speed

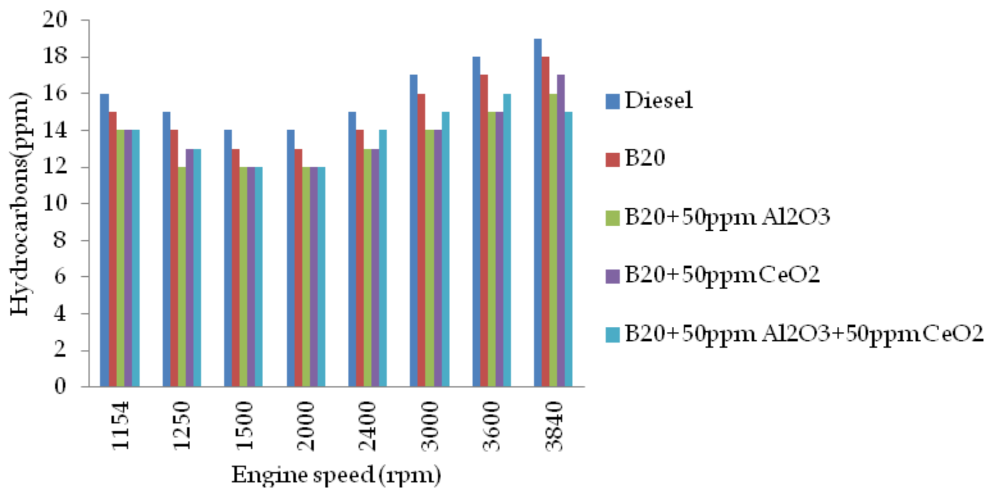

Figure 10. Variation of unburnt hydrocarbons emission concerning engine speed

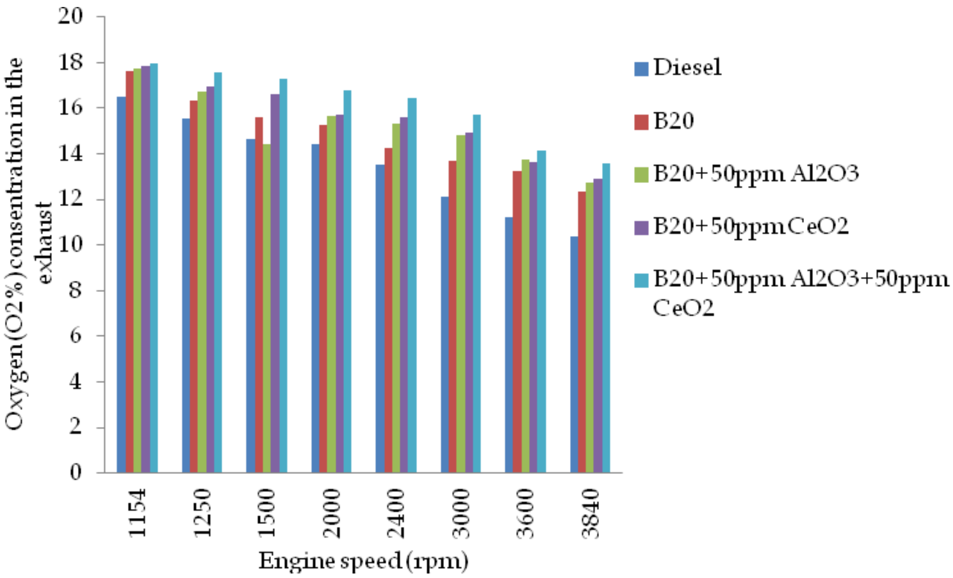

Figure 11. Variation of oxygen (O_2 %) emission with engine speed

Carbon monoxide emissions for diesel and cotton seed biodiesel blended fuel with aluminum oxide and cerium oxide nanoparticles are shown in Figure 8. The graph shows that COME blended fuels release less CO than petrol and diesel. Carbon monoxide production is primarily caused by insufficient oxygen and incomplete combustion. Because biodiesel is an oxygenated fuel, it allows for improved fuel combustion, resulting in lower CO emissions (Hawi et al., 2019). Furthermore, when compared to petrodiesel and diesel-biodiesel blend fuels, adding nanoparticles to diesel-biodiesel blended fuel reduces CO emissions even further. This is because CO is converted to CO_2 by oxidation between the Nano additives (aluminum oxide and cerium oxide) (Syed et al., 2017). The B20+50ppmAl_2O_3+50ppm CeO_2 test fuel produces the least CO emissions. B20, B20+50ppm Al_2O_3, B20+50ppm CeO_2, and B20+50ppm Al_2O_3+50ppm CeO_2 test fuels have average CO emission reductions of 6.7%, 11.2%, 9.7%, and 23.2% respectively.

The CO_2 emissions of a CI engine are shown in Figure 9 at various engine speeds. It has been shown that as engine speeds increased, CO_2 emissions increased significantly. Furthermore, because biodiesel has a lower carbon-to-hydrogen ratio than petrodiesel, the CO_2 emissions of biodiesel blended fuels are lower (Tesfa et al., 2014). The CO_2 emissions measured at 1154 rpm for pure petro diesel, B20, B20+50ppmAl_2O_3, B20+50ppm CeO_2, and B20+50ppmAl_2O_3+50ppm CeO_2 were 2.51%, 2.64%, 2.72%, and 2.87% respectively. According to the testing results, B20, B20 + 50ppm Al_2O_3, B20 + 50ppm CeO_2, and B20 + 50ppm Al_2O_3 + 50ppm CeO_2 reduced CO_2 emissions by 4.6%, 8.1%, 8.8%, and 14.8%, respectively, as compared to petro diesel fuel.

The change of HC emission with engine speed for all tested fuels is shown in Figure 10. According to the testing results, the HC emissions from all cotton seed biodiesel blended fuels are lower than those from diesel fuel. Compared to petro diesel and B20 fuels, adding Al_2O_3 and CeO_2 nanoparticles to the diesel-biodiesel blend (B20) reduces HC emissions. Al_2O_3 and CeO_2 nanoparticles increase complete combustion and can aid in the breakdown of unburned hydrocarbons, lowering HC emissions (Syed et al., 2017). As a result, there was a considerable reduction in HC emission values for nanoparticles dispersed test fuels. The lower value of HC emission was observed from all test fuels for B20+50ppm Al_2O_3+50ppm CeO_2 test fuel.

Figure 11 shows the O_2 emissions of various fuels from a diesel engine. At 1554 rpm, the O2 concentrations for diesel fuel, B20, B20+50ppm Al_2O_3, B20+50ppm CeO_2, and B20 + 50ppm Al_2O_3+ 50ppm CeO_2 were 16.51%, 17.63%, 17.74%, 17.83%, and 17.97%, respectively. Because biodiesel and nanoparticle blended fuels contain more O_2 than petro diesel, the O_2 concentrations in B20, B20 + 50ppm Al_2O_3, B20 + 50ppm CeO_2, and B20 + 50ppm Al_2O_3+ 50ppm CeO_2 were greater. Under working engine operation conditions, the O2 emissions of the CI engine running on biodiesel blended fuel were much higher. This increase in emissions is most likely due to biodiesel's high oxygen content and low carbon-hydrogen ratio.

Nanoparticles (oxygenated additives) promote complete combustion (Syed et al., 2017). Furthermore, when Al_2O_3 and CeO_2 nanoparticles are added to fuel blends, the oxygen emission is increased when compared to petro-diesel fuel. This is because the combustion process produces more oxygen by donating oxygen atoms from the structure.

CONCLUSIONS

This experimental investigation evaluated CI engines' performance and emission on diesel and cotton seed oil biodiesel with aluminum oxide and cerium oxide nanoparticles. The biodiesel was produced from cottonseed oil by transesterification process and blended with diesel fuel, and aluminum oxide and cerium oxide nanoparticles were dispersed. The performance and emission characteristics of the single cylinder four stroke CI engine were tested using diesel (B0), B20, B20+50ppm Al_2O_3, B20+50ppm CeO_2, and B20+50ppm Al_2O_3+50ppm CeO_2 as fuel. Based on the experimental testing, performance, and emission characteristics, results show that:

- The brake power of the engine, when fueled with diesel-biodiesel (B20) blend fuel, was lower (2.89kW) than that of petrodiesel (B0) 3.02kW fuel.
- Due to the higher combustion energy of the aluminum oxide and cerium oxide nanoparticles, nanoparticle blended (B20+50ppm Al_2O_3, B20+50ppm CeO_2, and B20+50ppm Al_2O_3+50ppm CeO_2) fuels have higher brake power than that of B0 and B20 fuels which were 3.21kW, 3.35kW and 3.56kW respectively.
- The engine brake torque for B0, B20, B20+50ppm Al_2O_3, B20+50ppm CeO_2 and B20+50ppm Al_2O_3+50ppm CeO_2 was 8.5Nm, 8.1Nm, 8.2Nm, 8.4Nm and 8.6Nm respectively. It was concluded from the experiment an improved engine brake torque was realized for nanoparticles added fuels compared with B0 and B20
- The BSFC of B20 was higher than all the test fuels due to the lower calorific value of cotton seed oil biodiesel, but B20+50ppmAl_2O_3+50ppmCeO_2 has the lowest BSFC.
- For B20, B20+50ppm Al_2O_3, B20+50ppm CeO_2, and B20+50ppm Al_2O_3+50ppm CeO_2, the emissions of carbon monoxide reduced by 6.7%, 11.2%, 9.7% and 23.2% and emissions of carbon dioxide reduces by 4.6%, 8.1%, 8.8%, and 14.8% as compared with petrodiesel (B0) fuel.
- Hydrocarbon emissions from all cotton seed biodiesel blended (B20, B20+50ppm Al_2O_3, B20 + 50ppm CeO_2,B20 + 50ppm Al_2O_3 + 50ppm CeO_2) fuels are lower than that of the diesel (B0) fuel. Moreover, all cotton seed blended fuels' oxygen concentrations were higher than diesel fuel.

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